Chapter 1
Introduction – part 2

School of Computing
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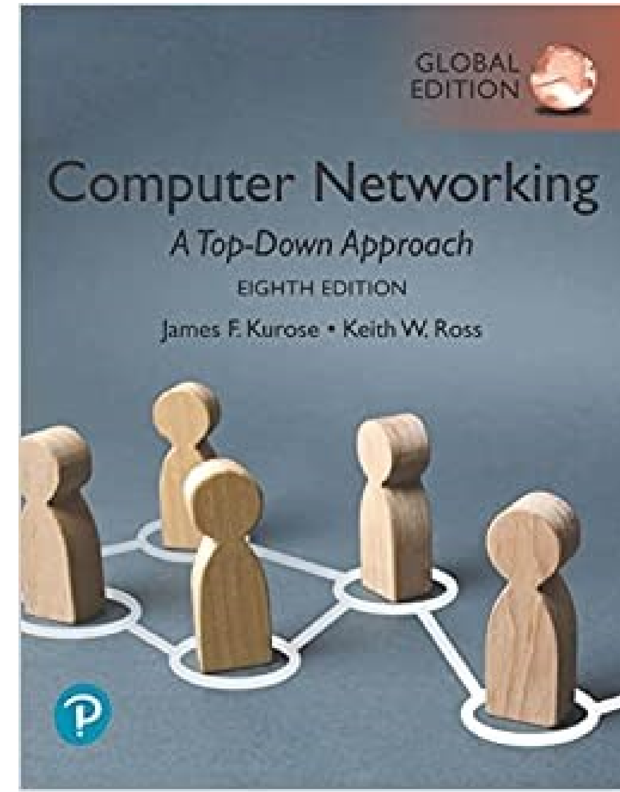

Computer Networking: A Top-Down Approach
8th edition (Global edition)
Jim Kurose, Keith Ross
Pearson, 2021

Many slides from J.F Kurose and K.W. Ross

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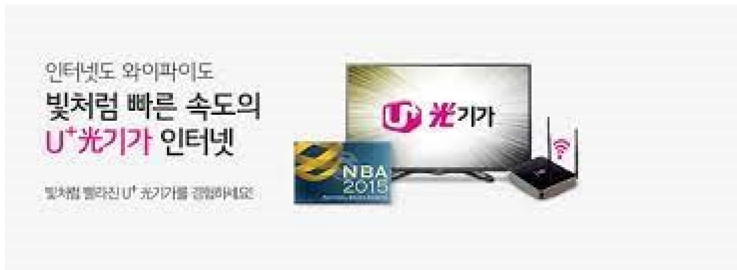
Question

How do we measure the performance of a network?



Chapter 1: roadmap

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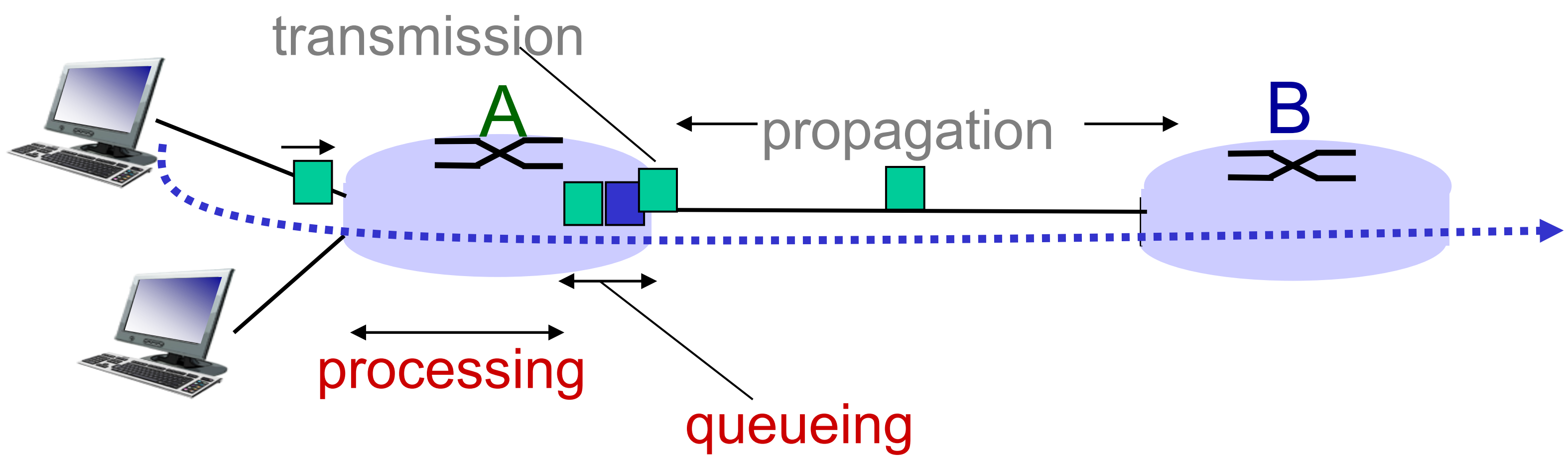
Four sources of packet delay



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

1. d_{proc}: processing delay
- examines packet header
- determine where to direct packet (=output link), e.g., link to router B.
- typically usec

2. d_{queue}: queueing delay
- time waiting at output link for transmission
- depends on earlier arriving packets that are queued and waiting
- typically usec ~ msec

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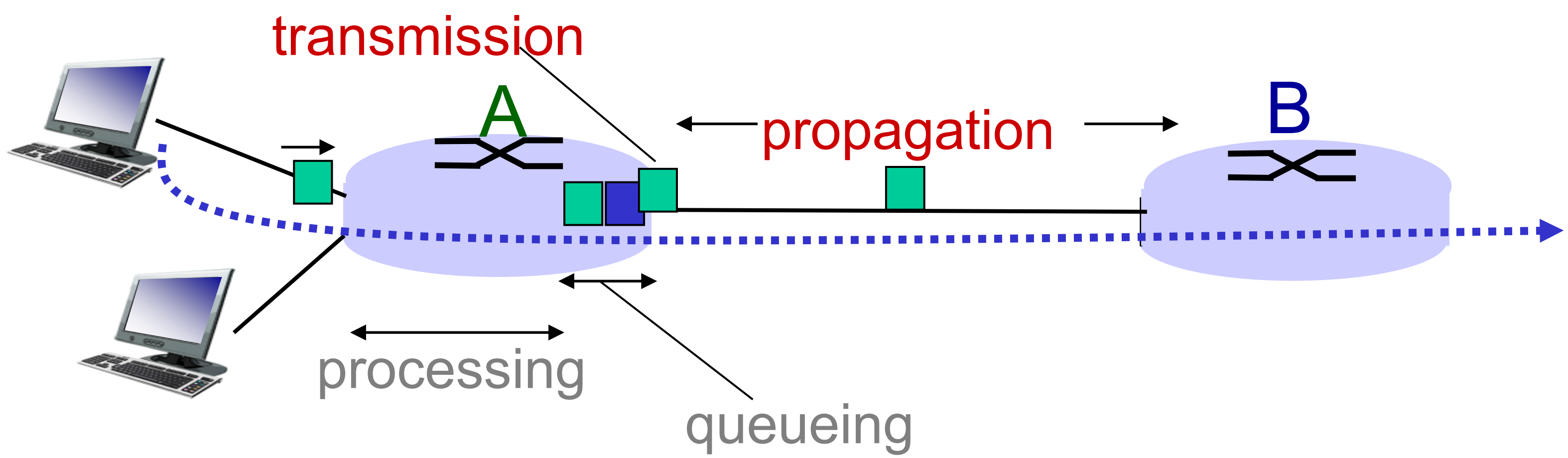
Four sources of packet delay



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

3. d_{trans}: transmission delay:

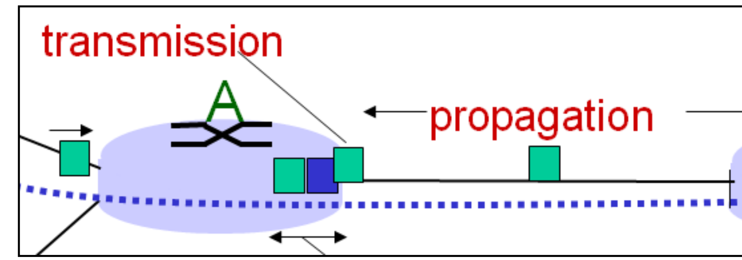
- time to transmit all the packet's bits into the link (e.g., link AB)
- $d_{trans} = L/R$
  - L: packet length (bits)
  - R: link *bandwidth (bps)*

4. d_{prop}: propagation delay:

- time to propagate from beginning of the link to next router (e.g., router B)
- $d_{prop} = d/s$
  - d: length of physical link
  - s: propagation speed in medium (~2×10^8 m/sec) – similar to speed of light

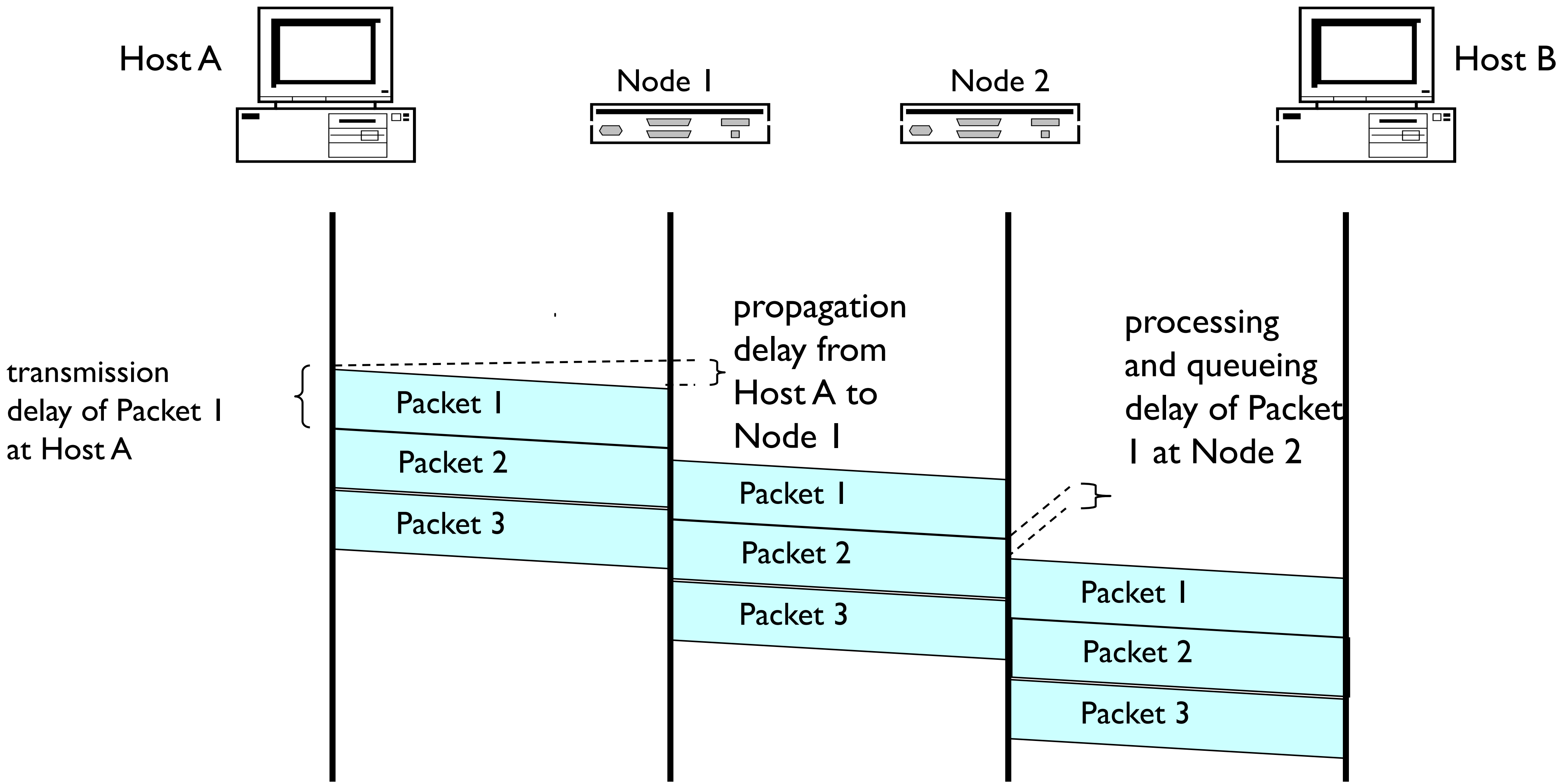
Transmission vs. Propagation Delay

- Transmission (전송) delay
  - Time for router to push out the packet
  - Function of packet's length (L bits) and transmission rate (R bps) of link
    - $d_{trans} = L/R$
  - Nothing to do with distance between two routers



- Propagation (전파) delay
  - Time a bit to propagate from one router to the next
  - Function of distance between the two routers
    - $d_{prop} = d/s$
  - Nothing to do with packet's length or the transmission rate of link

Timing Diagram of Packet Switching



Nodal delay

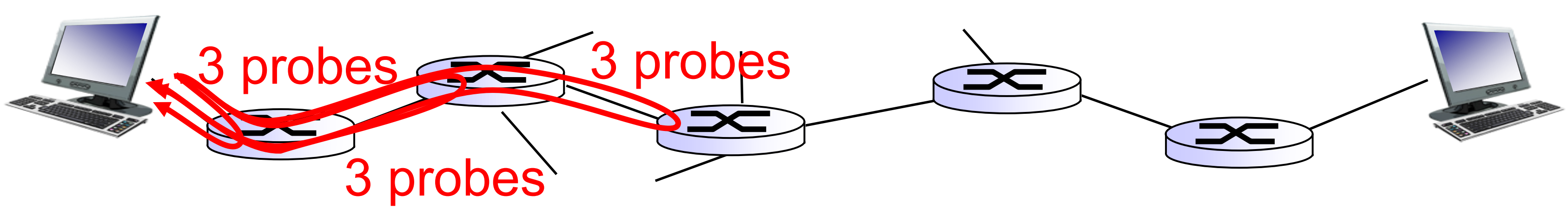
$$\boxed{d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}}$$

- d_{proc} = processing delay
  - typically a few microsecs or less
- d_{queue} = **queuing delay**
  - depends on congestion of network

- d_{trans} = transmission delay = L/R
  - negligible for 10Mbps and higher
  - but significant for low-speed links (e.g., dial-up modem, 2G)
- d_{prop} = propagation delay
  - a few microsecs (e.g., same campus) to hundreds of msecs (e.g., satellite link)

"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: gaia.cs.umass.edu to www.eurecom.fr

3 delay measurements from gaia.cs.umass.edu to cs-gw.cs.umass.edu

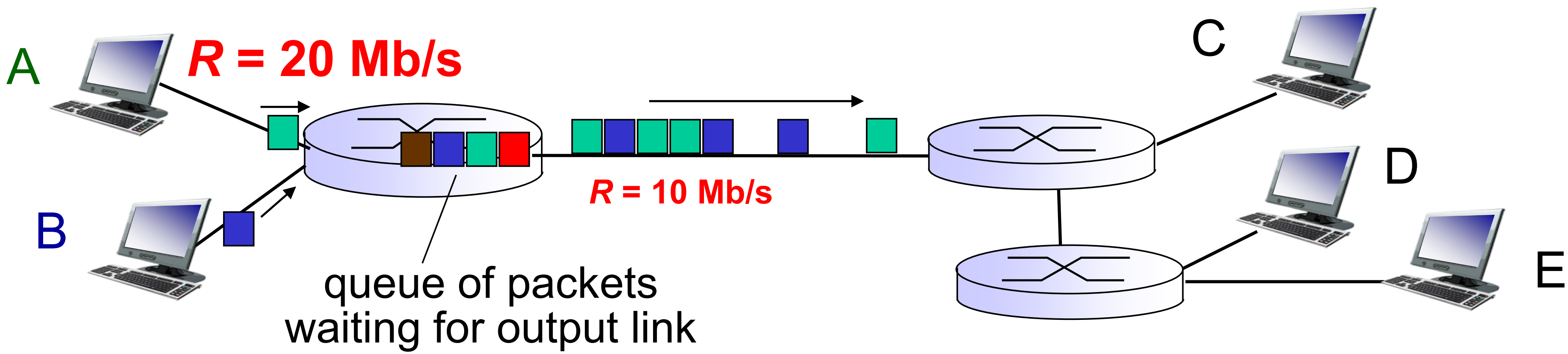
1 cs-gw (128.119.240.254) 1 ms 1 ms 2 ms
2 border1-rt-fa5-1-0.gw.umass.edu (128.119.3.145) 1 ms 1 ms 2 ms
3 cht-vbns.gw.umass.edu (128.119.3.130) 6 ms 5 ms 5 ms
4 jn1-at1-0-0-19.wor.vbns.net (204.147.132.129) 16 ms 11 ms 13 ms
5 jn1-so7-0-0-0.wae.vbns.net (204.147.136.136) 21 ms 18 ms 18 ms
6 abilene-vbns.abilene.ucaid.edu (198.32.11.9) 22 ms 18 ms 22 ms
7 nycm-wash.abilene.ucaid.edu (198.32.8.46) 22 ms 22 ms 22 ms
8 62.40.103.253 (62.40.103.253) 104 ms 109 ms 106 ms
9 de2-1.de1.de.geant.net (62.40.96.129) 109 ms 102 ms 104 ms
10 de.fr1.fr.geant.net (62.40.96.50) 113 ms 121 ms 114 ms
11 renater-gw.fr1.fr.geant.net (62.40.103.54) 112 ms 114 ms 112 ms
12 nio-n2.cssi.renater.fr (193.51.206.13) 111 ms 114 ms 116 ms
13 nice.cssi.renater.fr (195.220.98.102) 123 ms 125 ms 124 ms
14 r3t2-nice.cssi.renater.fr (195.220.98.110) 126 ms 126 ms 124 ms
15 eurecom-valbonne.r3t2.ft.net (193.48.50.54) 135 ms 128 ms 133 ms
16 194.214.211.25 (194.214.211.25) 126 ms 128 ms 126 ms
17 * * *
18 * * *
19 fantasia.eurecom.fr (193.55.113.142) 132 ms 128 ms 136 ms

trans-oceanic link

* means no response (probe lost, router not replying)

* Do some traceroutes from exotic countries at www.traceroute.org

Packet Switching: queueing delay, loss



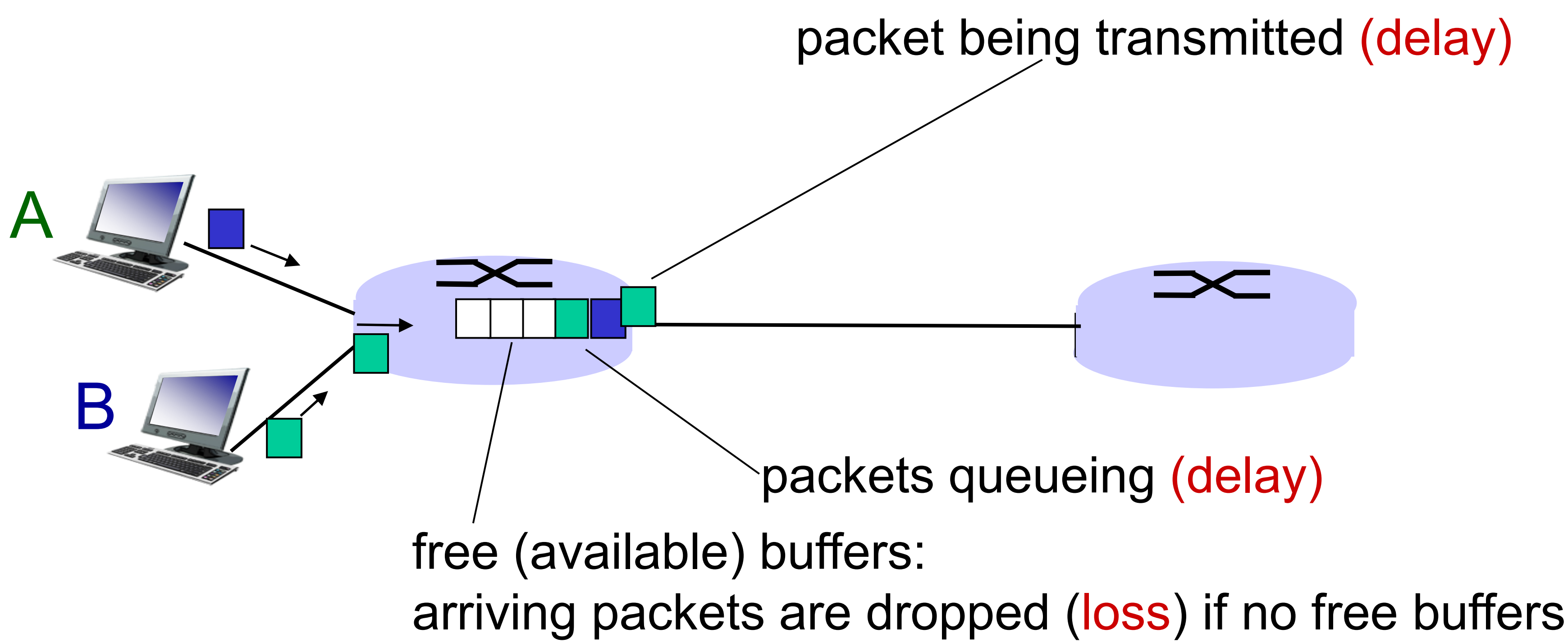
queuing and loss:

- 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 – **queueing delay**
  - packets can be dropped if memory (buffer) fills up – **loss**

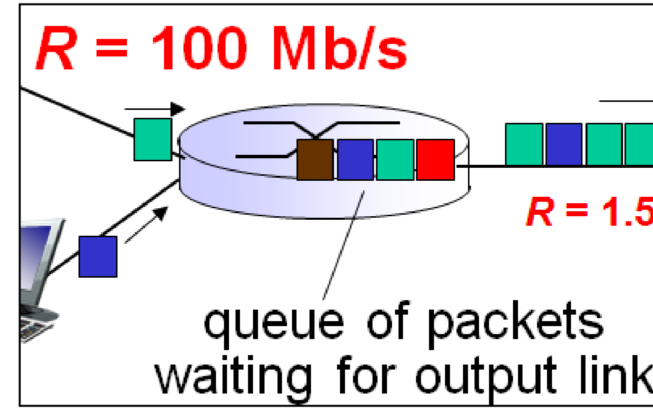
How do loss and delay occur?

packets *queue* in router buffers

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

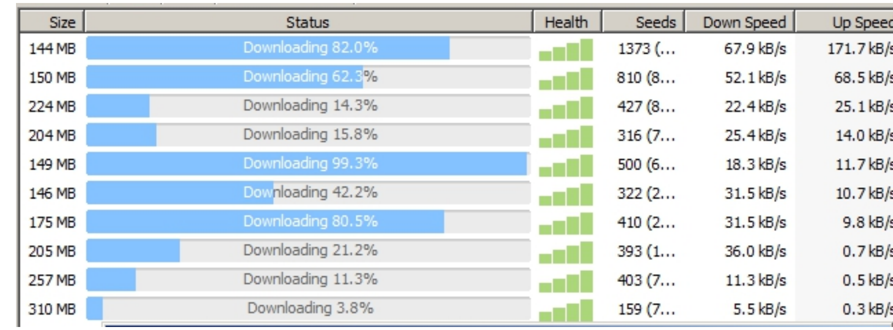


loss and delay



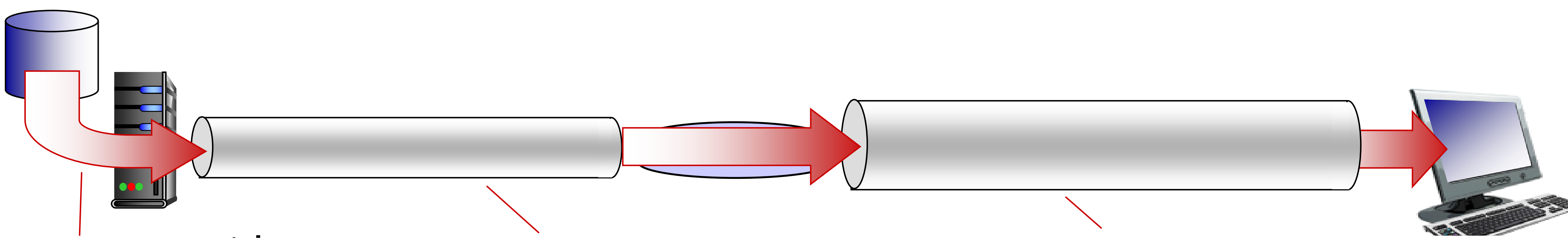
- Queueing delay
  - 10 packets arrive at router almost at the same time
    - Currently the router buffer is empty
  - First packet has no queueing delay
  - 10th packet has to wait for 9 other packets to be transmitted – **queueing delay** occurs
- Loss
  - If the router buffer (i.e., memory) is full
  - Next arriving packet will be **dropped** – **packet loss** occurs
- Queueing delay and loss will increase as traffic intensity (i.e., congestion) increases

Throughput



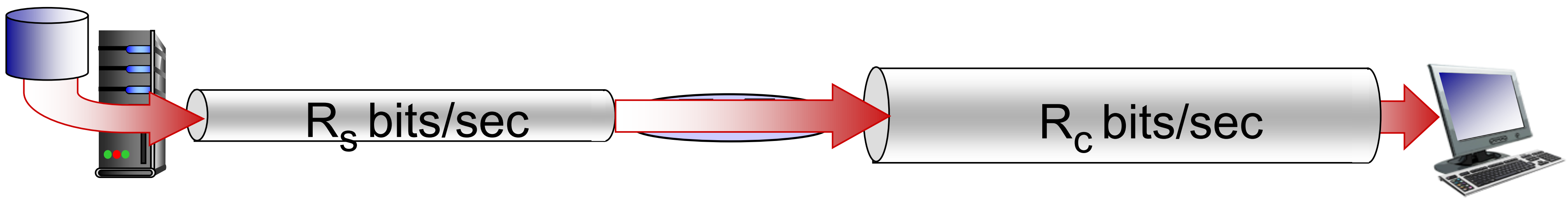
Size	Status	Health	Seeds	Down Speed	Up Speed
144 MB	Downloading 82.0%		1373 (...	67.9 kB/s	171.7 kB/s
150 MB	Downloading 62.3%		810 (8...	52.1 kB/s	68.5 kB/s
224 MB	Downloading 14.3%		427 (8...	22.4 kB/s	25.1 kB/s
204 MB	Downloading 15.8%		316 (7...	25.4 kB/s	14.0 kB/s
149 MB	Downloading 99.3%		500 (6...	18.3 kB/s	11.7 kB/s
146 MB	Downloading 42.2%		322 (2...	31.5 kB/s	10.7 kB/s
175 MB	Downloading 80.5%		410 (2...	31.5 kB/s	9.8 kB/s
205 MB	Downloading 21.2%		393 (1...	36.0 kB/s	0.7 kB/s
257 MB	Downloading 11.3%		403 (7...	11.3 kB/s	0.5 kB/s
310 MB	Downloading 3.8%		159 (7...	5.5 kB/s	0.3 kB/s

- *throughput:* rate (bits/time) at which bits transferred between sender/receiver
  - *instantaneous:* rate at given point in time
  - *average:* rate over longer period of time

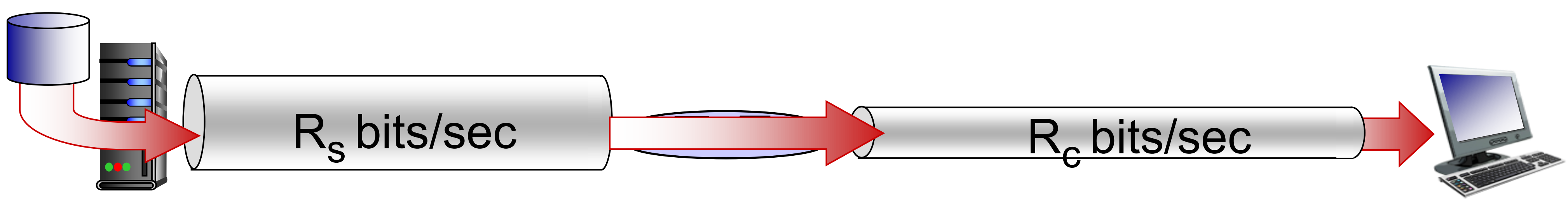


Throughput (more)

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



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



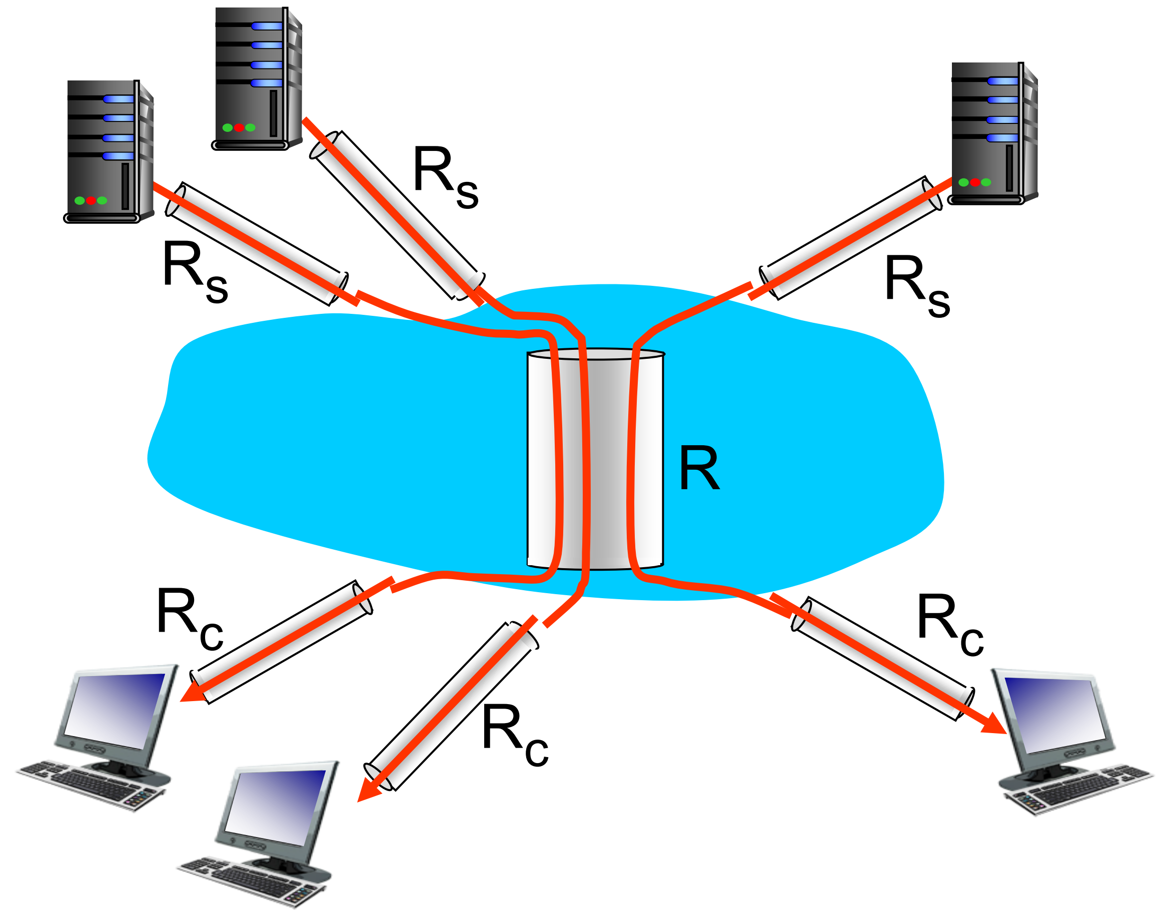
bottleneck link

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
  - R is often much larger
  - Even R/10, R/100, … is larger

- Throughput depends on the transmission rates of links on the data path



10 connections

Chapter 1: roadmap

1.1 what *is* the Internet?

1.2 network edge

- end systems, access ispworks, links

1.3 network core

- packet switching, circuit switching, network structure

1.4 delay, loss, throughput in networks

1.5 protocol layers, service models

Protocol "layers"

Networks are ***complex****,*
with many "pieces":

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

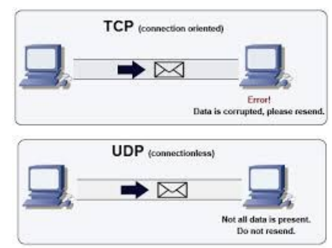
Question:

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

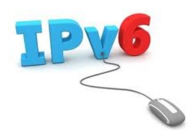
…. or at least our discussion of networks?

Internet protocol stack

- *application:* supporting various network applications
  - HTTP, SMTP, FTP, DNS
- *transport:* process-process data transfer
  - TCP, UDP

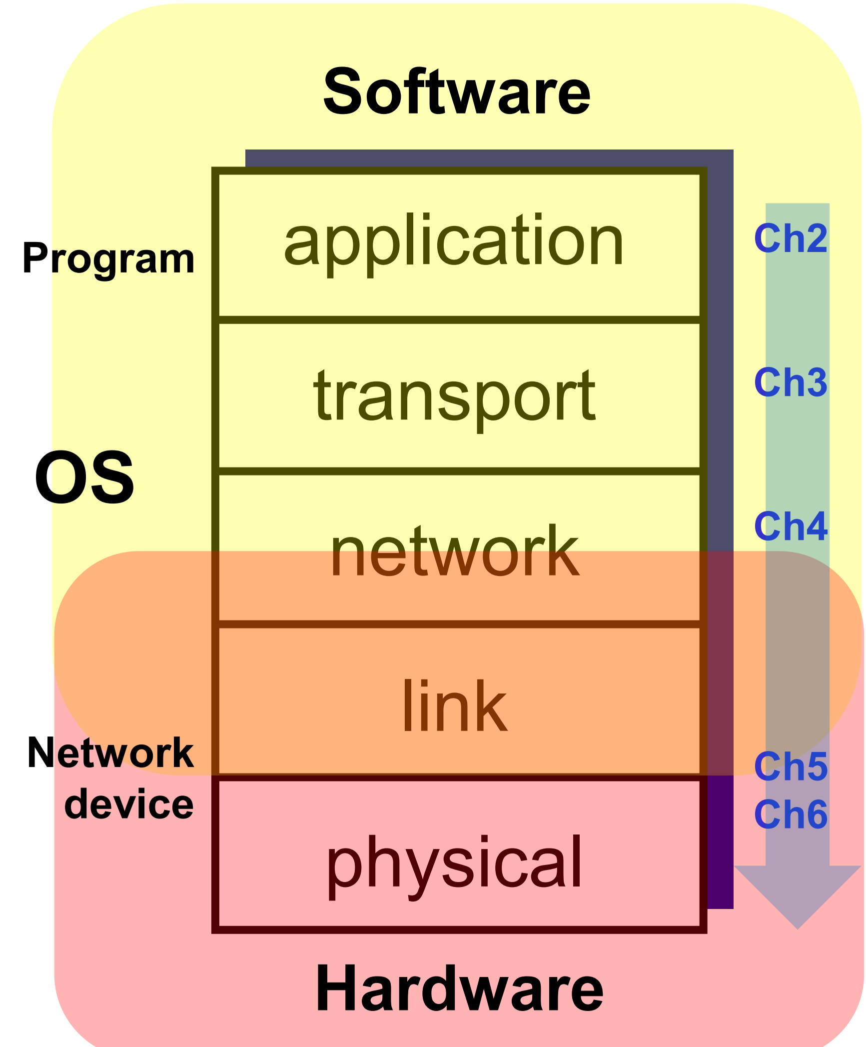


- *network:* routing of datagrams from source to destination
  - IP, routing protocols



- *link:* data transfer between neighboring network elements
  - Ethernet, 802.11 (WiFi)

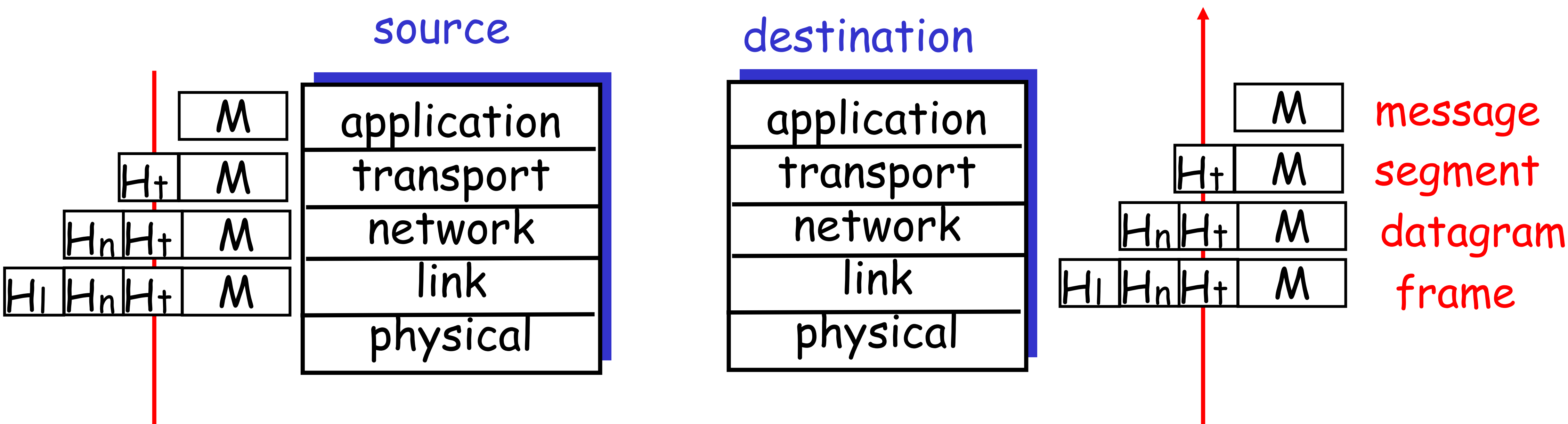
- *physical:* bits "on the wire"



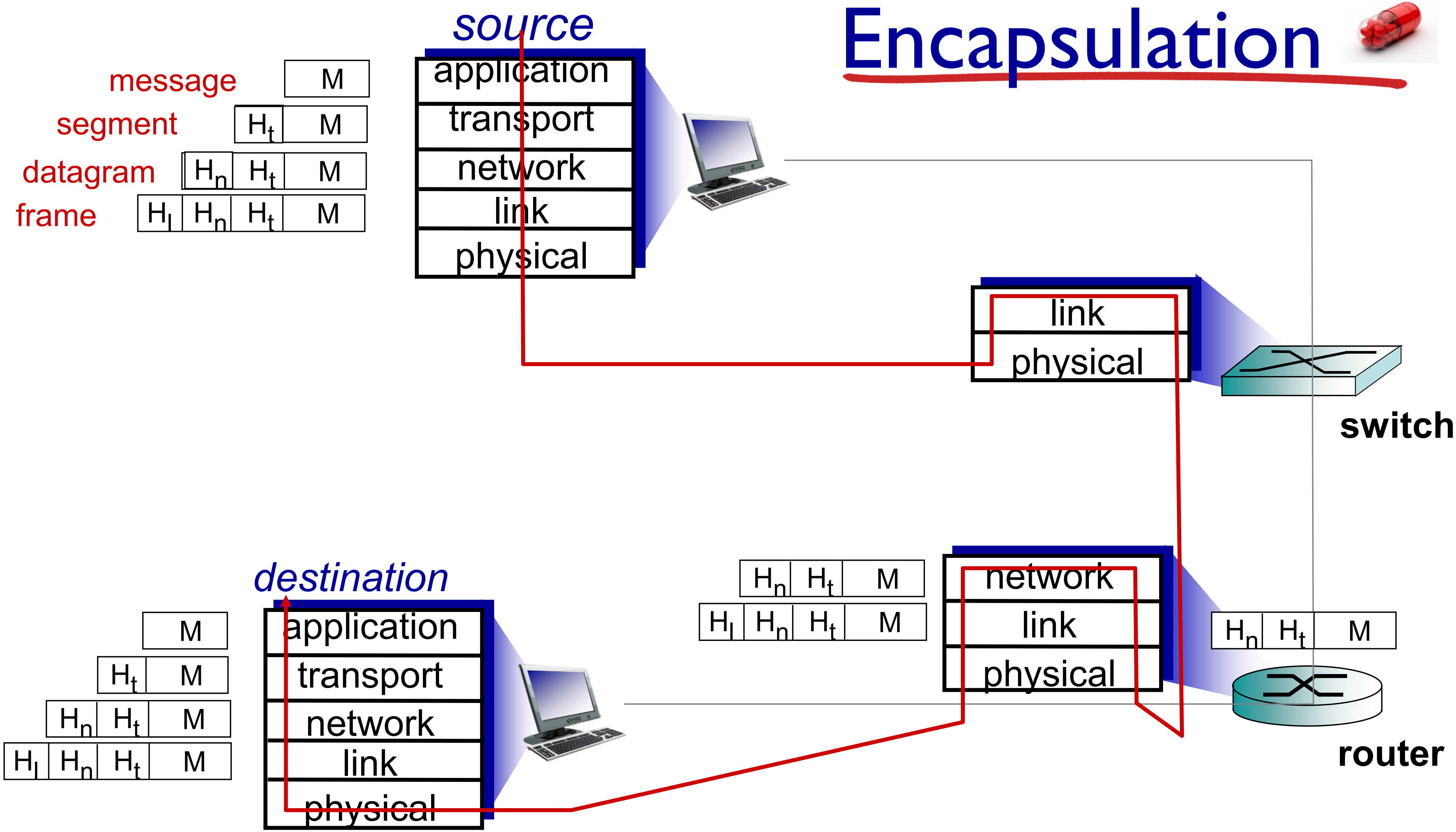
Protocol layering and data

Each layer takes data from above

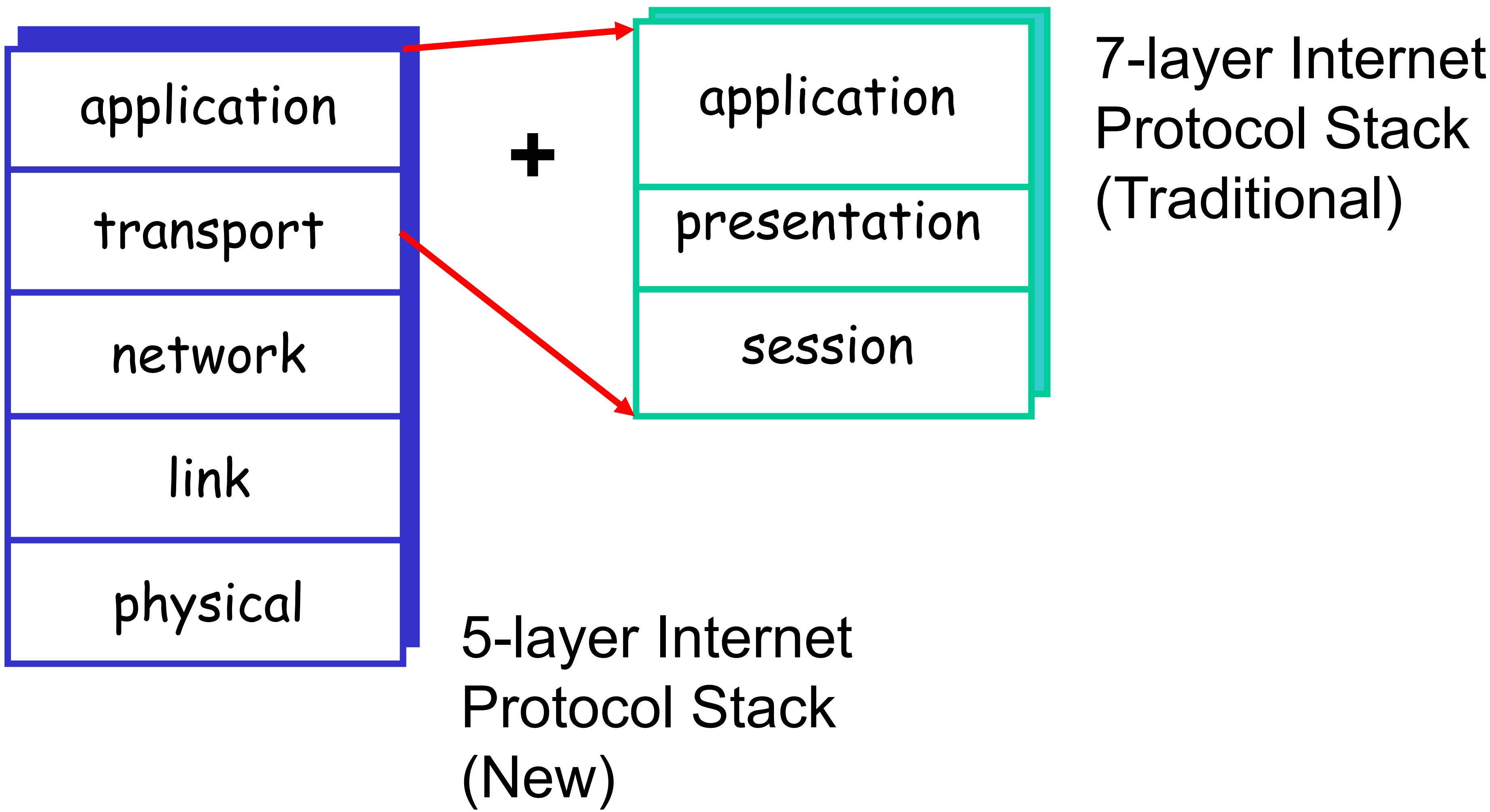
- adds header information to create new data unit
- passes new data unit to layer below



Encapsulation



ISO 7-layer reference model



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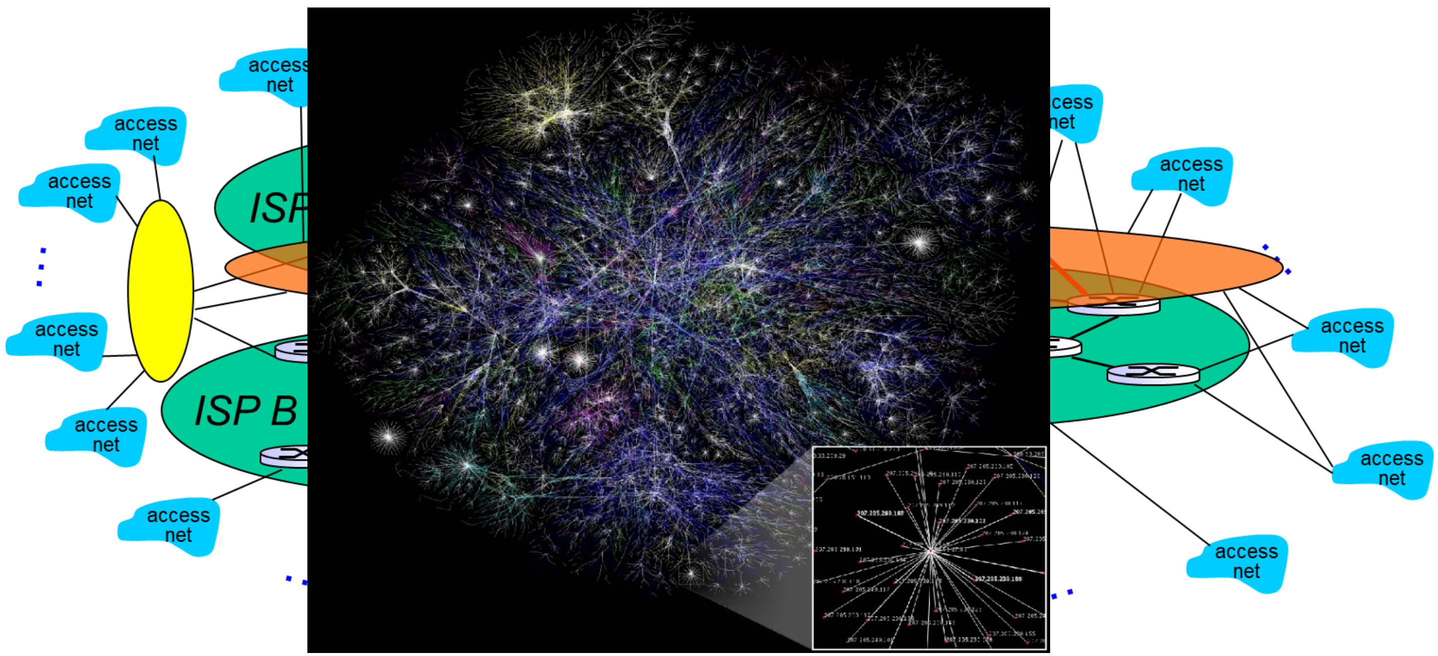
Question

Who takes care of the complex Internet?



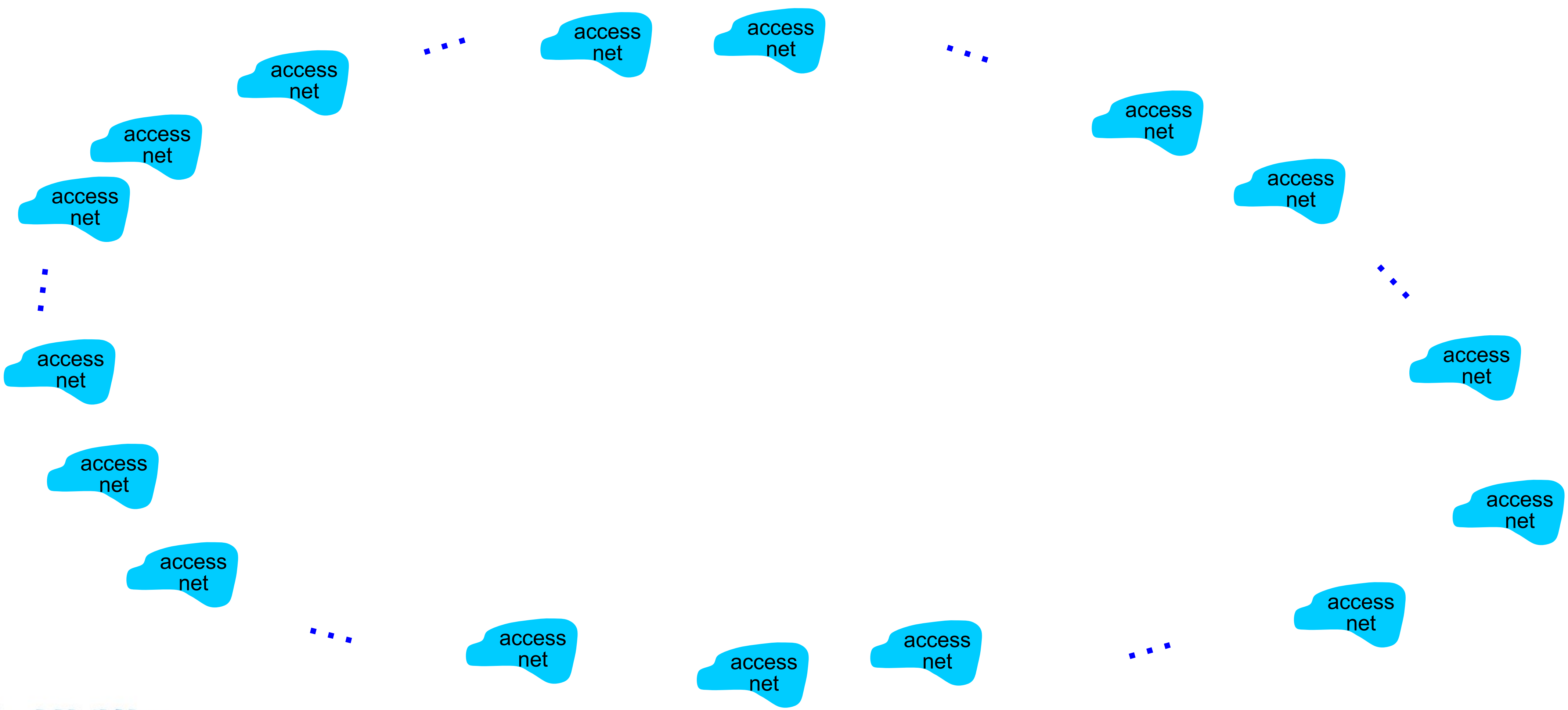
Internet structure: network of networks (Ch. 1.3.3)

- End systems connect to Internet via access **ISPs** (**Internet Service Providers**)
  - DSL, cable, FTTH, Wi-Fi, cellular, …
  - Telco (e.g., AT&T, Sprint, KT, SKT), Residential (e.g., KT, SK, LG), company and university ISPs
- Access ISPs in turn must be interconnected.
  - Network of Networks
  - 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

ISP is an "administrative view" of the network

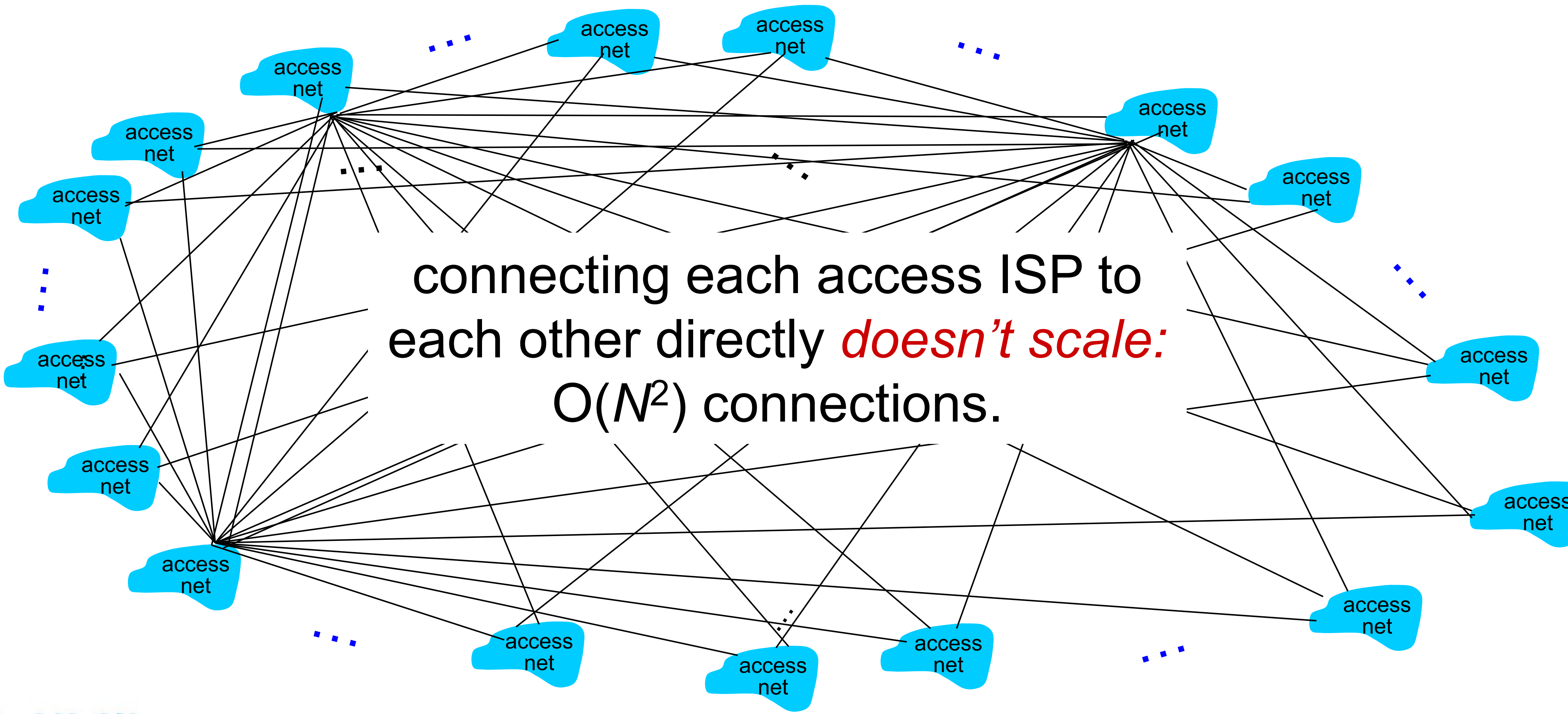
Internet structure: network of networks

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



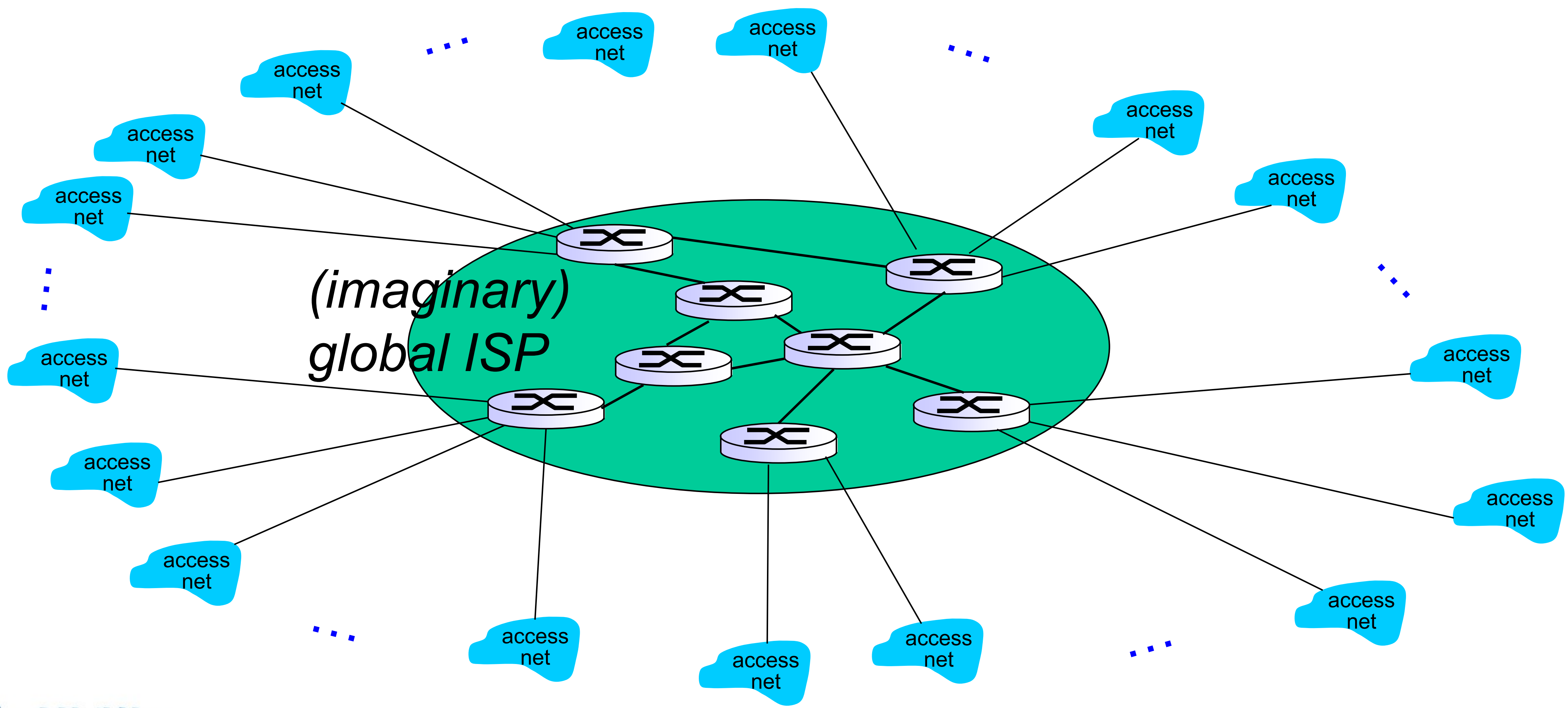
Internet structure: network of networks

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



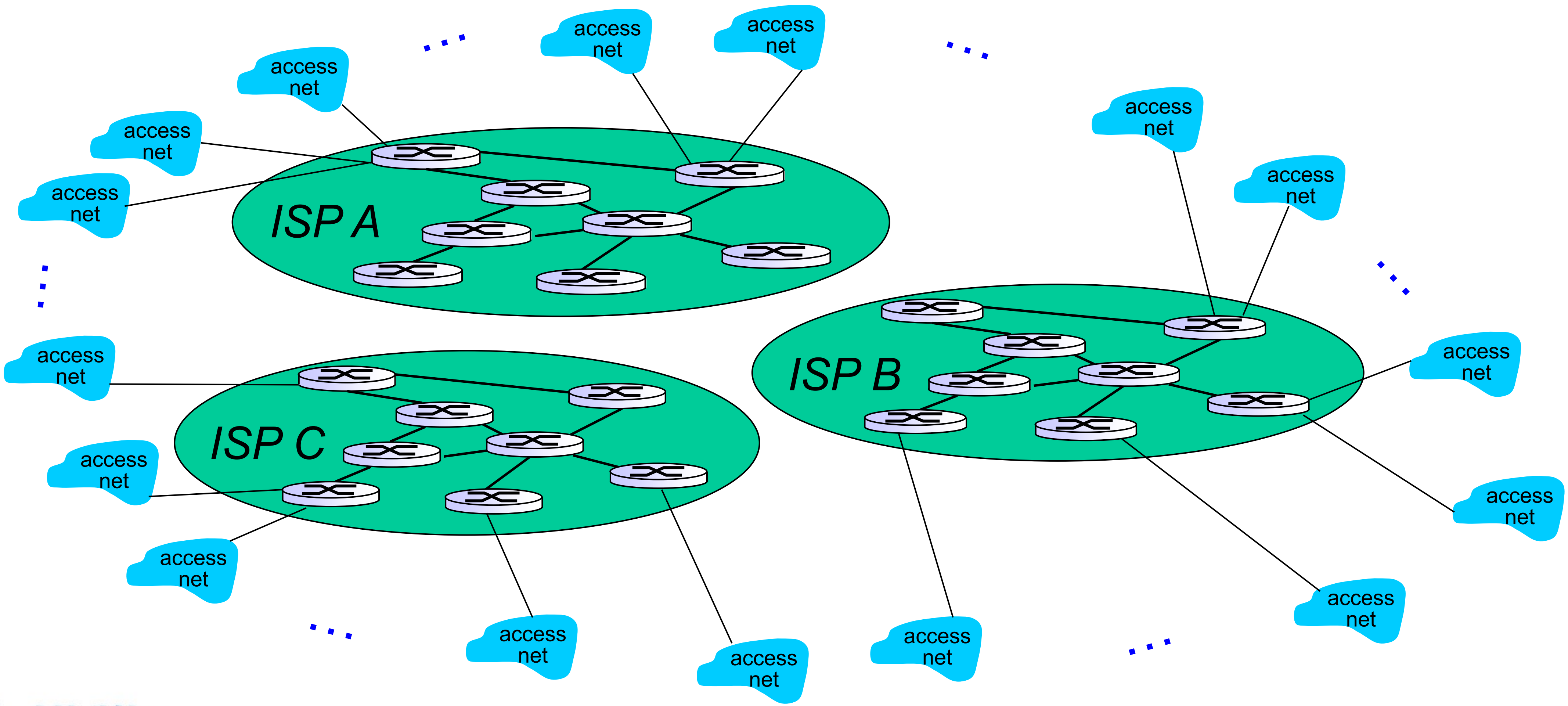
Internet structure: network of networks

Option: connect each access ISP to a global transit ISP? Customer (who?) and provider ISP (who?) have economic agreement.



Internet structure: network of networks

But if one global ISP is viable business, there will be competitors called **tier-1 ISPs**. – around a dozen tier-1 ISPs world-wide. (e.g., Level 3 communications, Sprint, AT&T, NTT), national & international coverage



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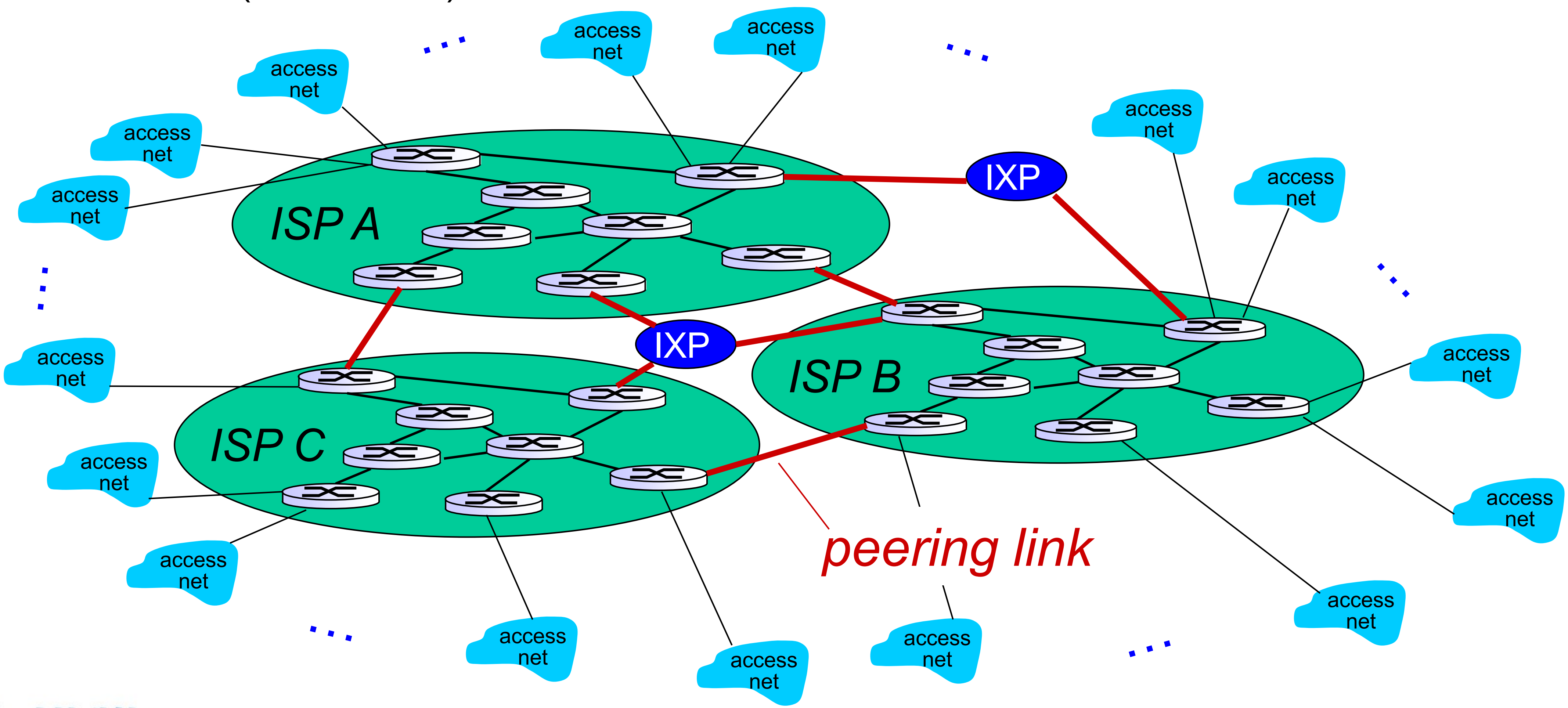
Internet structure: network of networks

Tier-1 ISPs must be interconnected by **Internet exchange point** (**IXP**): 3rd party stand-alone building with its own switches, over 600 IXPs in the Internet (as of 2020)



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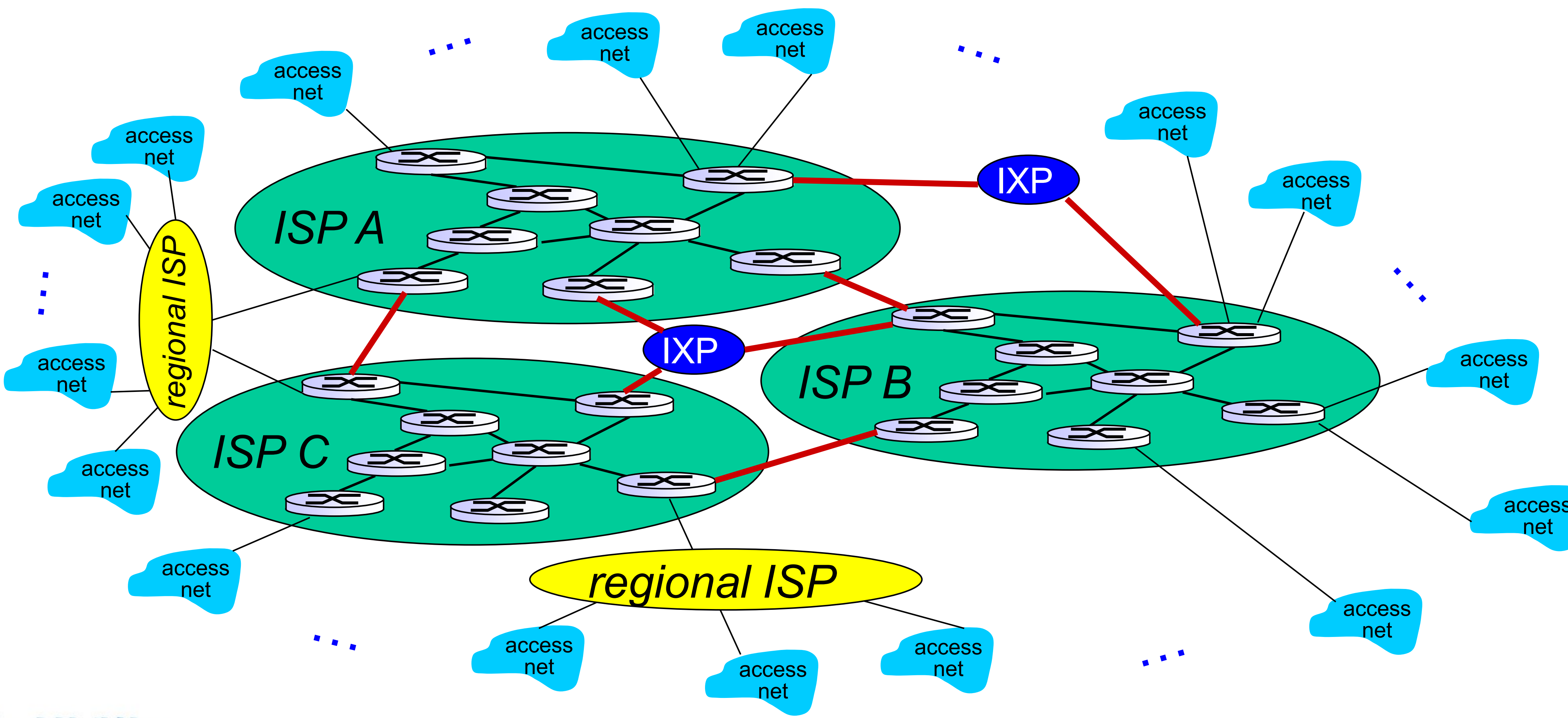
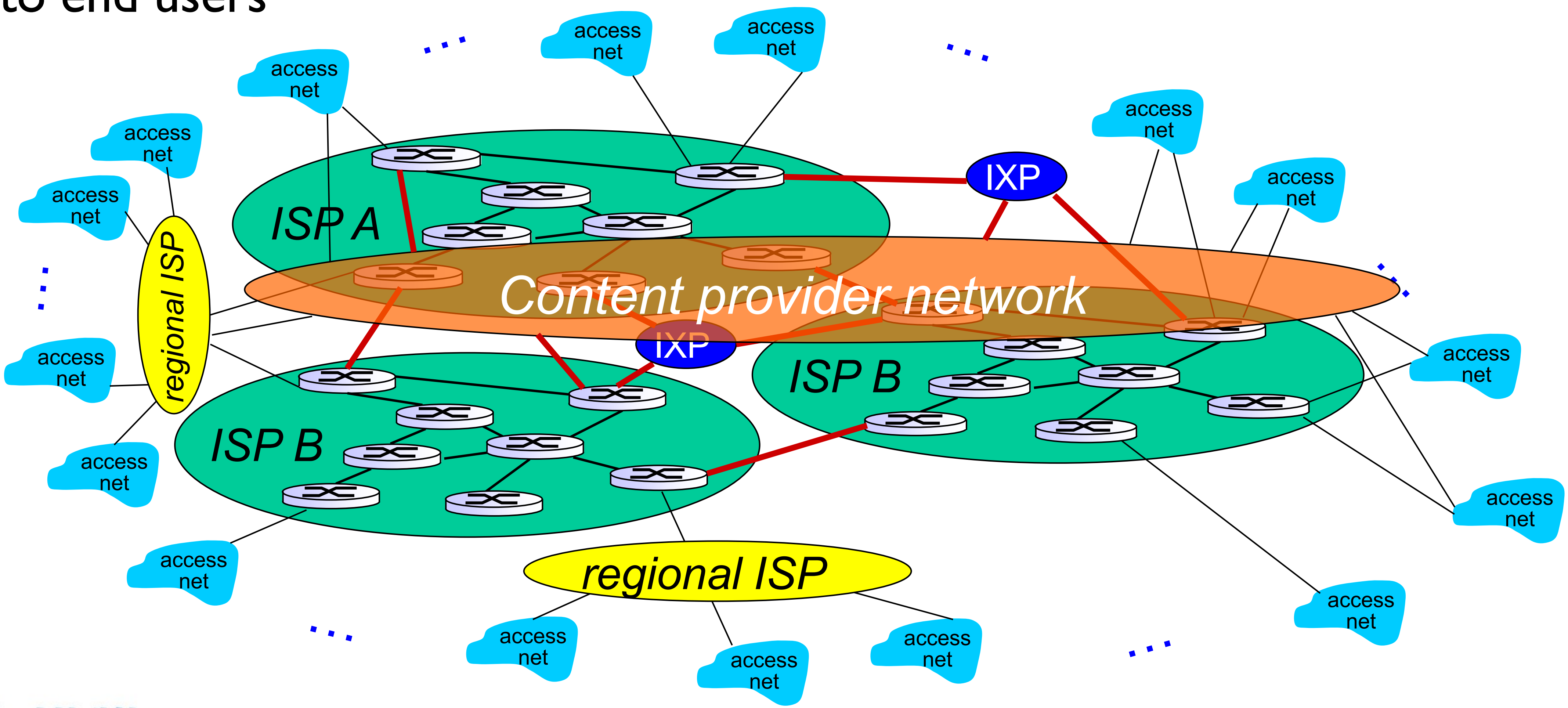
Internet structure: network of networks

A few tier-1 ISPs cannot be close to all access IPSs.
regional ISPs may arise to connect access ISPs in the region.

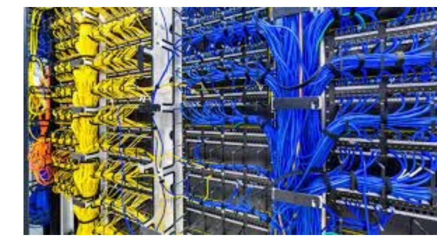


Internet structure: network of networks

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

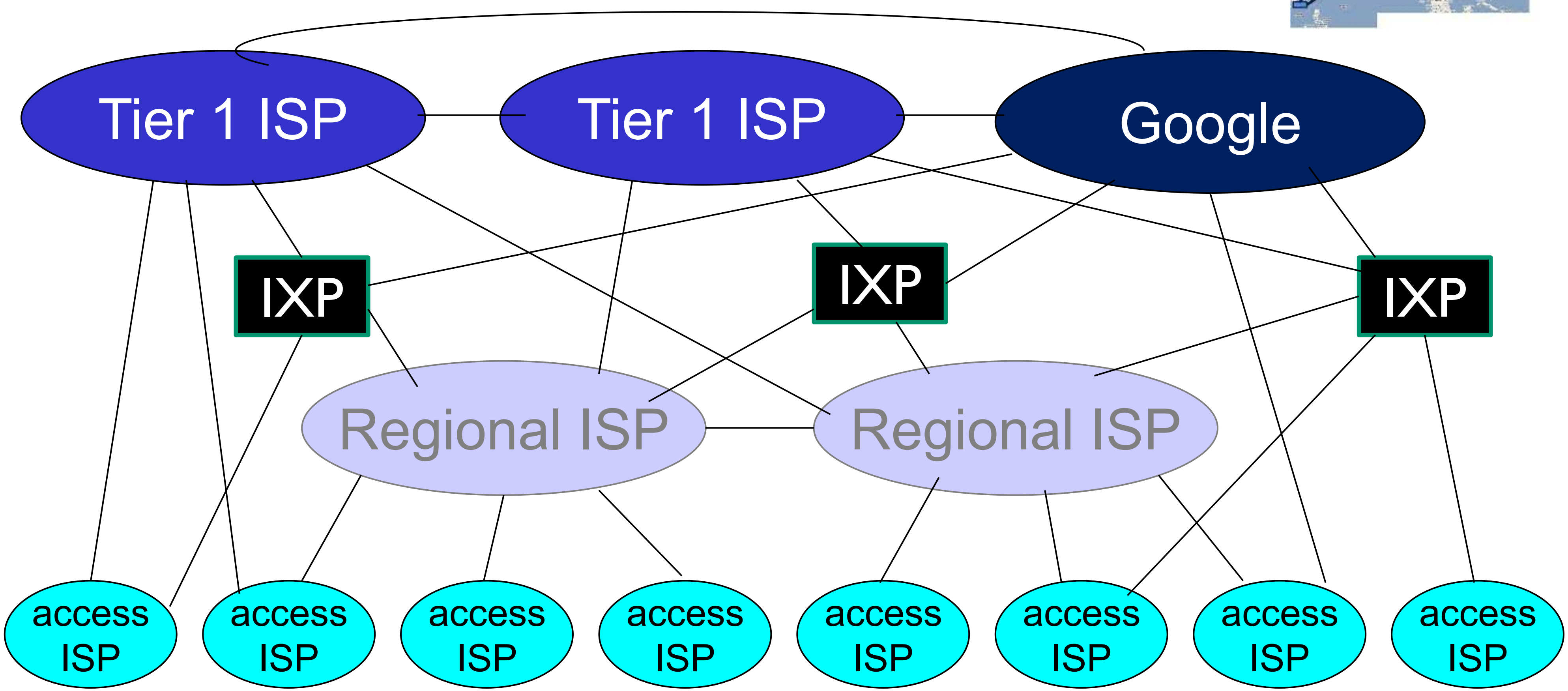


Data Centers and Cloud Computing (Ch. 1.2)



- Internet companies such as Google, Microsoft, Amazon, and Alibaba have built data centers, each hosting hundreds and thousand of hosts
- Data centers are not only connected to the Internet, but also internally include complex data center networks that interconnect data center hosts
- Data center service example: Amazon
  - **Amazon e-commerce** page for users
  - **Parallel computing** infrastructures for Amazon-specific data processing tasks
  - **Cloud computing** to other companies
    - (Initial) Netflix and Airbnb ran their entire web services in Amazon Web Service (AWS)

Internet structure: network of networks



- at center: small # of well-connected large networks
  - content provider network (e.g, Google): private network that connects it data centers to Internet, often bypassing tier-1, regional ISPs

Chapter 1: roadmap

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1.5 protocol layers, service models

1.6 networks under attack: security

Network security

- field of network security:
  - how bad guys can attack computer networks
  - how we can defend networks against attacks
  - how to design architectures that are immune to attacks
- Internet not originally designed with (much) security in mind
  - *original vision:* "a group of mutually trusting users attached to a transparent network" ☺
  - Internet protocol designers playing "catch-up"
  - security considerations in all layers!

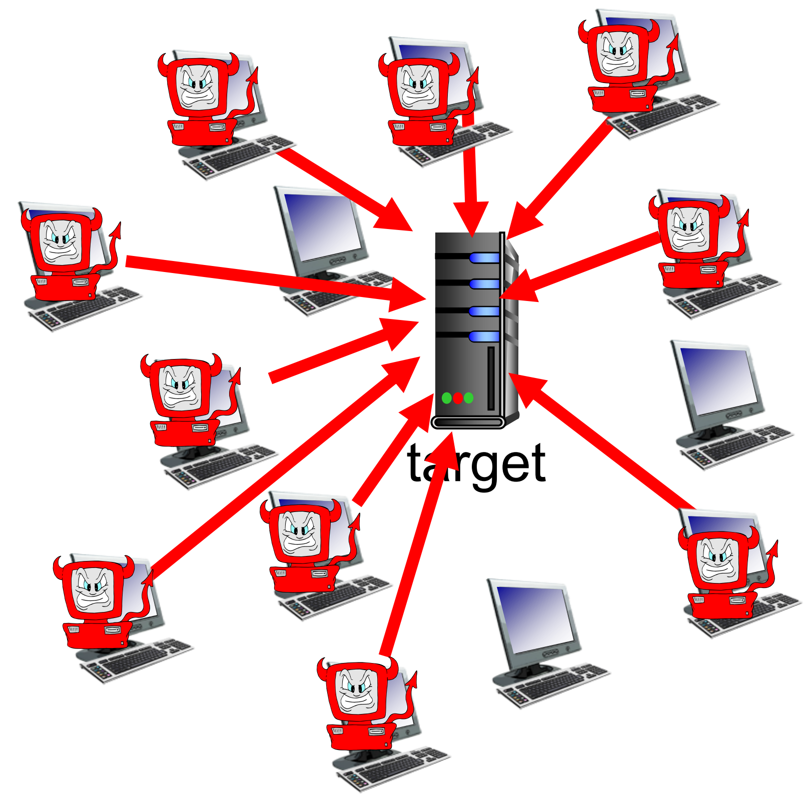
Bad guys: put malware into hosts via Internet

- Malware
  - *virus:* self-replicating infection by receiving/executing object (e.g., e-mail attachment)
  - *worm:* self-replicating infection by passively receiving object that gets itself executed
  - spyware: can record keystrokes, web sites visited, upload info to collection site
- infected host can be enrolled in botnets;
  - A network of thousands of similarly compromised devices
  - The bad guys control the leverage for spam e-mail distribution or Distributed DoS (DDoS) attacks

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

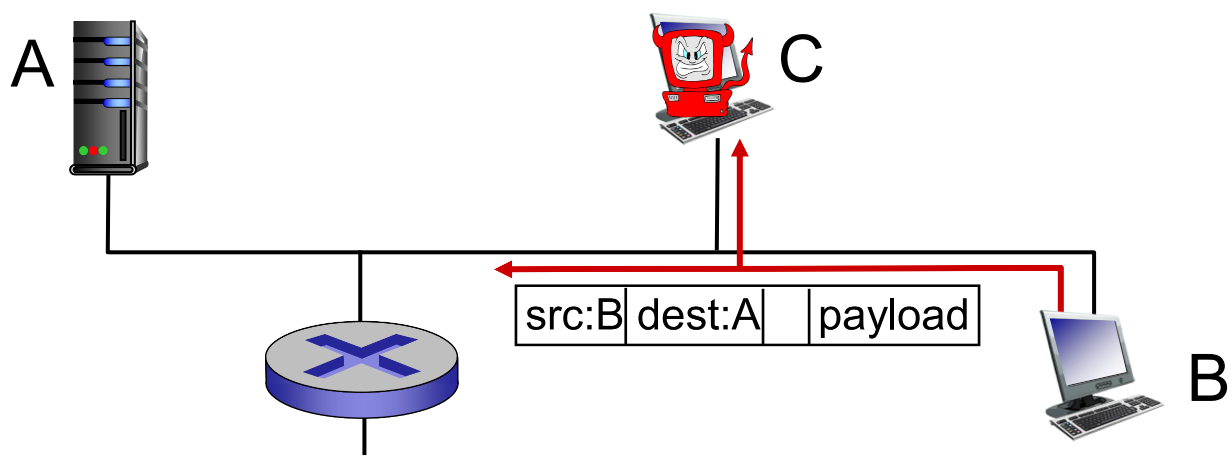
1. select target
2. break into hosts around the network (comprising a botnet)
3. send packets to target from compromised hosts
4. results in vulnerability attack, bandwidth flooding, and/or connection flooding



Bad guys can sniff packets

packet "sniffing":

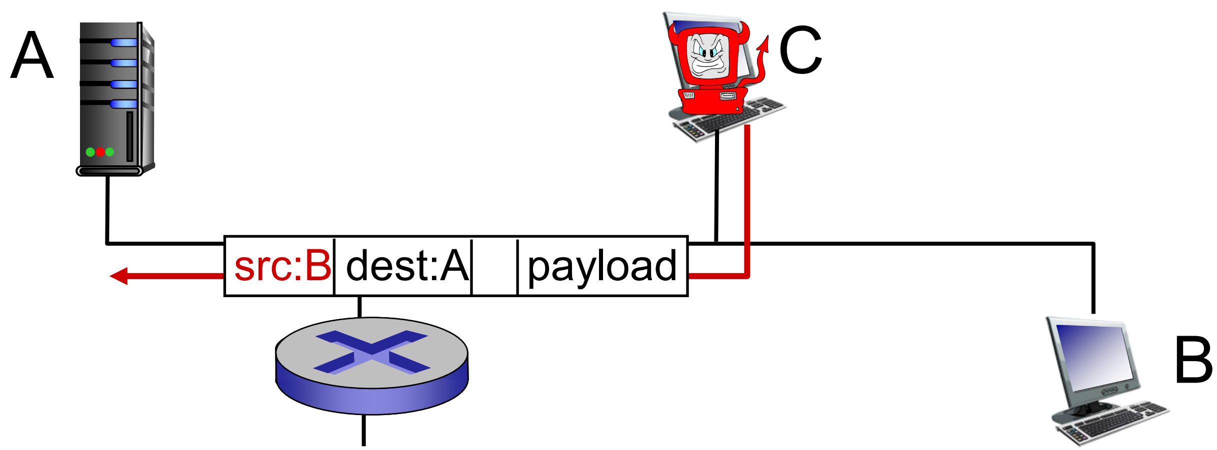
- broadcast media (shared Ethernet, wireless)
- promiscuous network interface reads/records all packets (e.g., including passwords!) passing by



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

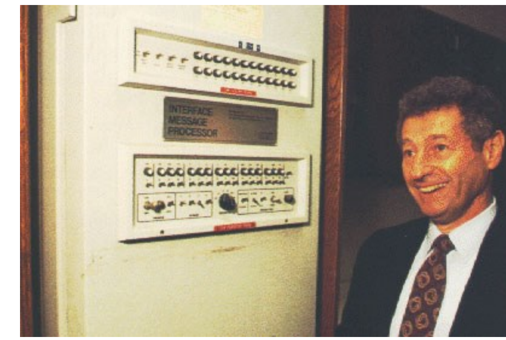
Bad guys can use fake addresses

IP spoofing: send packet with false source address



Brief Internet history

1961-1990: Early packet-switching, protocols



- 1961: Kleinrock - queueing theory shows effectiveness of packet-switching
- 1969: first packet-switched ARPAnet node operational (15 nodes in 1972)
  - login UCLA to SRI (Stanford Research Institute) system – crashing the system
- 1974: Cerf and Kahn - architecture for interconnecting networks
  - defined today's TCP/IP Internet architecture
- 1983: deployment of TCP/IP
- 1982: smtp e-mail protocol defined
- 1983: DNS defined for name-to-IP-address translation
- 1988:TCP congestion control
- 100,000 hosts connected to confederation of networks

Internet history

1990, 2000's - present: the Web, new apps

- early 1990's: ARPAnet decommissioned
- early 1990s: World Wide Web
  - hypertext [Bush 1945, Nelson 1960's]
  - HTML, HTTP: Berners-Lee
  - 1994: Mosaic, later Netscape
  - late 1990's: commercialization of the Web

late 1990's – 2000's:

- more killer apps: instant messaging, P2P file sharing

2005-present

- 20.35B devices attached to Internet (2017)
- emergence of online social networks:
  - Facebook: 1.47B active users (2018)
- online-video streaming
  - YouTube: 1.57B active users (2018)
  - Netflix: 37% of US Internet traffic (2015)

South Korea

- 1982년 5월, 전길남 교수가 서울대학교 컴퓨터공학과와 구미 전자기술연구소(KIET)의 두 개의 중형 컴퓨터에 IP 주소를 할당 받아 전용선으로 연결하고 이를 패킷 교환 방식으로 연결하는데 성공
- 데이콤(현 LG유플러스)이 1986년 PC 통신 '천리안' 서비스를 시작
- 연구 목적으로 일부만 사용할 수 있었던 인터넷은 1994년 한국통신(현 KT)이 코넷(KORNET)이라는 이름으로 인터넷 상용 서비스를 개시

https://ko.wikipedia.org/wiki/대한민국의_인터넷

CH1: summary

covered a "ton" of material!

- Internet overview
- what's a protocol?
- network edge, core, access ispwork
  - 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!*

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