Lecture 2

Introduction, Part II

Overview

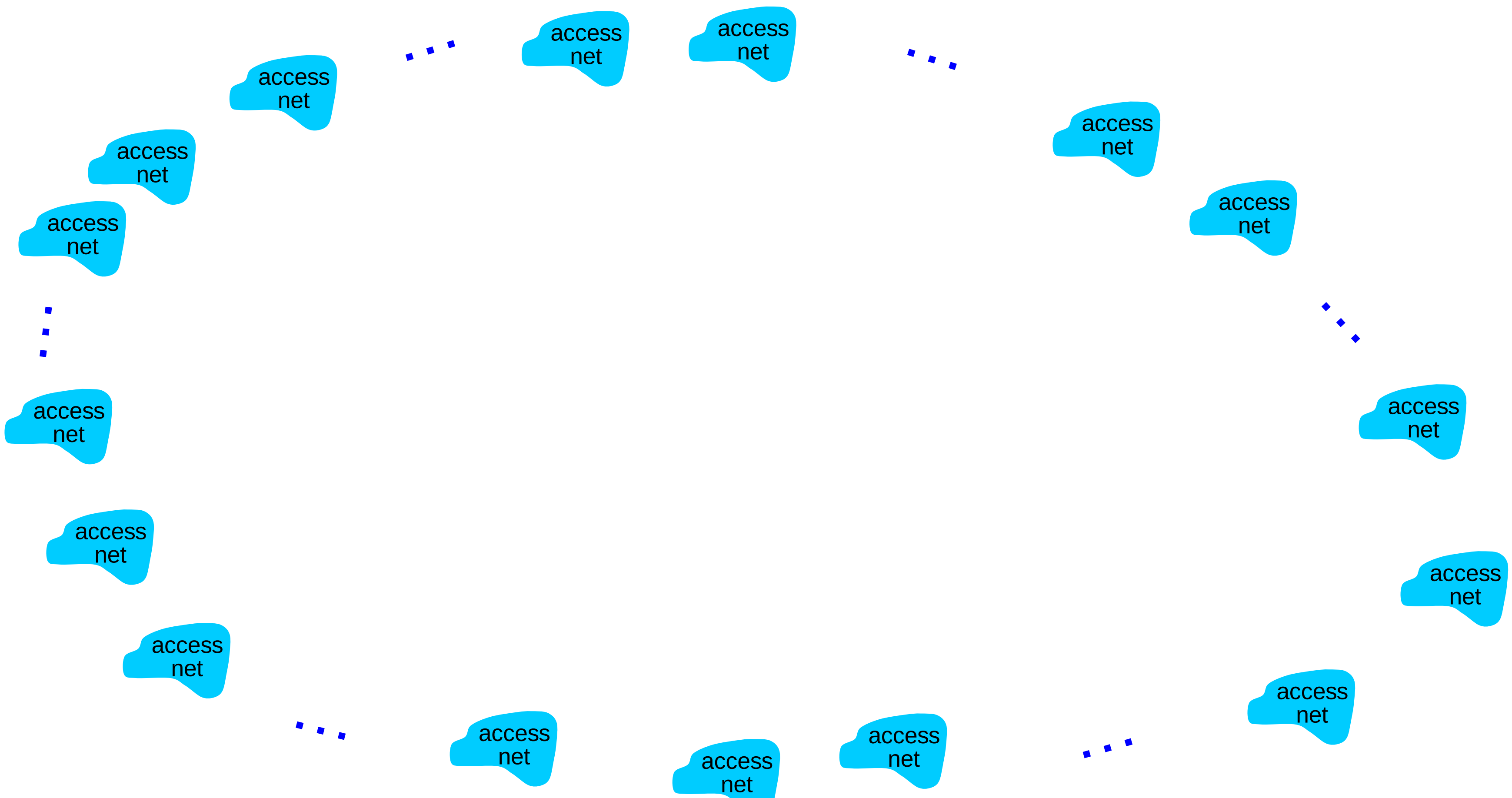
- what's the Internet?
- network edge
  - End-systems, access net, physical media
- network core
  - Packet switching, circuit switching, network structure
- performance: loss, delay
- protocol layers, service models
- backbones, NAPs, ISPs
- history

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

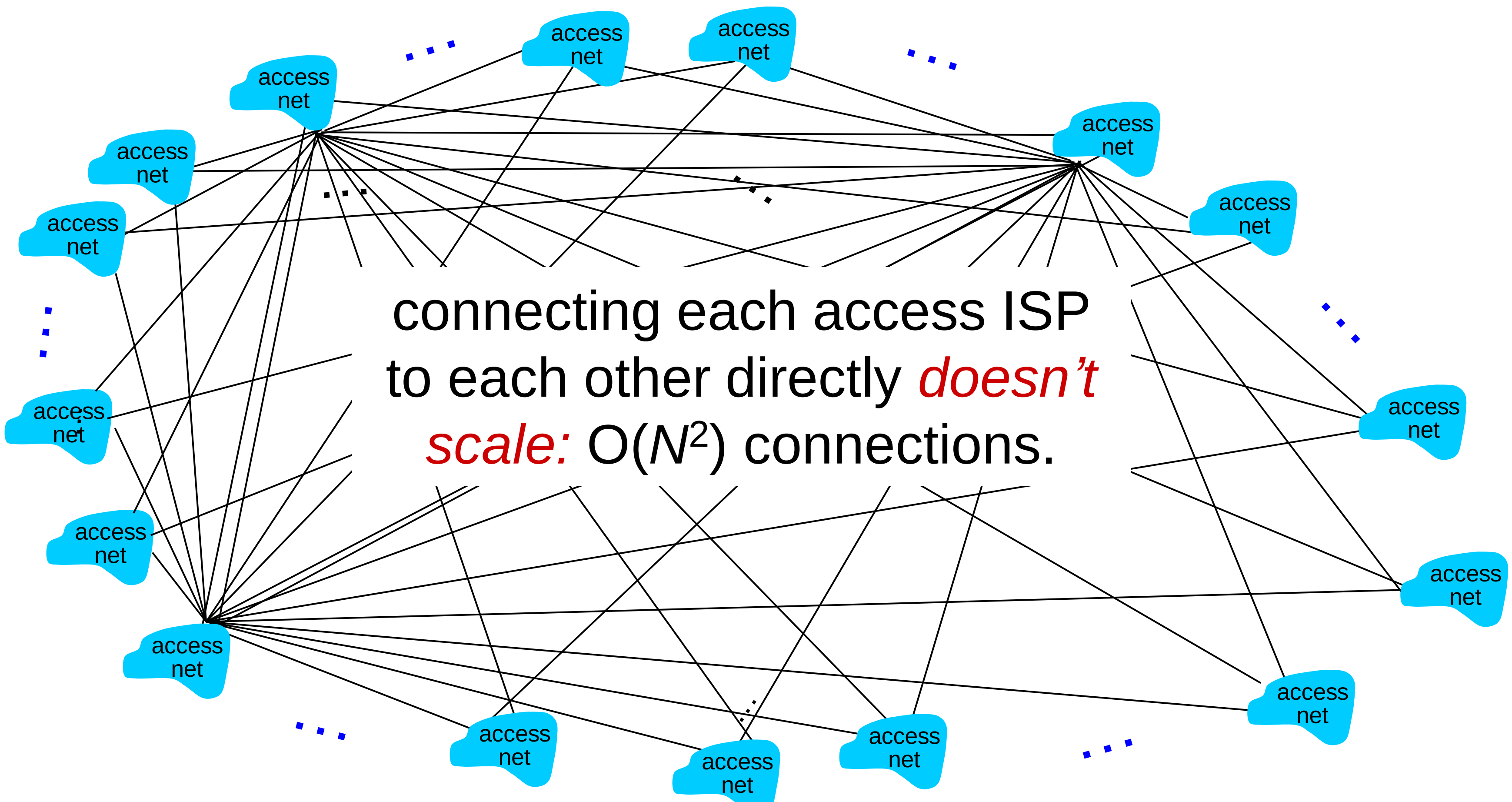
Internet structure: network of networks

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



Internet structure: network of networks

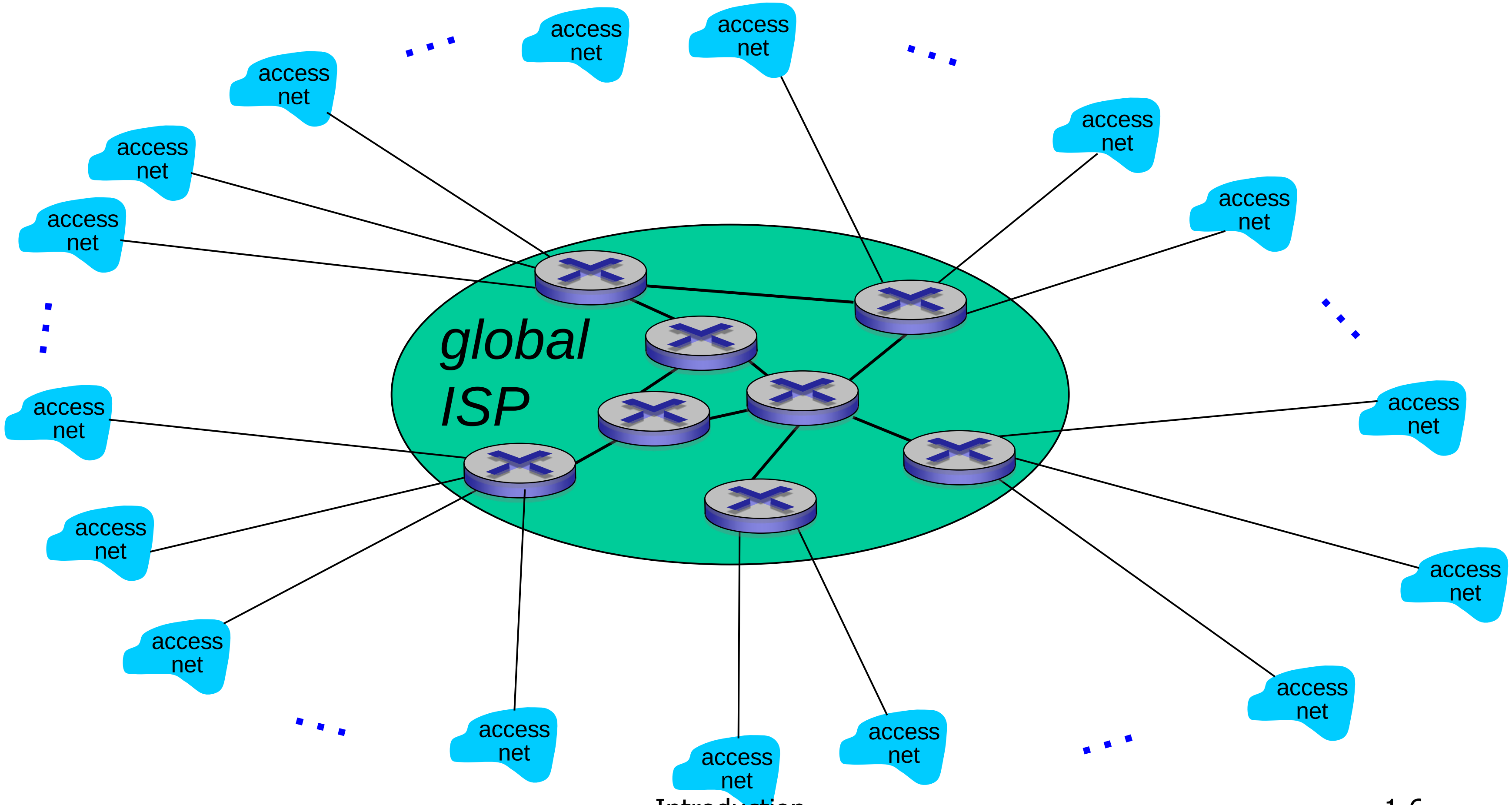
Option: connect each access ISP to every other access ISP?



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

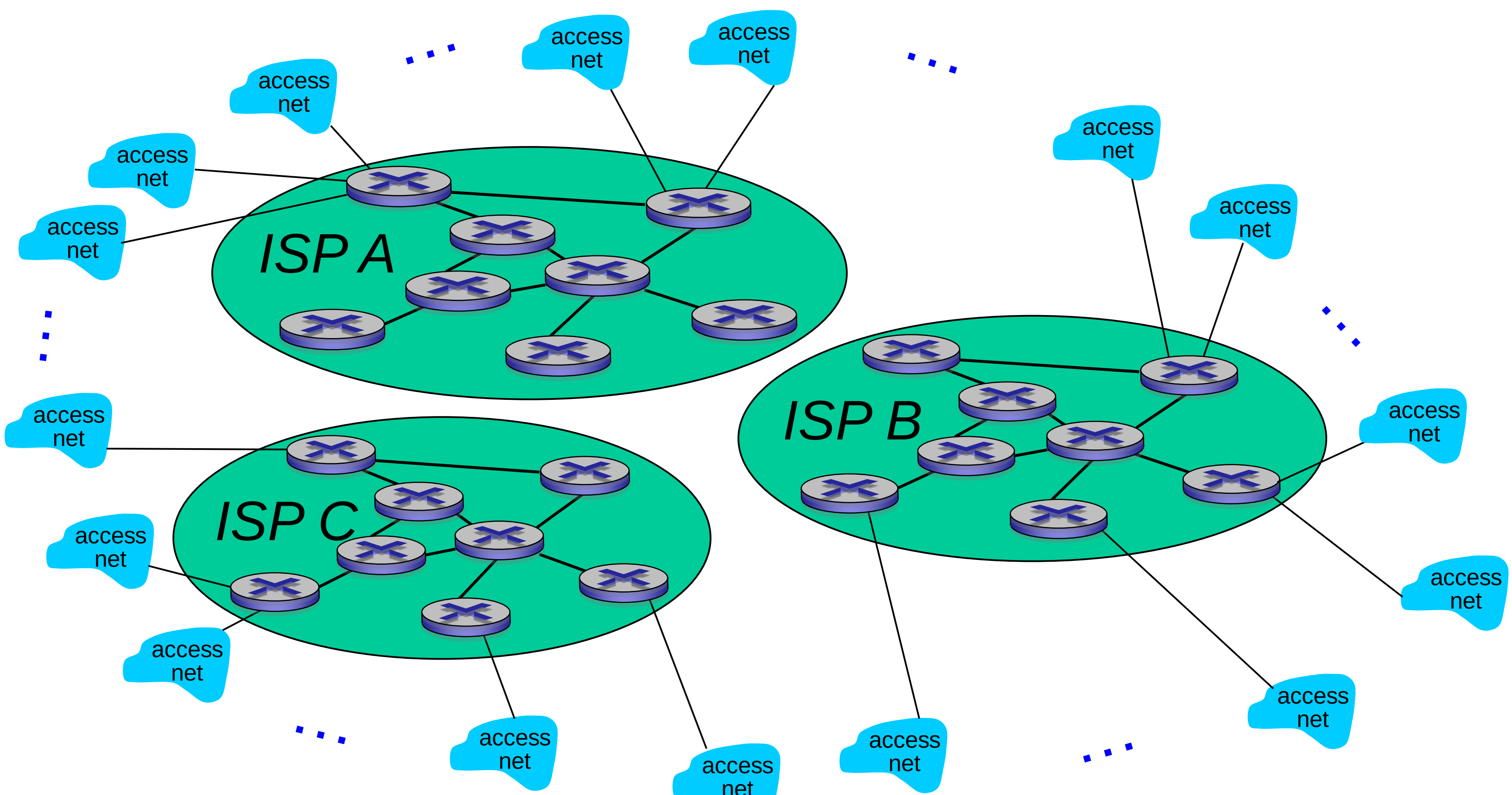
Internet structure: network of networks

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



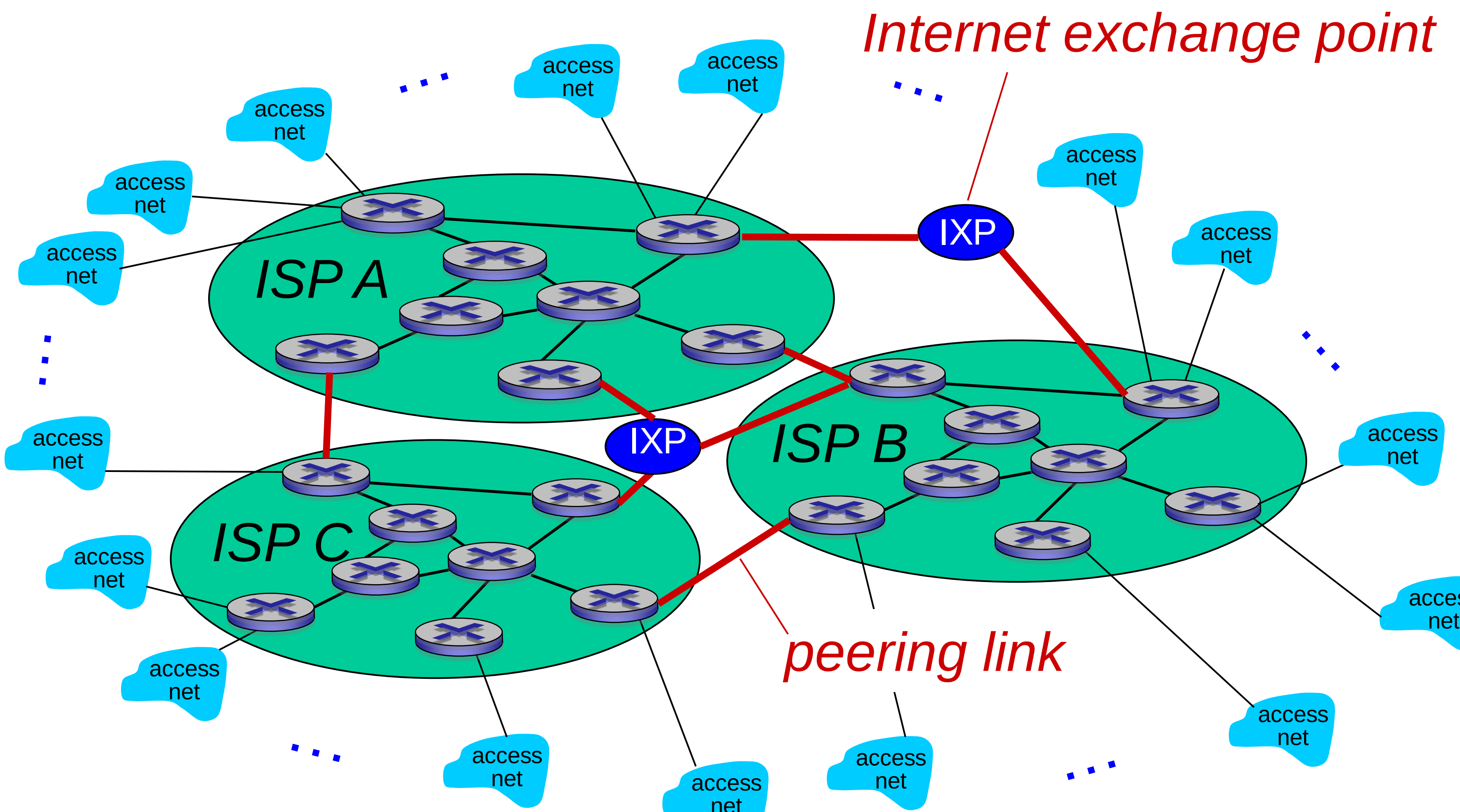
Internet structure: network of networks

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



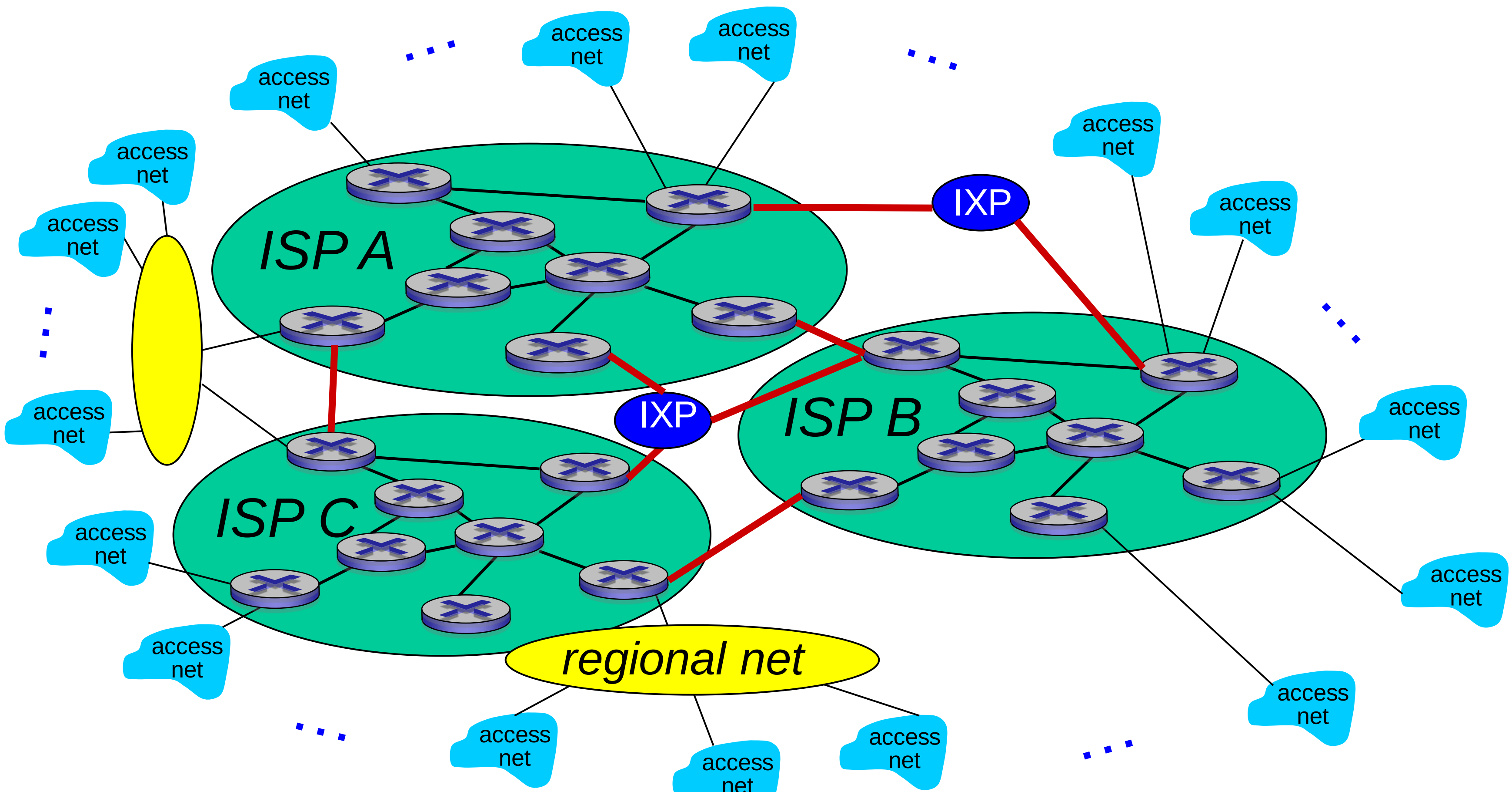
Internet structure: network of networks

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



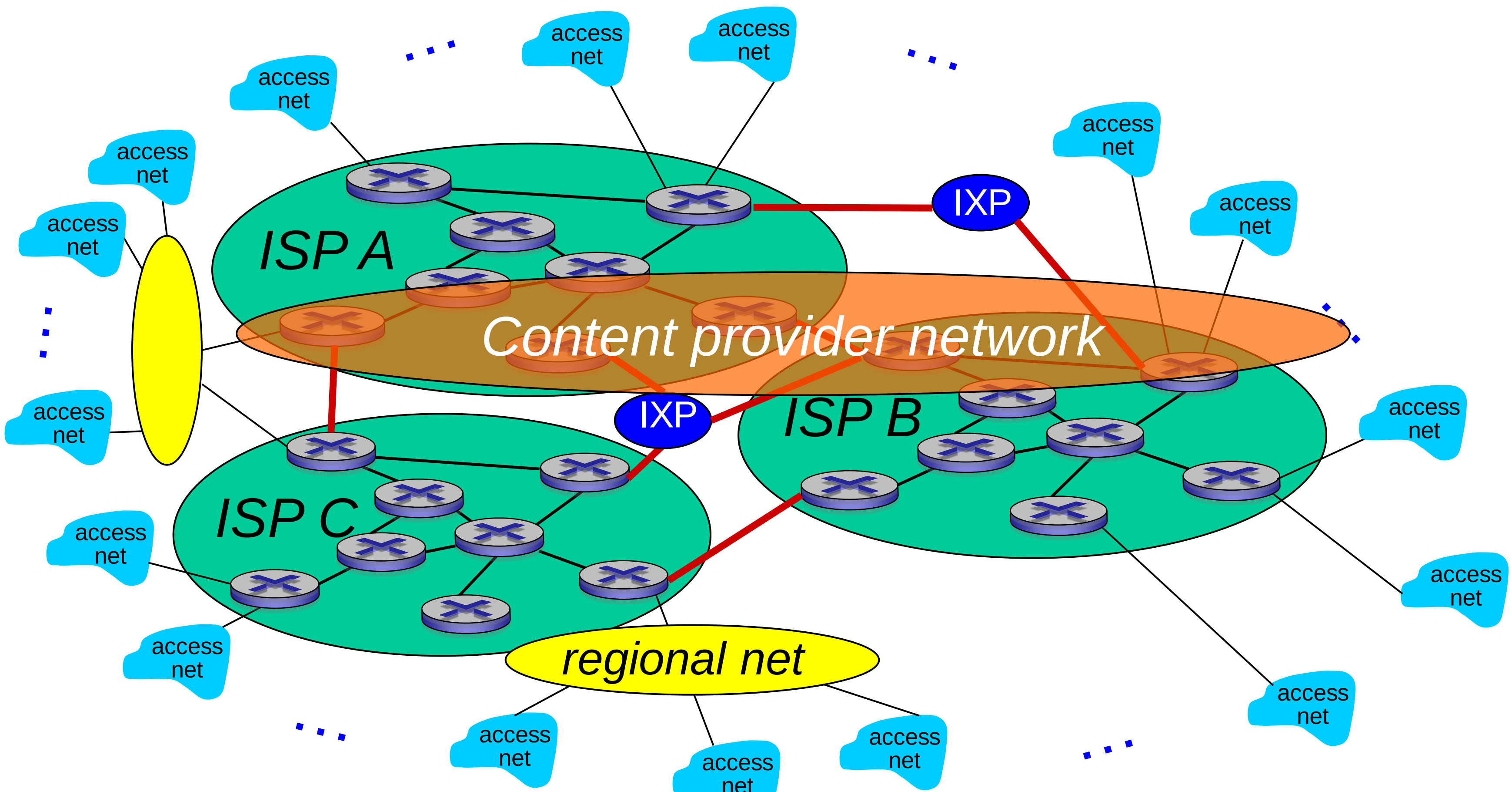
Internet structure: network of networks

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

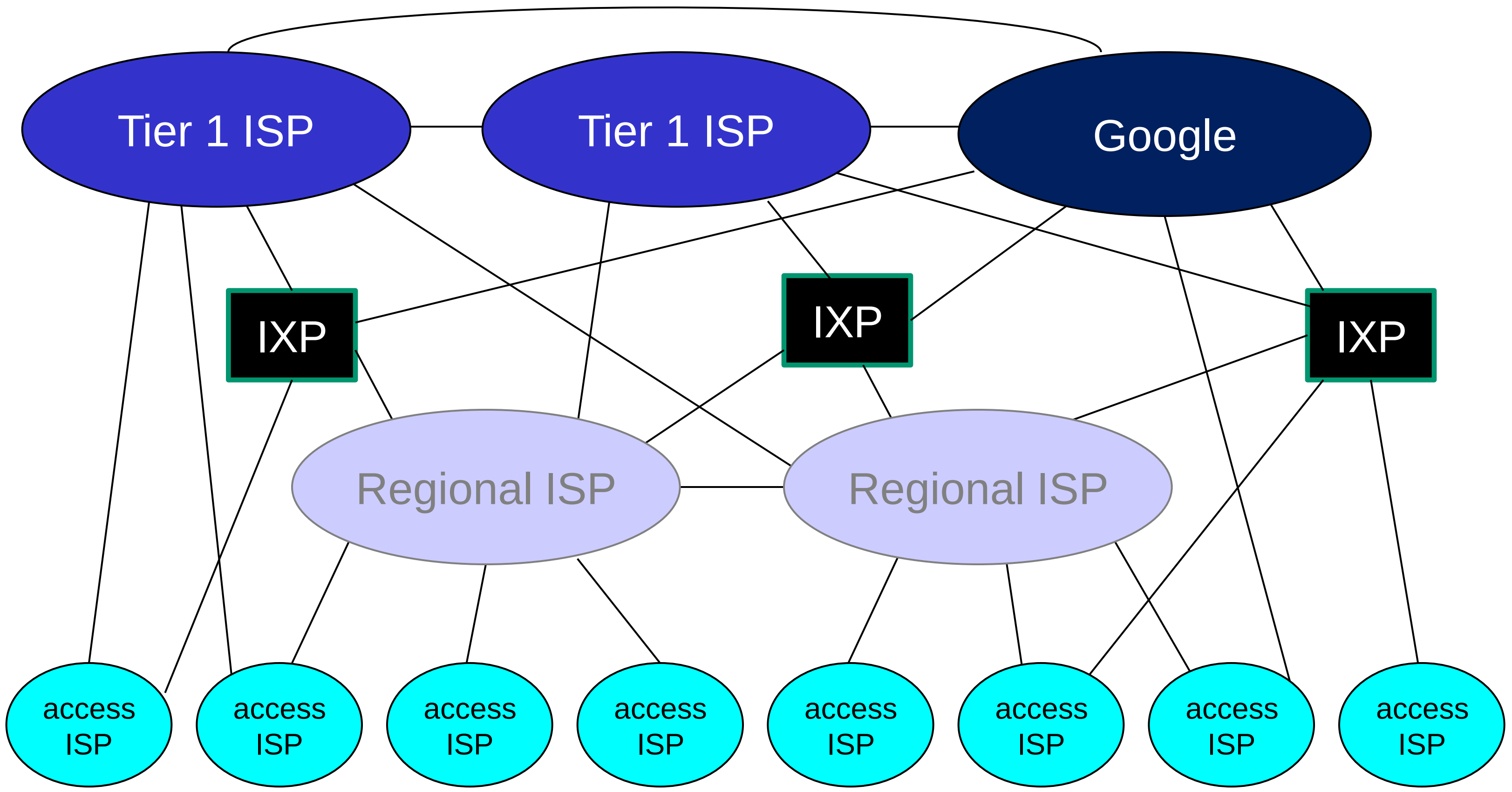


Internet structure: network of networks

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

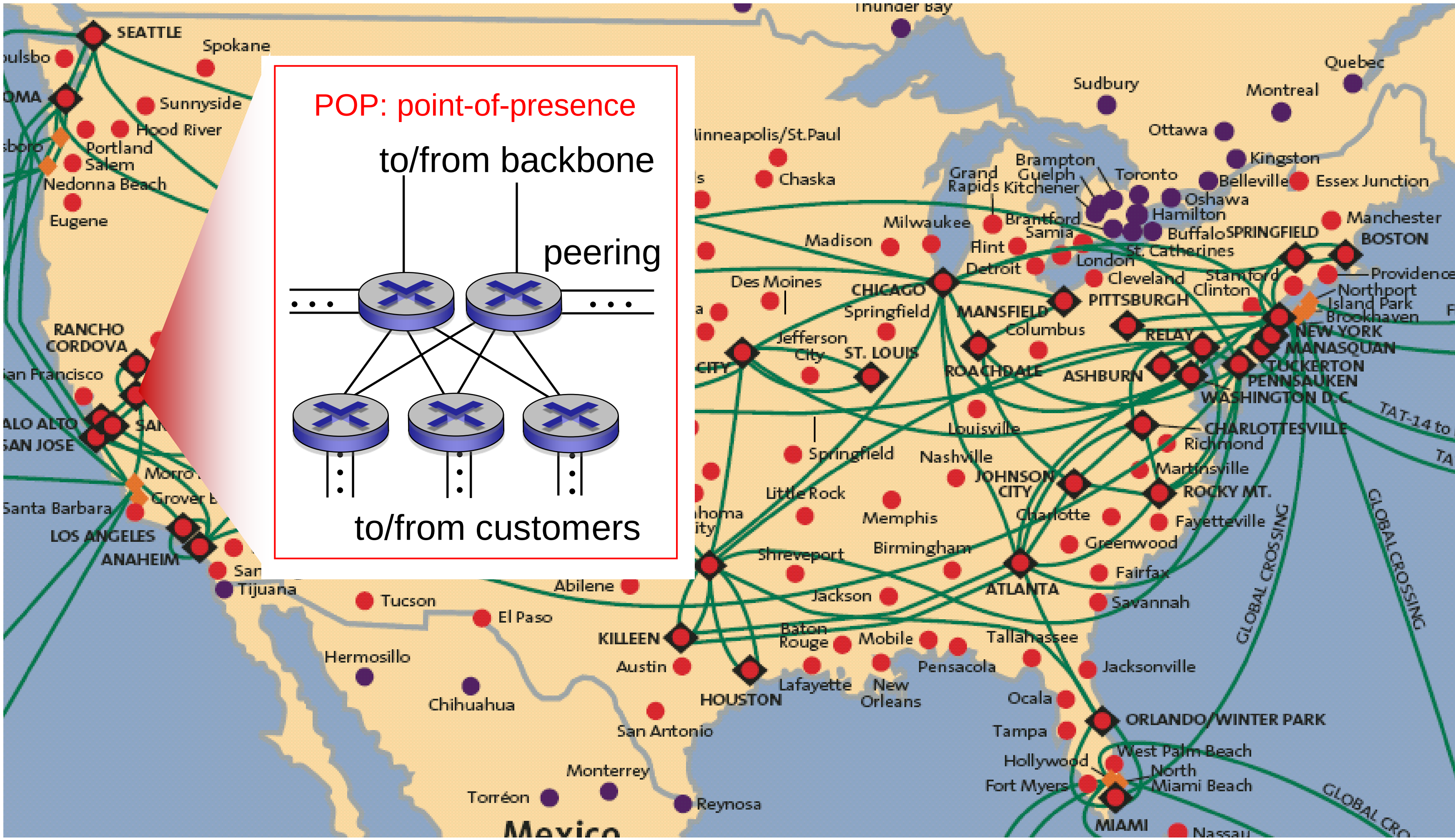


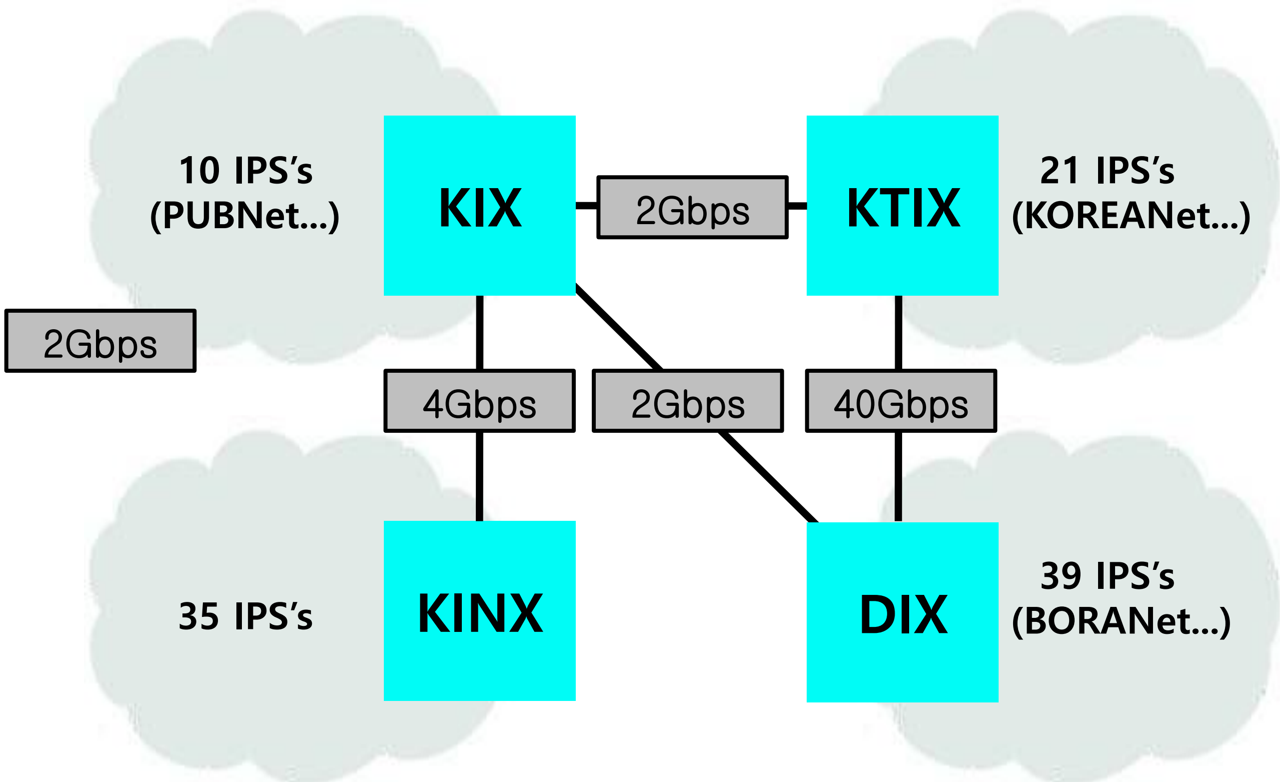
Internet structure: network of networks



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

Tier-1 ISP: e.g., Sprint





Source: National Computerization Agency(NCA), Dec. 2003

Company	Service Name	Network State	Network Connection	
			Domestic	Foreign
KT	KORNET	· Total nodes nationwide: 100 · Links between major cities: 2.5Gbps~10Gbps · Links between small and mid-sized cities: 155~622Mbps	(Total bandwidth of IX:42Gbps · DIX: 40Gbps · KIX:2Gbps) (Total connected ISPs:130.5G)	(Total 17.5Gbps) · U.S.(UUNET and 6 companies) : 13Gbps · Japan, China, Hong Kong, Australia, New Zealand, Southeast Asia: 4.5Gbps
Dacom	BORANET	· Total nodes nationwide: 71 · Links between major cities: 310Mbps~5Gbps, 2 lines · Links between small and mid-sized cities: 45~155Mbps	(Total bandwidth of IX:42Gbps · KTIX:40Gbps · KIX:2Gbps) (Total connected ISPs: 50Gbps)	(Total 5.2Gbps) · U.S.(Qwest, PAIX etc.) : 2Gbps · Asia(9 countries like Japan(555M) and China(555M) : 3.0G
Hanaro Telecom	HANANET	· Total nodes nationwide: 200 · Links between major cities: 40Gbps~800Gbps · Links between small and mid-sized cities: 155Mbps~2.5Gbps	(Total bandwidth of IX: 83.5Gbps · DIX: 25Gbps · KINX: 5Gbps · KIX: 1Gbps · KTIX: 52.5Gbps) (Total connected ISPs:25.7G)	(Total 5.2Gbps) · U.S. : 3.3Gbps · U.K. : 310Mbps · Asia : 1Gbps · Others : 620Mbps
Onse Telecom	SHINBIRO	· Total nodes nationwide: 19 · Links between major cities: 465M~5Gbps · Links between small and mid-sized cities: 45Mbps~310Mbps	(Total bandwidth of IX: 12Gbps · DIX: 4.5Gbps · KINX: 4Gbps · KTIX: 3.5Gbps) (Total connected ISPs: Total 4.7Gbps)	(Total 1,030Mbps) · U.S. (Onse US POP) : 975Mbps · Japan(Japan Telecom) : 45Mbps · Taiwan : 10Mbps · Hong Kong(NWT) : 128Kbps
Thrunet	Thrunet	· Total nodes nationwide: 124 · Links between major cities: 5Gbps~10Gbps	(Total bandwidth of IX: 19.5Gbps · KT-IX : 7.5Gbps · KNIX:5Gbps/KIDC:5Gbps · DIX: 2Gbps) (Total connected ISPs: 17.1Gbps)	(Total 1,705bps) · U.S.(Dacomcossing, Onse Telecom) : 1,395Mbps · Asia(Transit node, AGC) : 310Mbps

Company	Service Name	Network State	Network Connection	
			Domestic	Foreign
Enterprise Networks	GNGIDC	· Total nodes nationwide: 63 · Links between major cities: 2.5Gbps node-to-node duplexing	(Total bandwidth of IX: 13.6Gbps · KT-IX : 7.5Gbps · KINX : 3Gbps · DIX: 2Gbps · KIX : 1Gbps · BIX : 100Mbps) (Total connected ISPs: 8.6Gbps)	(Total 775Mbps) · U.S.(MCI,Reach): 465Mbps · Japan(NTT): 310Mbps
SK Telecom	SK speedNet	· Links between major cities: 622MGbps · Links between small and mid-sized cities: 155MGbps · Jeju: 45Mbps	(Total bandwidth of IX: 6Gbps · KT-IX : 2.5Gbps/DIX: 2Gbps · KINX : 1Gbps) (Total connected ISPs: 2.545Mbps)	(Total 155Mbps) · Dacom-international: 155Mbps
Dreamline	DreamLine	· Between major node links: 45Mbps~2Gbps	(Total bandwidth of IX: 7Gbps · KIX : 5Gbps · KINX : 2Gbps) (Total connected ISPs: 7.4Gbps)	(Total 310Mbps) · Hanaro Telecom: 155Mbps · AGC: 155Mbps
Powercomm	POWER-COMM	· Total nodes nationwide: 75 · City links: 2.5Gbps · Subscriber network: 155Mbps	-	-

Source: National Computerization Agency(NCA), Dec. 2003

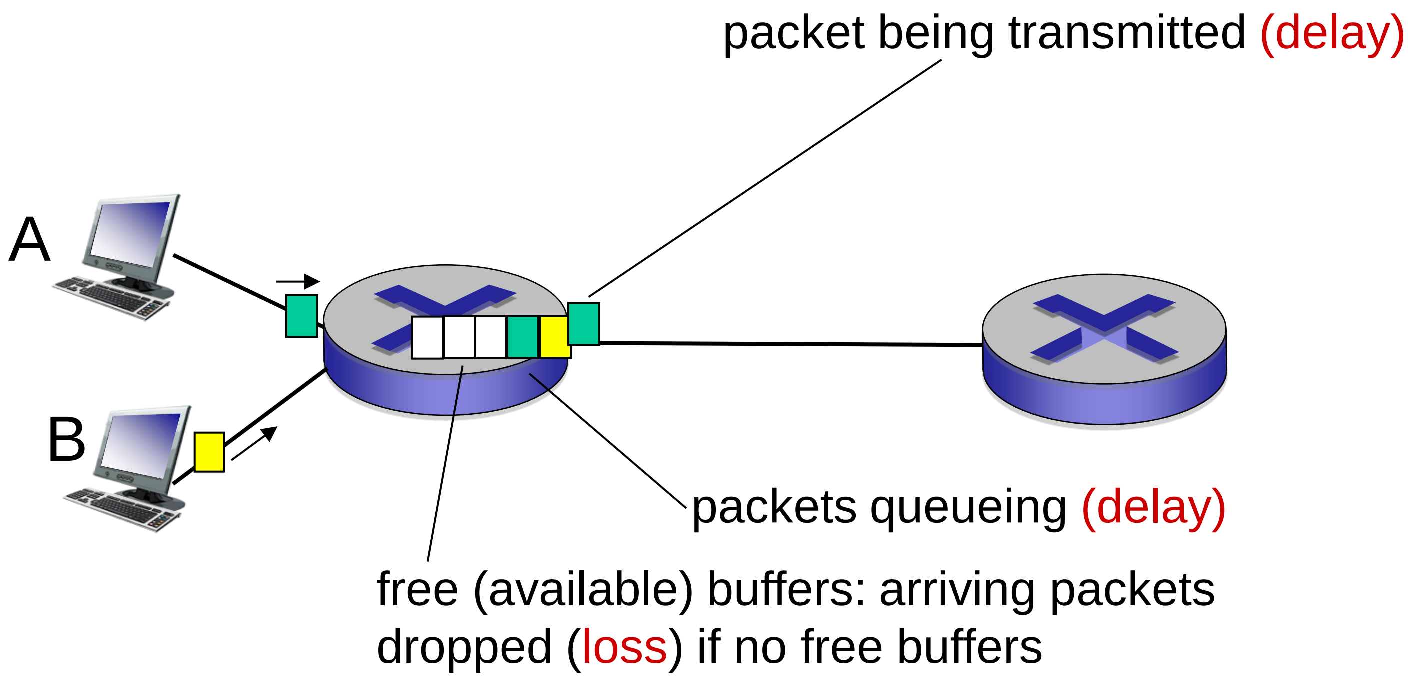
Company (Service Name)	Network State	Service Targets	Network Connection	
			Domestic	Foreign
KT (PUBNet)	· ATM network-based nodes nationwide: 18 · Between majors cities: 155M~622Mbps · Between small and mid-sized cities: 155Mbps	· Public & non-profit organizations · Elementary & secondary schools	(Total bandwidth of IX: 13.6Gbps · KIX : 5G · KT-IX : 7.5G · DIX : 2.5G) (Connected ISPs: Connected to KIX, KT-IX)	· U.S.(KIX): 75Mbps
Dacom (PUBNET-PLUS)	· Between ATM network-based nodes nationwisde: 45Mbps, 155Mbps, 622Mbps	· Public & non-profit organizations	(Total bandwidth of IX: 4Gbps · 6KANet: 2Gbps · BORANet : 2Gbps) (Connected ISPs: Connected to KIX, DIX)	· U.S.(KIX): 75Mbps
NCA (6KANet)	· Between Seoul and Youngin: 45Mbps	· Central administration, judiciary & legislative bodies · Educational organization, organizations in leading application business	(Total bandwidth of IX: 1Gbps 6NGIX : 1G) (Connected ISPs: 2.5Gbps -Interconnected via 6NGIX)	· U.S.(6NGIX, KIX) :775Mbps
KERIS (EDUNET)	· Between the six nodes nationwide: 2Mbps~4Mbps	· All citizens including students, teachers, parents	(Total bandwidth of IX: 310Mbps · KT-IX : 155M · DIX: 155M (Connected ISPs: 400Mbps)	· 155M (Interconnection via KIX)

Source: National Computerization Agency(NCA), Dec. 2003

How do loss and delay occur?

packets *queue* in router buffers

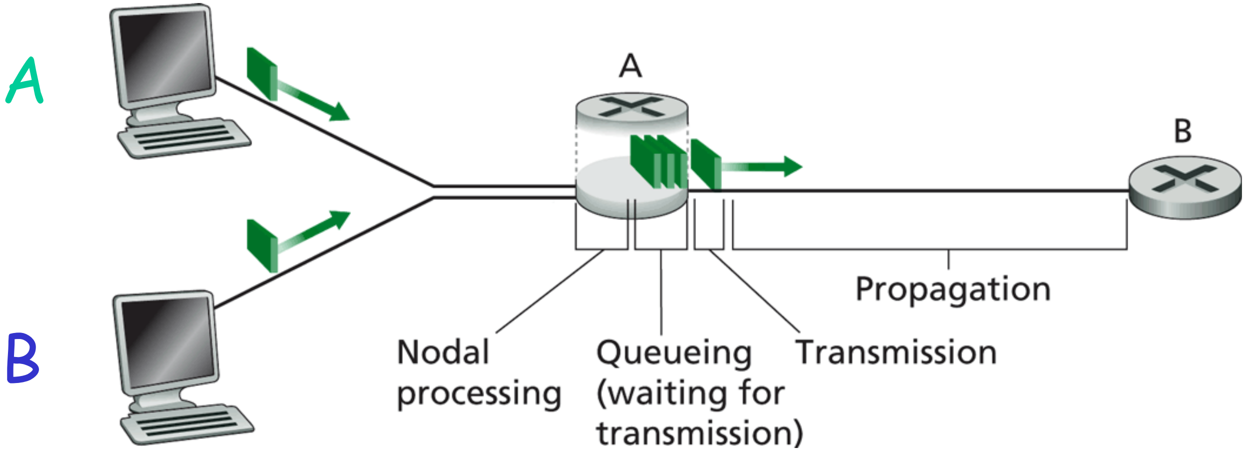
- packet arrival rate to link (temporarily) exceeds output link capacity
- packets queue, wait for turn



Delay in packet-switched networks

- packets experience delay on end-to-end path
- four sources of delay at each hop

- nodal processing: d_{proc}
  - check bit errors
  - determine output link
- Queueing: d_{queue}
  - time waiting at output link for transmission
  - depends on congestion level of router



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

Delay in packet-switched networks

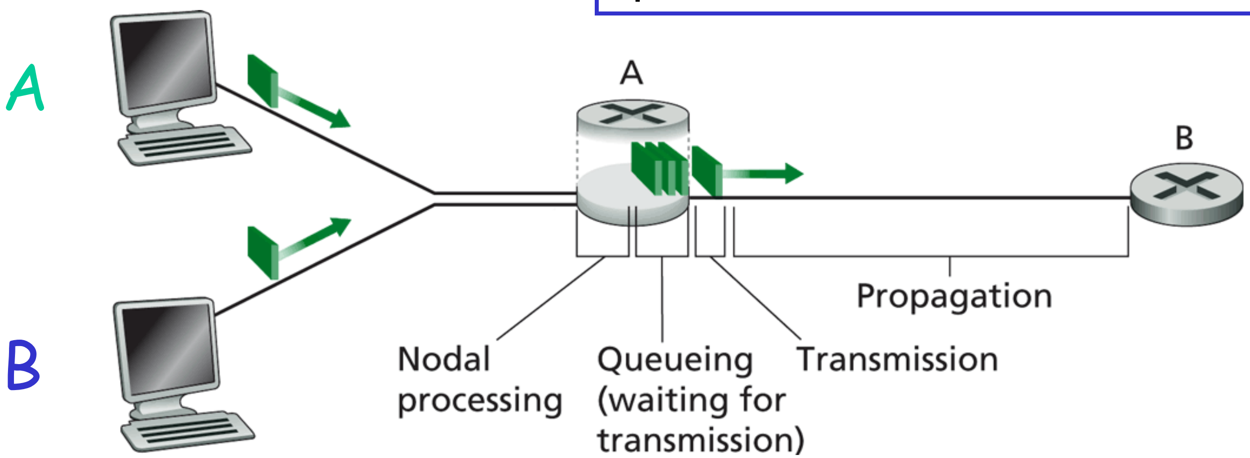
Transmission delay: d_{trans}

- R=link bandwidth (bps)
- L=packet length (bits)
- time to send bits into link = L/R

Propagation delay: d_{prop}

- d = length of physical link
- s = propagation speed in medium (~2x10^8 m/sec)
- propagation delay = d/s

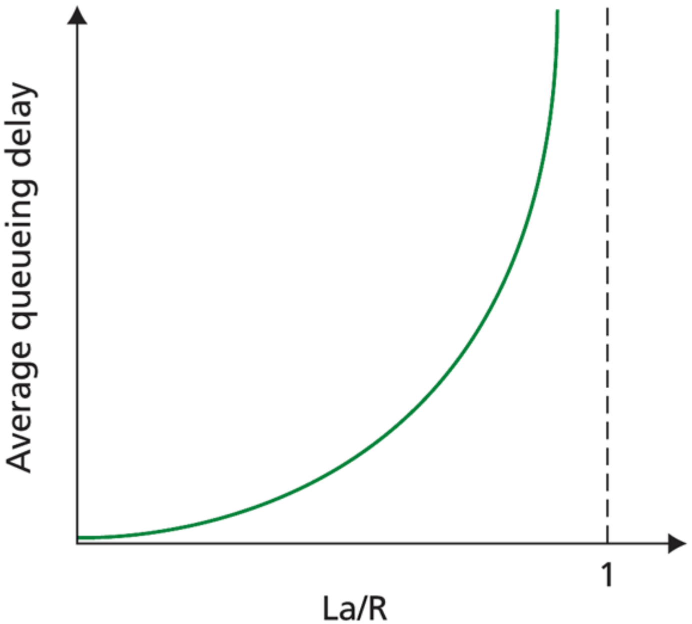
Note: s and R are *very* different quantities!



* https://wps.pearsoned.com/ecs_kurose_compnetw_6/216/55463/14198700.cw/index.html

Queueing delay (revisited)

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

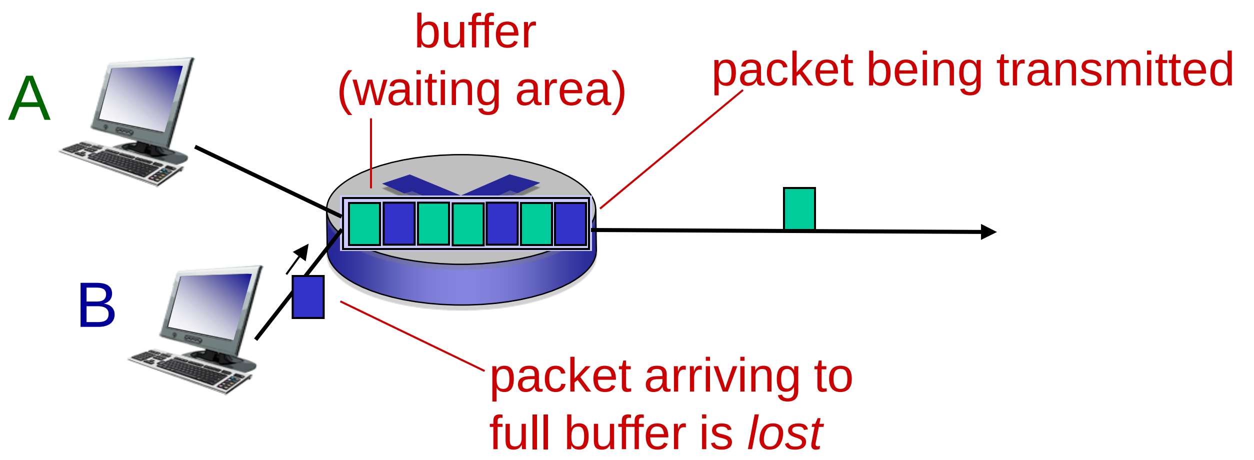


traffic intensity = La/R

La/R ~ 0: average queueing delay small
La/R →1: delays become large
La/R > 1: more "work" arriving than can be serviced, average delay infinite!

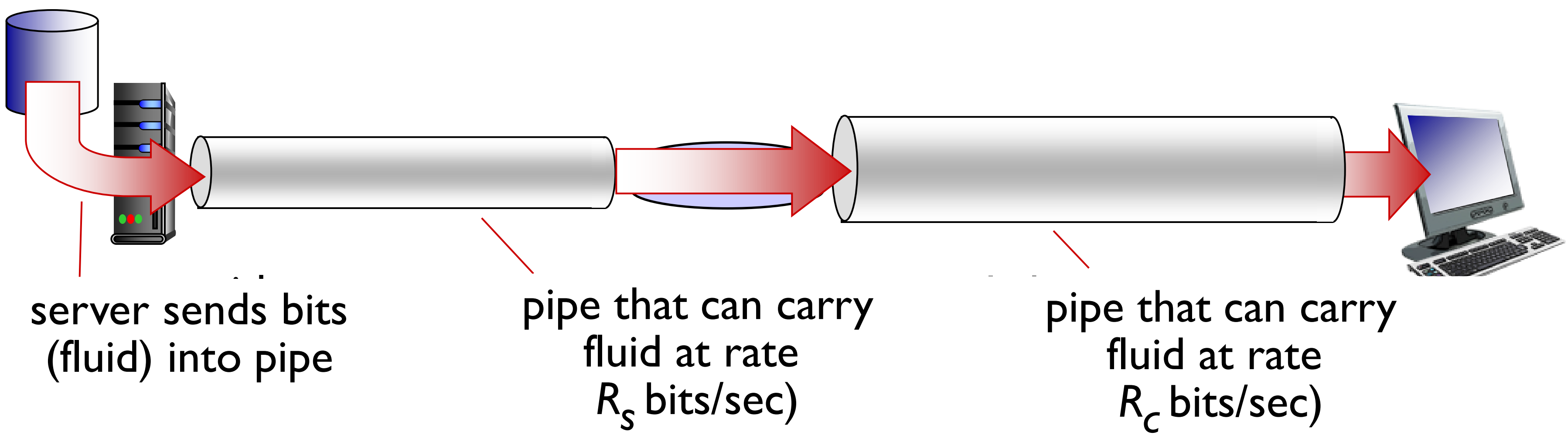
Packet loss

- 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



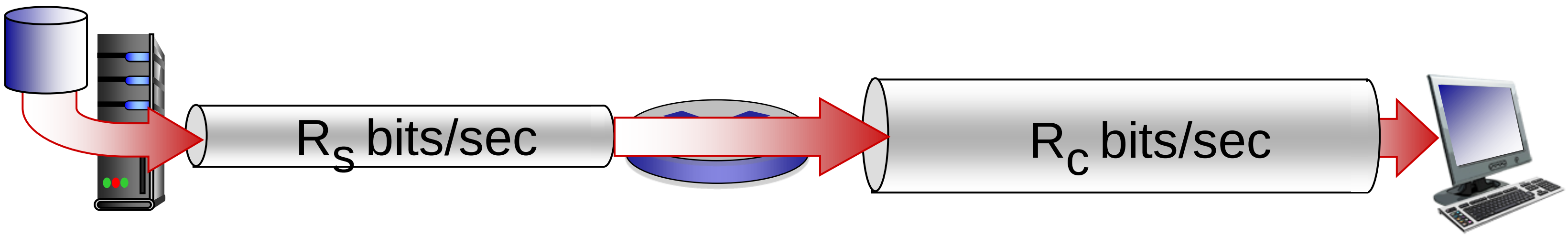
Throughput

- *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

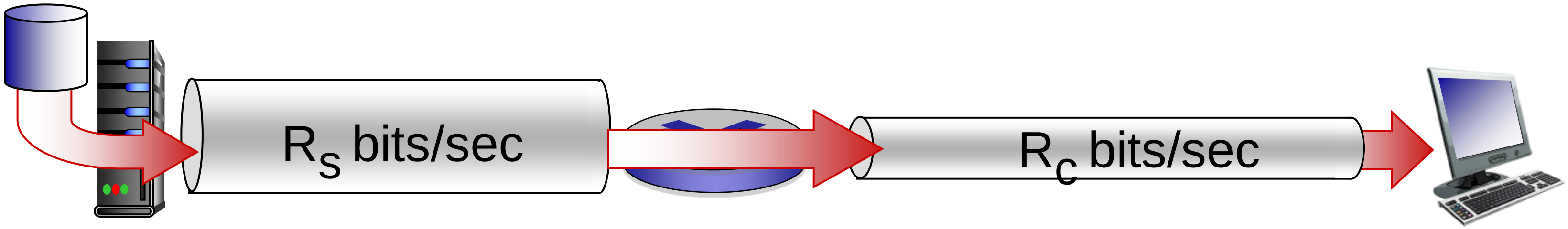


Throughput (more)

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



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

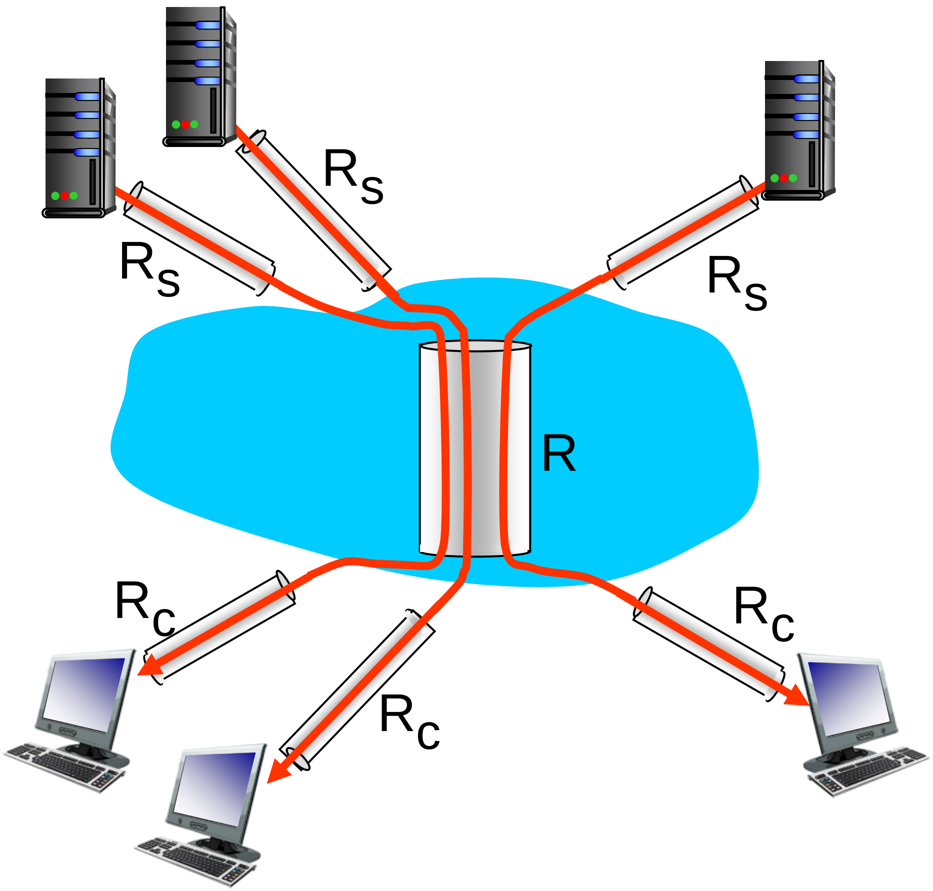


bottleneck link

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"

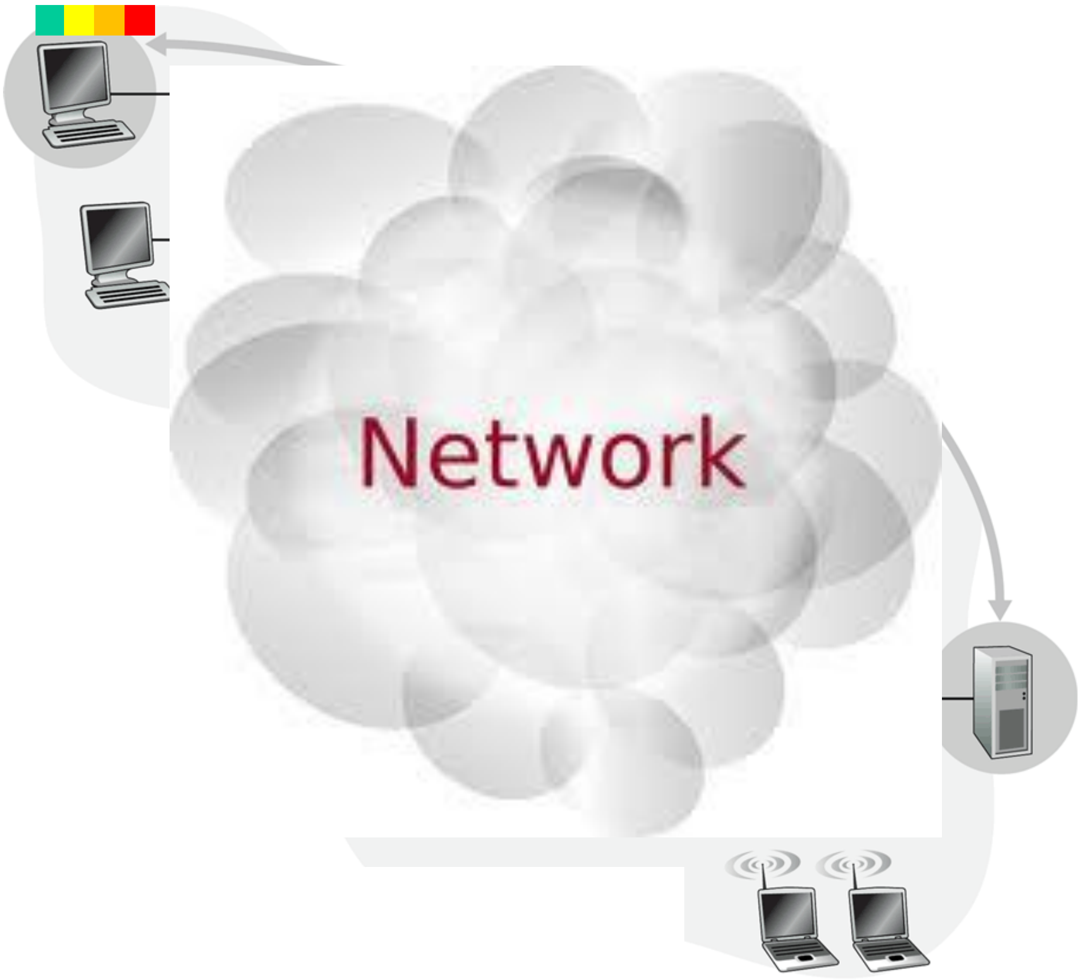
Networks are complex, with many "pieces":

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

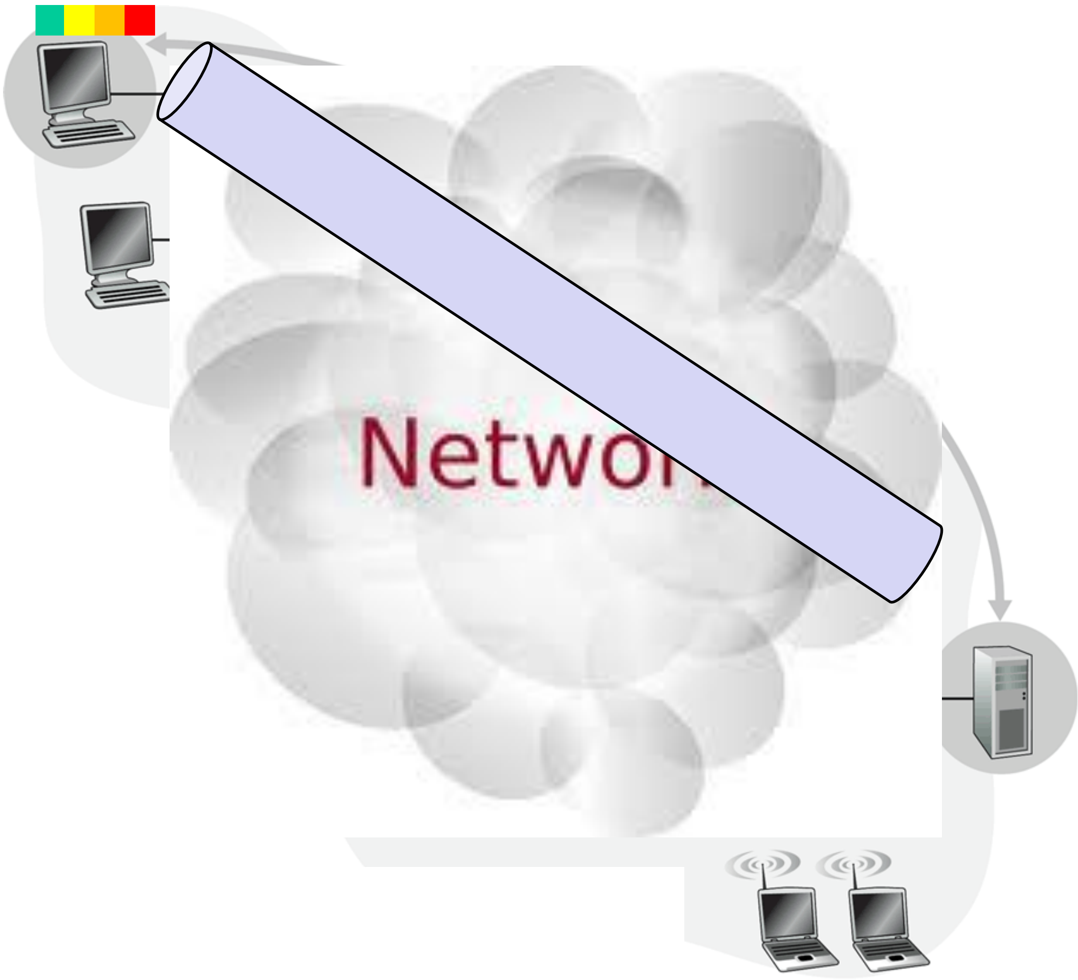
Question:

Is there any hope of *organizing* the structure of a network?

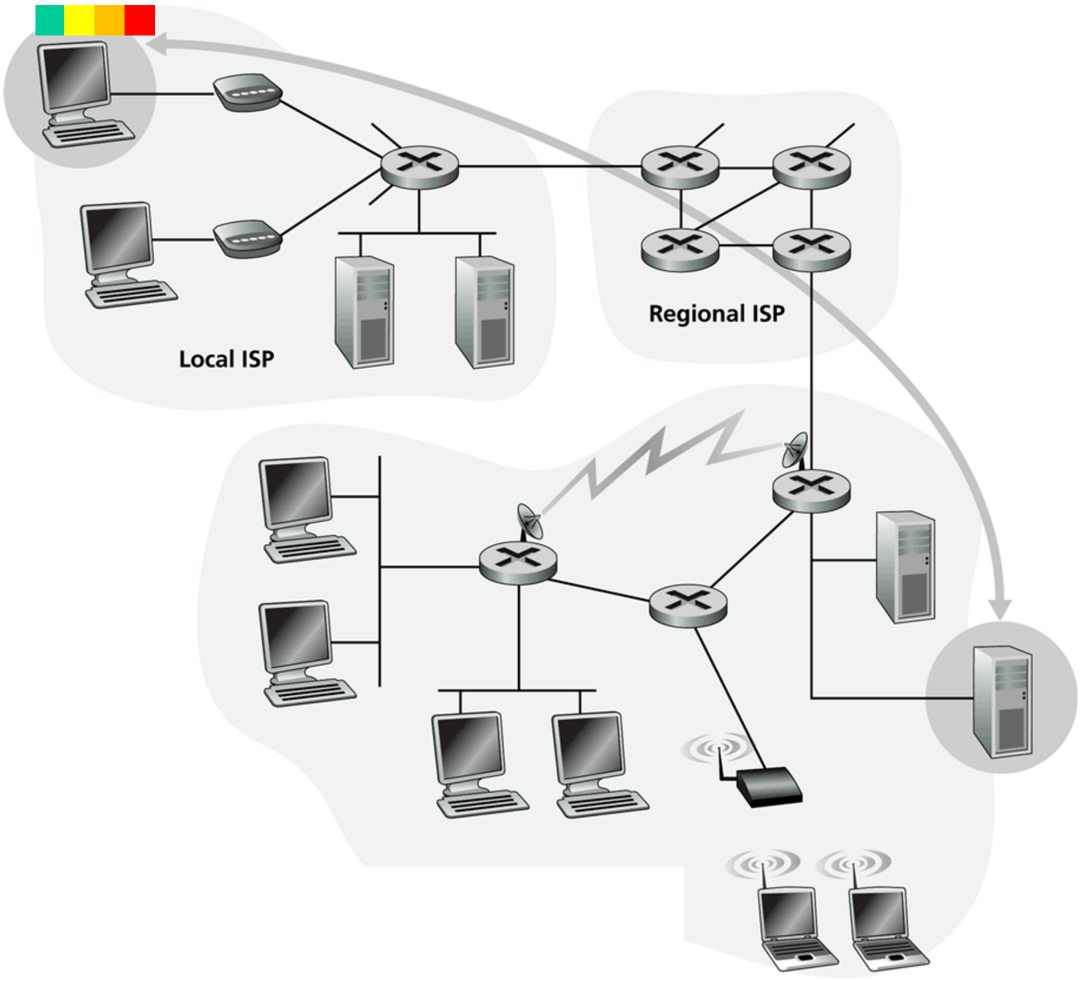
Application Layer



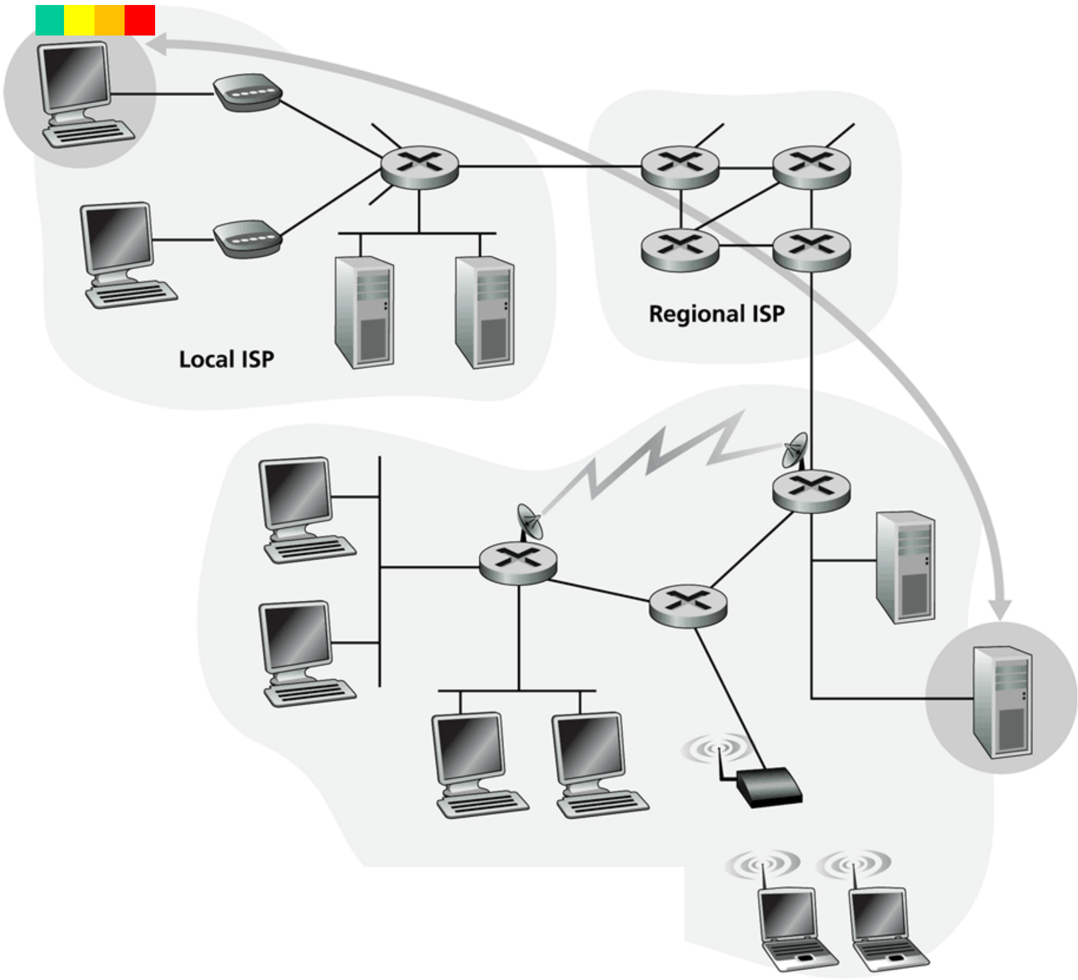
Transport Layer



Network Layer



Data Link Layer



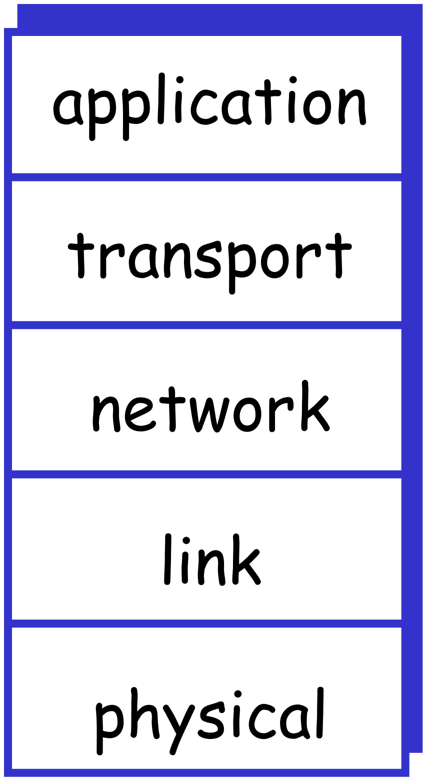
Why layering?

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?

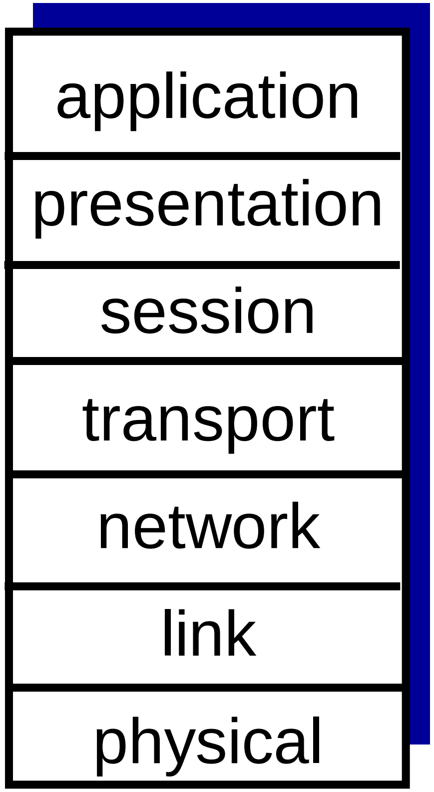
Internet protocol stack

- application: supporting network applications
  - ftp, smtp, http
- transport: host-host data transfer
  - tcp, udp
- network: routing of datagrams from source to destination
  - ip, routing protocols
- link: data transfer between neighboring network elements
  - ppp, ethernet
- physical: bits “on the wire”

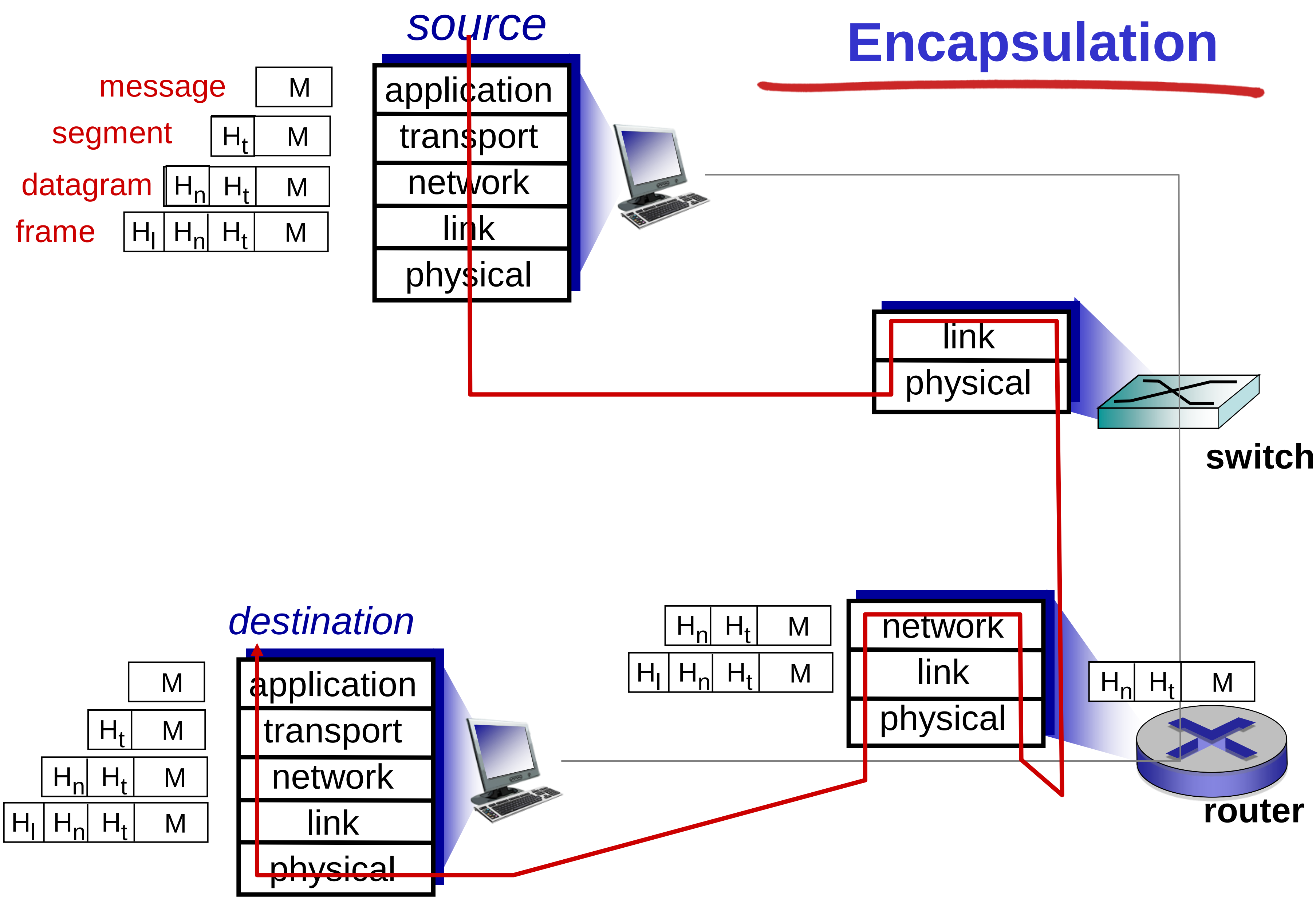


ISO/OSI reference model

- *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



Internet History

1961-1972: Early packet-switching principles

- 1961: Kleinrock - queueing theory shows effectiveness of packet-switching
- 1964: Baran - packet-switching in military nets
- 1967: ARPAnet conceived by Advanced Research Projects Agency
- 1969: first ARPAnet node operational
- 1972:
  - ARPAnet demonstrated publicly
  - NCP (Network Control Protocol) first host-host protocol
  - first e-mail program
  - ARPAnet has 15 nodes

Internet History

1972-1980: Internetworking, new and proprietary nets

- 1970: ALOHAnet satellite network in Hawaii
- 1973: Metcalfe's PhD thesis proposes Ethernet
- 1974: Cerf and Kahn - architecture for interconnecting networks
- late70's: proprietary architectures: DECnet, SNA, XNA
- late 70's: switching fixed length packets (ATM precursor)
- 1979: ARPAnet has 200 nodes

Cerf and Kahn's internetworking principles:

- minimalism, autonomy - no internal changes required to interconnect networks
- best effort service model
- stateless routers
- decentralized control

define today's Internet architecture

Internet History

1980-1990: new protocols, a proliferation of networks

- 1983: deployment of TCP/IP
- 1982: smtp e-mail protocol defined
- 1983: DNS defined for name-to-IP-address translation
- 1985: ftp protocol defined
- 1988: TCP congestion control
- new national networks: Csnet, BITnet, NSFnet, Minitel
- 100,000 hosts connected to confederation of networks

Internet History

1990's: commercialization, the WWW

- Early 1990's: ARPAnet decomissioned
- 1991: NSF lifts restrictions on commercial use of NSFnet (decommissioned, 1995)
- Early 1990s: WWW
  - hypertext [Bush 1945, Nelson 1960's]
  - HTML, http: Berners-Lee
  - 1994: Mosaic, later Netscape
  - late 1990's: commercialization of the WWW
- Late 1990's-2000's:
  - more killer apps: instant messaging, P2P file sharing
  - network security to forefront
  - est. 50 million host, 100 million+ users
  - backbone links running at Gbps

Internet history

2005-present

- ~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)

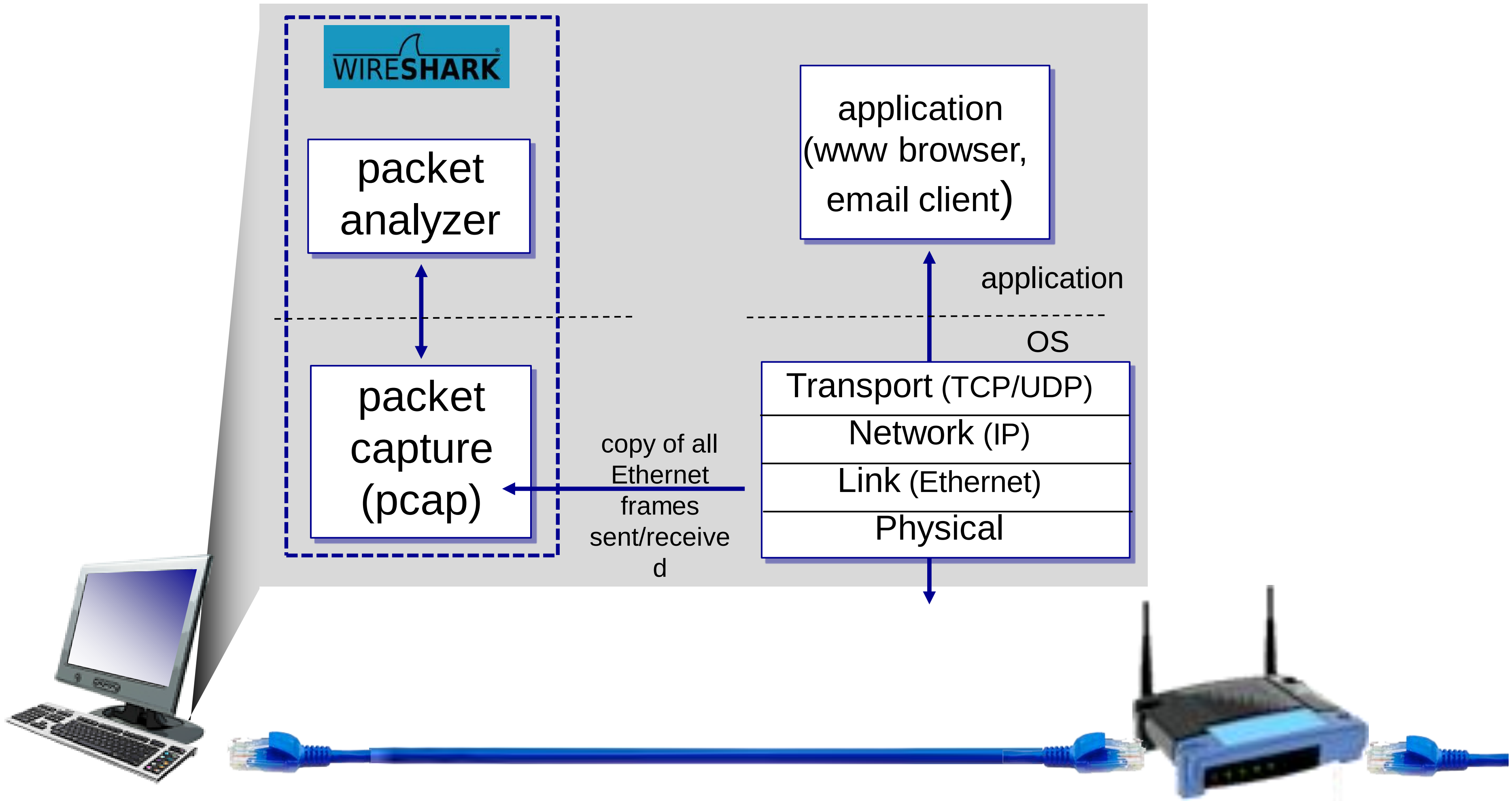
Chapter 1: Summary

Covered a “ton” of material!

- Internet overview
- what’s a protocol?
- network edge, core, access network
- performance: loss, delay
- layering and service models
- backbones, NAPs, ISPs
- history

You now hopefully have:

- context, overview, “feel” of networking
- more depth, detail *later* in course



WIRESHARK
packet analyzer
packet capture (pcap)
application (www browser, email client)
application
OS
Transport (TCP/UDP)
Network (IP)
Link (Ethernet)
Physical
copy of all Ethernet frames sent/receive d