Chapter 1: roadmap

1.1 What is the Internet?

1.2 Network edge

- end systems, access networks, links

1.3 Network core

- circuit switching vs packet switching,
- network structure

1.4 Performance:

- delay, loss and throughput

1.5 Protocol layers, service models

1.6 Networks under attack: security

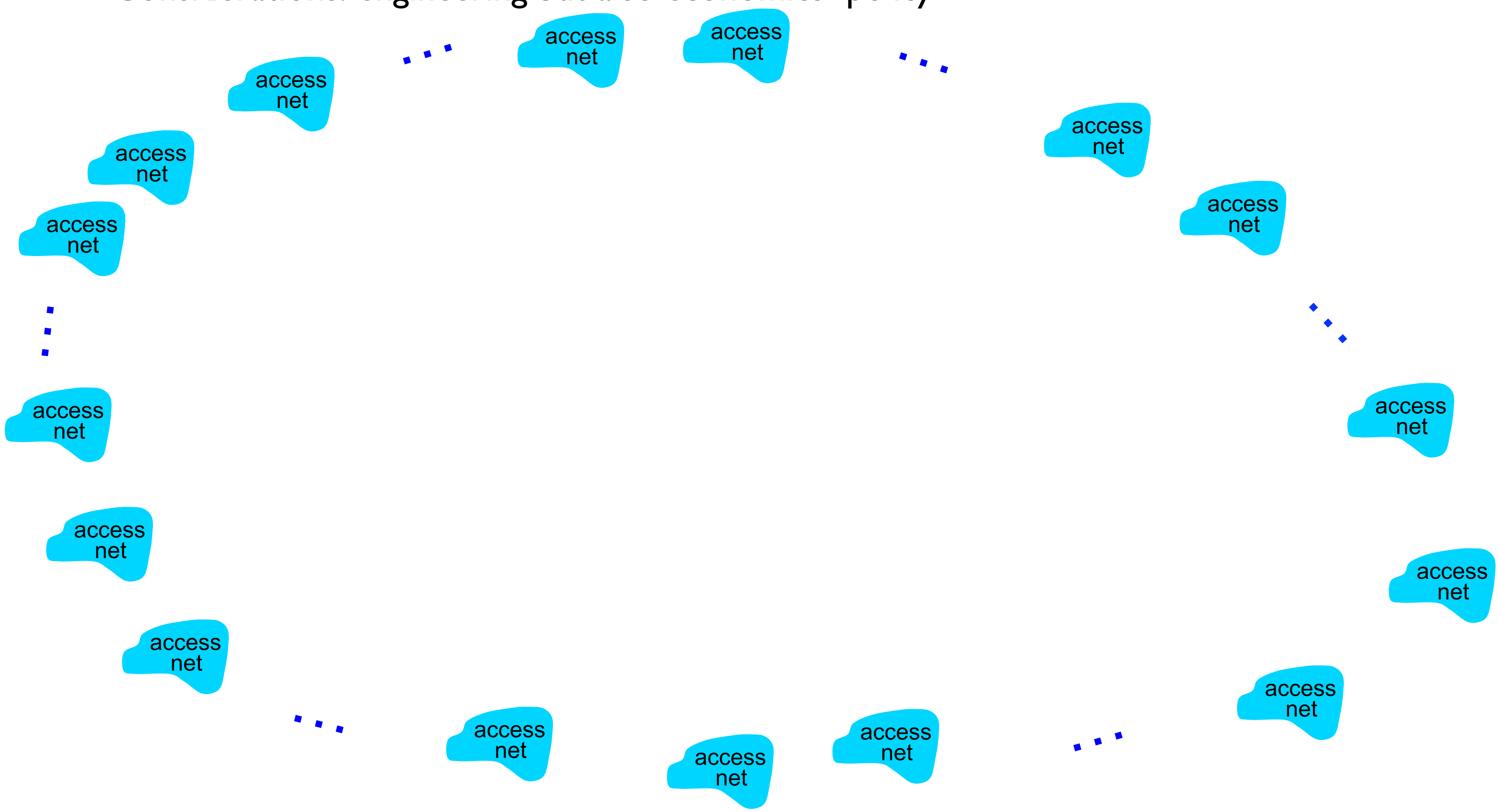
1.7 History

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

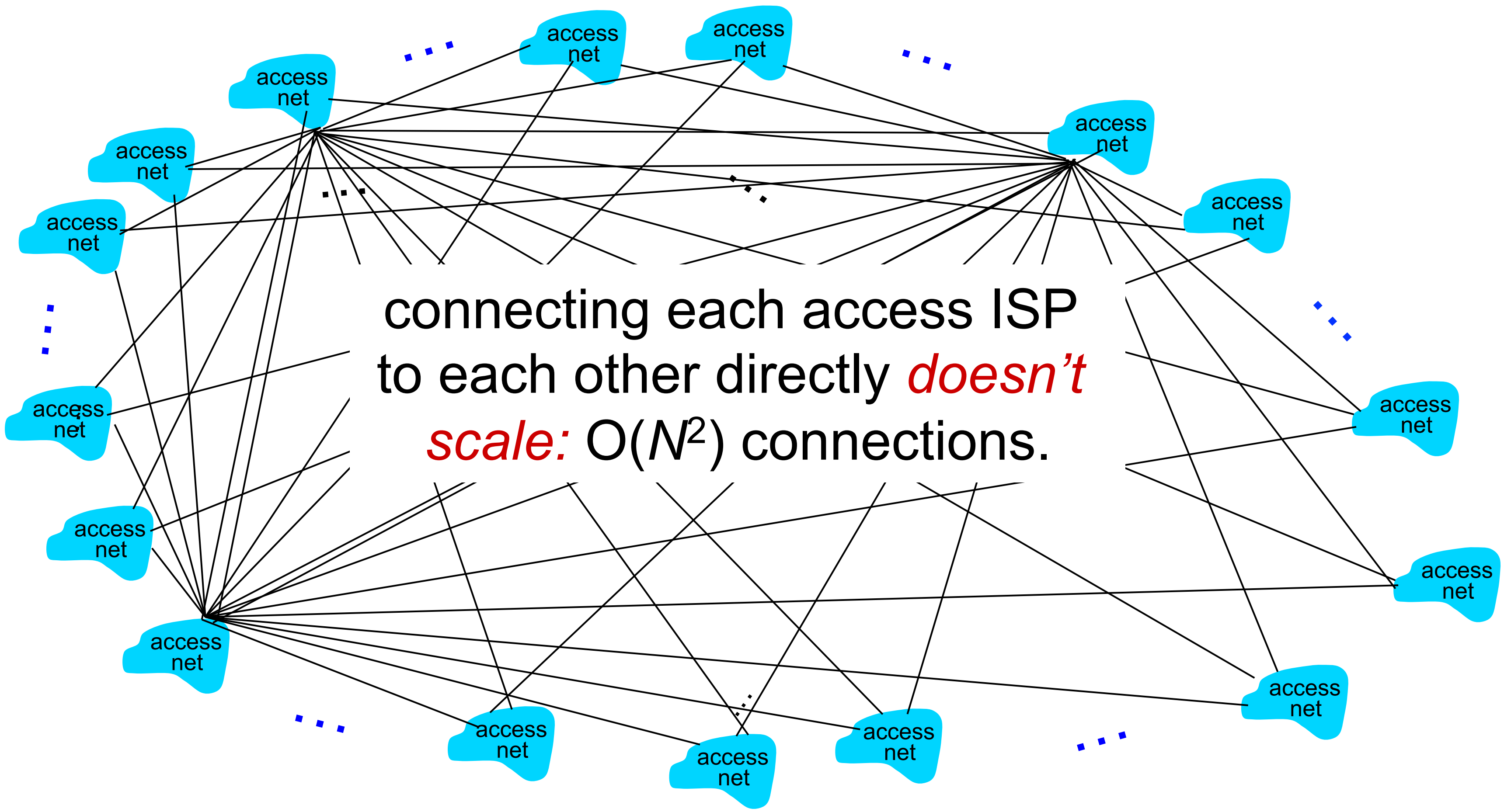
Internet structure: network of networks

- End systems connect to Internet via access ISPs:
  - residential, company and university ISPs
- *Question:* given *millions* of access ISPs, how to connect them together?
  - Considerations: engineering but also economics+policy



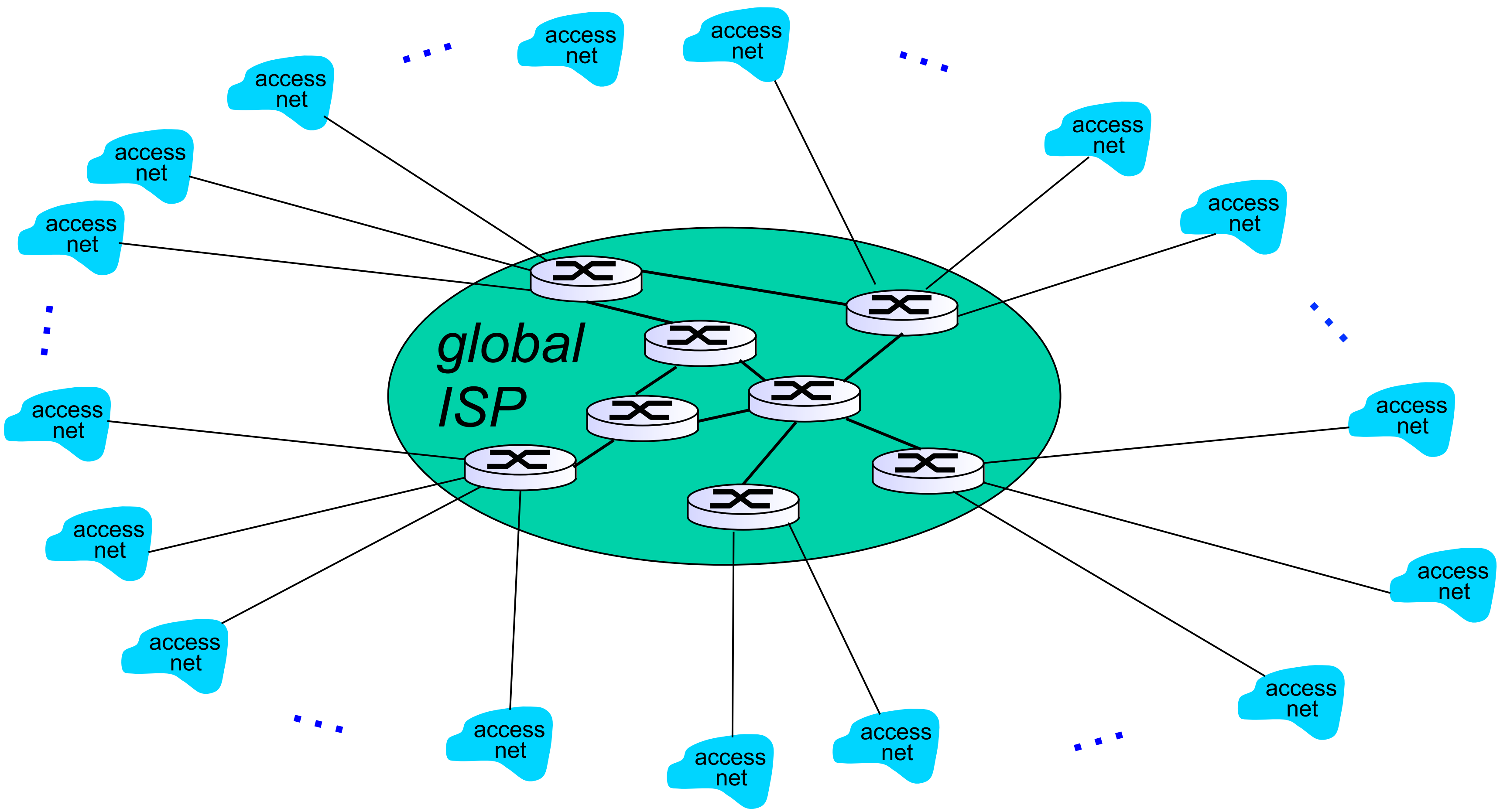
Internet structure: network of networks

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



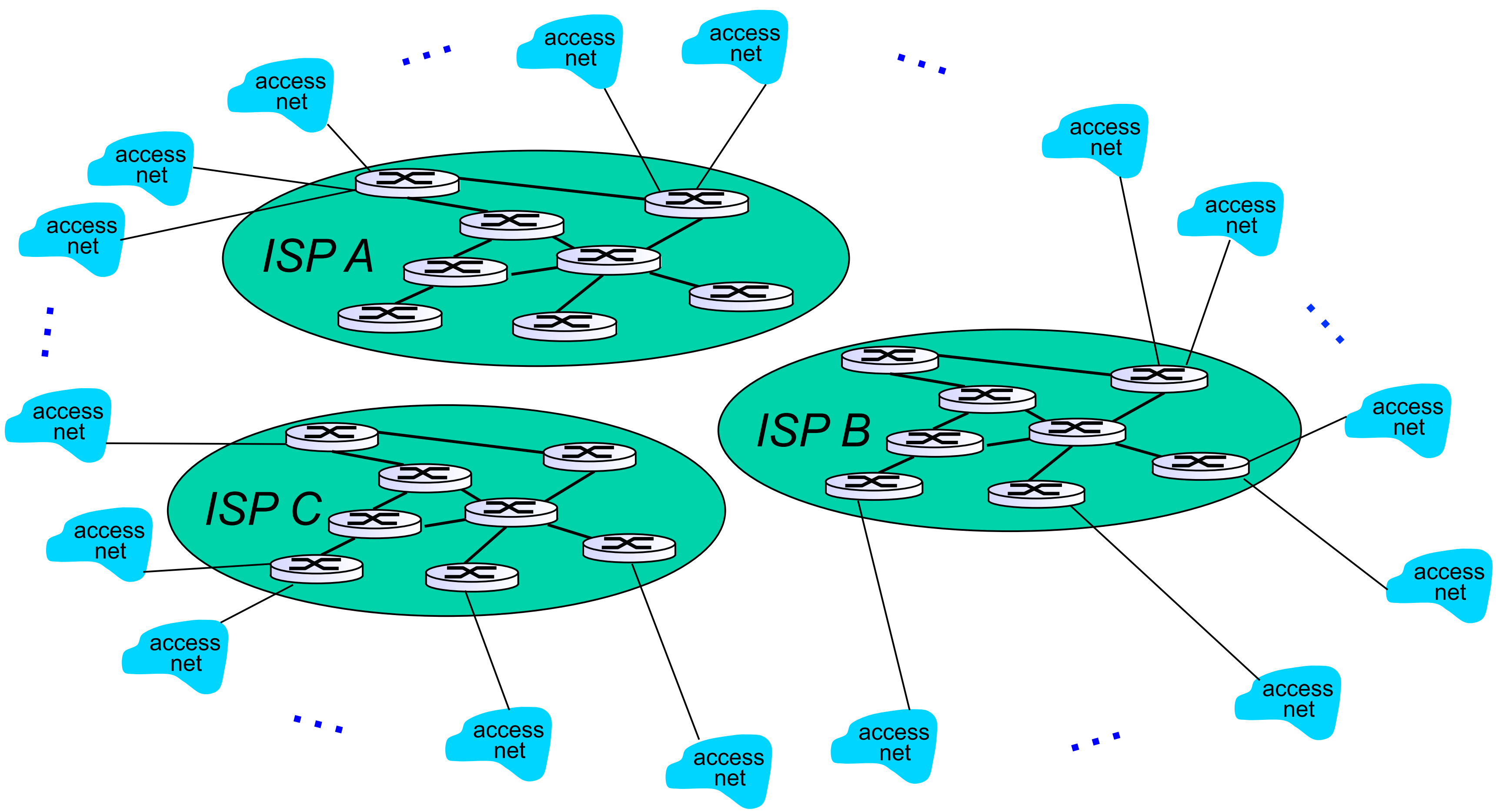
Internet structure: network of networks

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



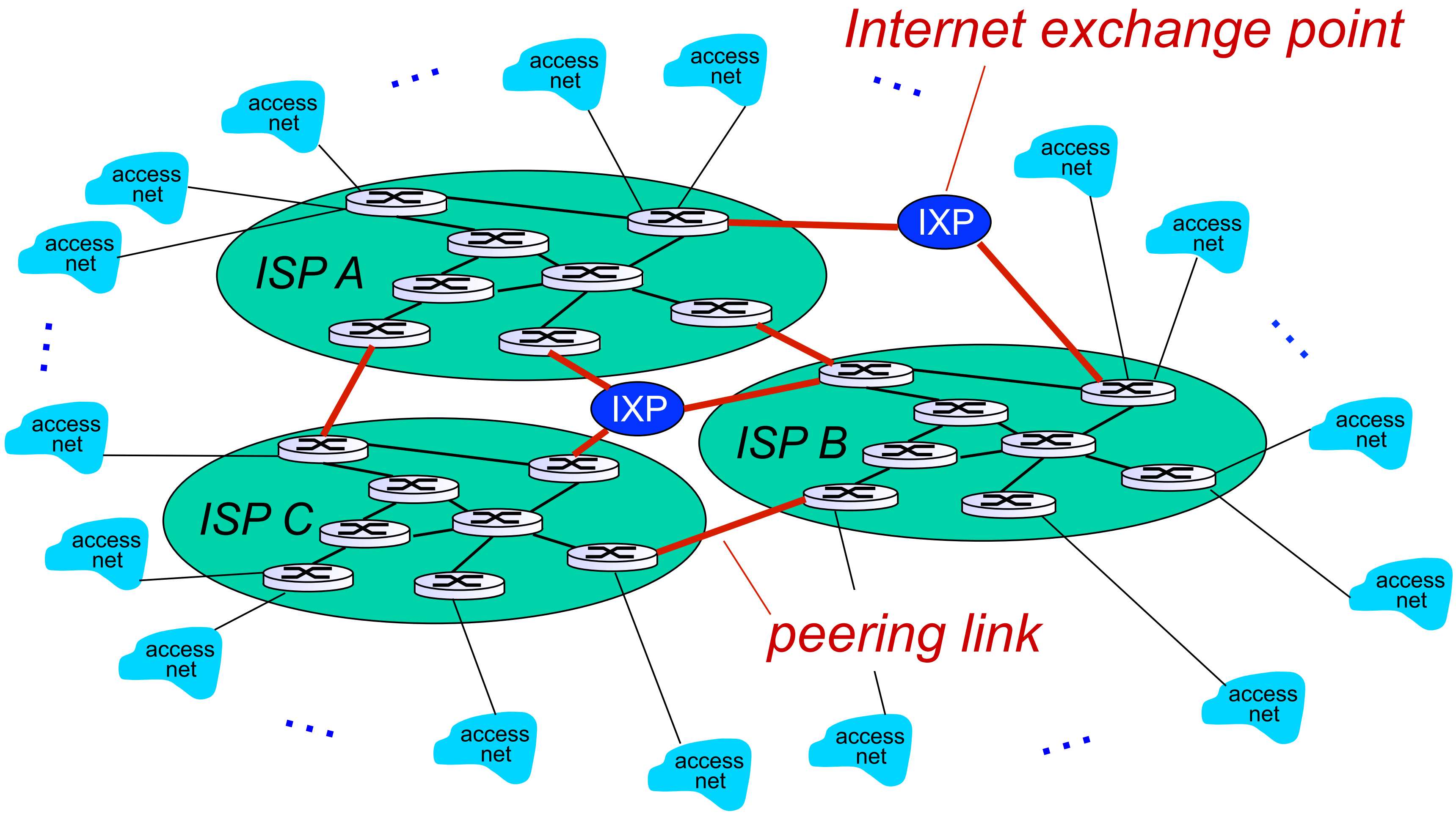
Internet structure: network of networks

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



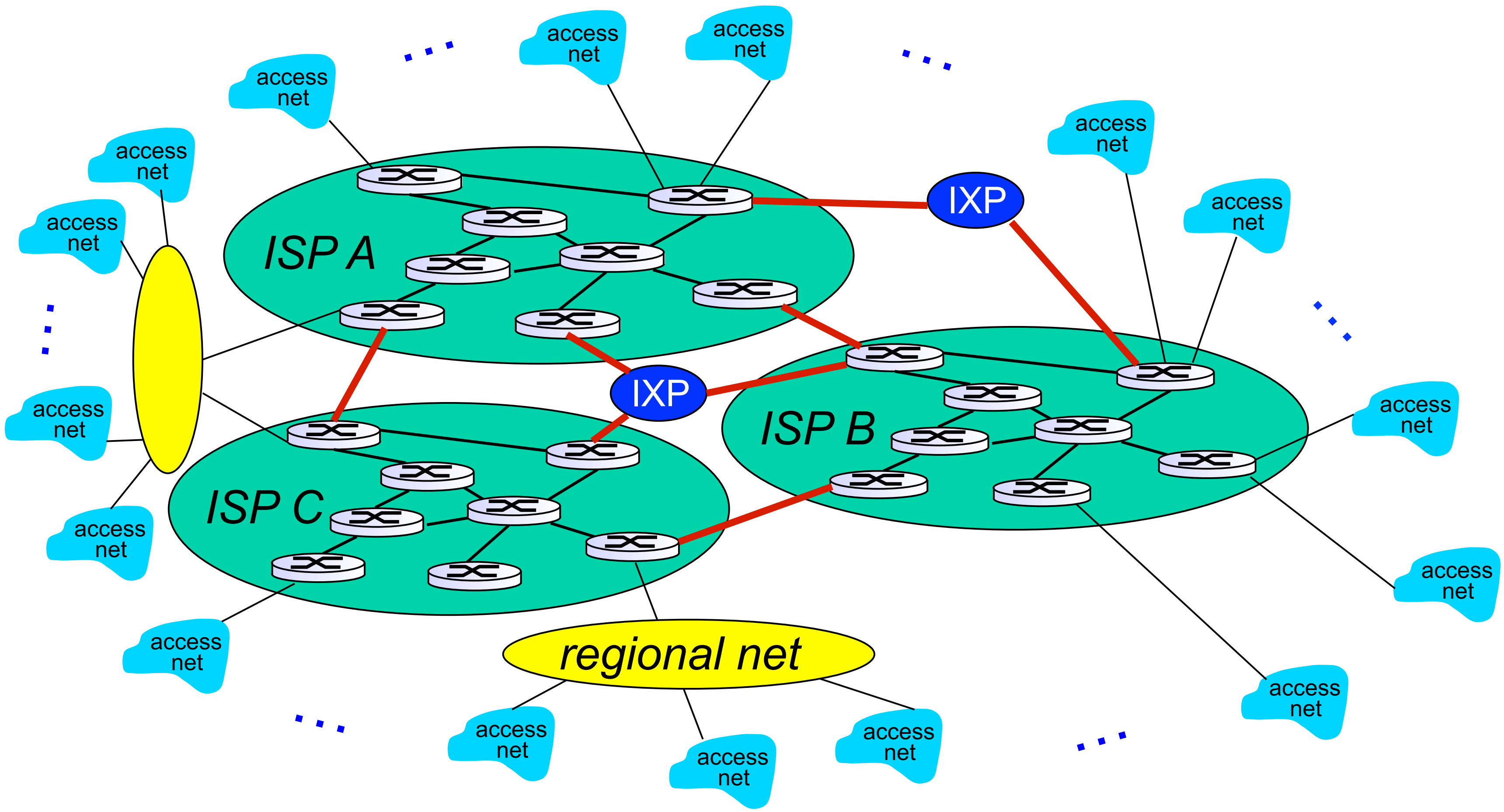
Internet structure: network of networks

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



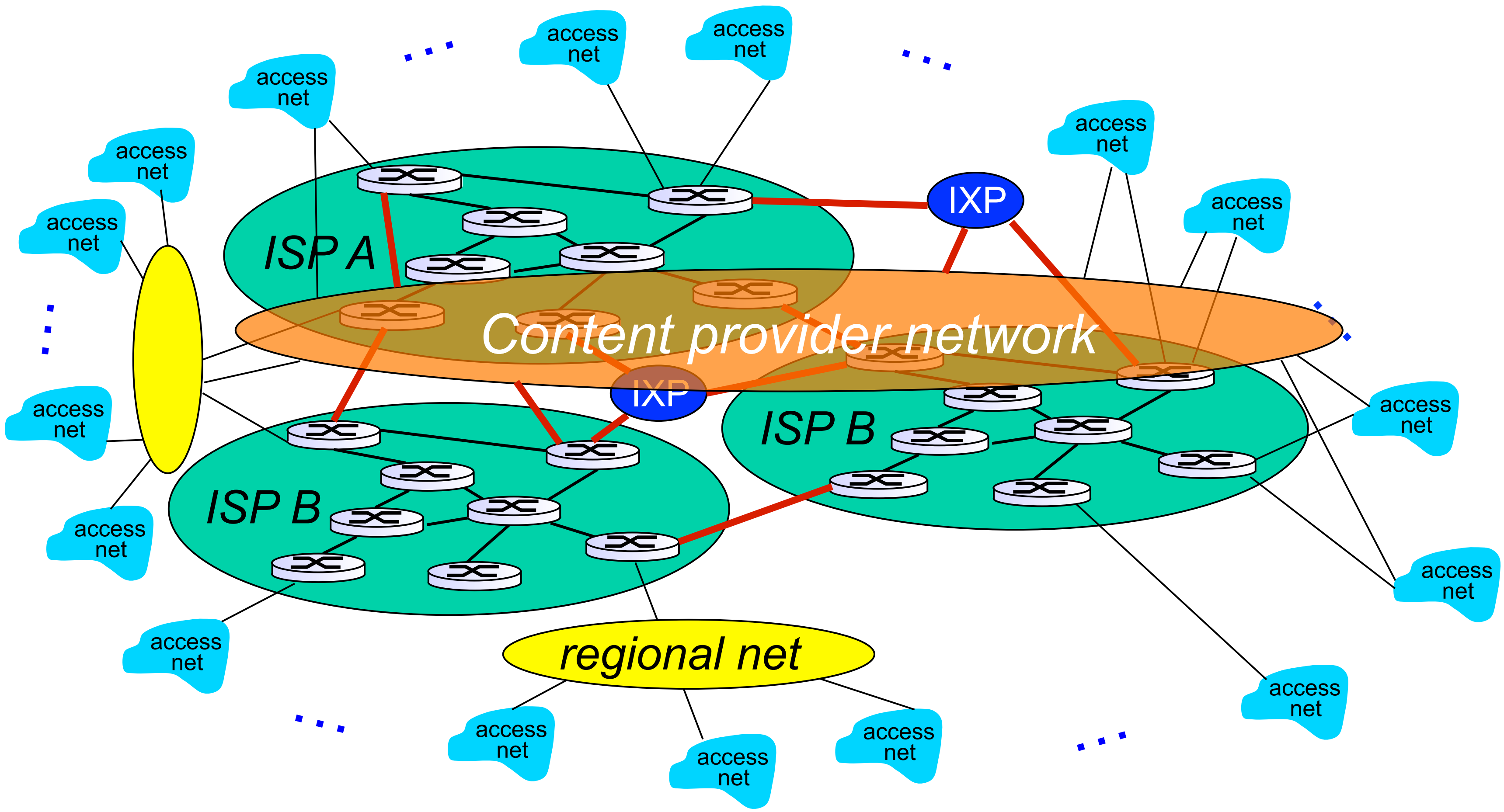
Internet structure: network of networks

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

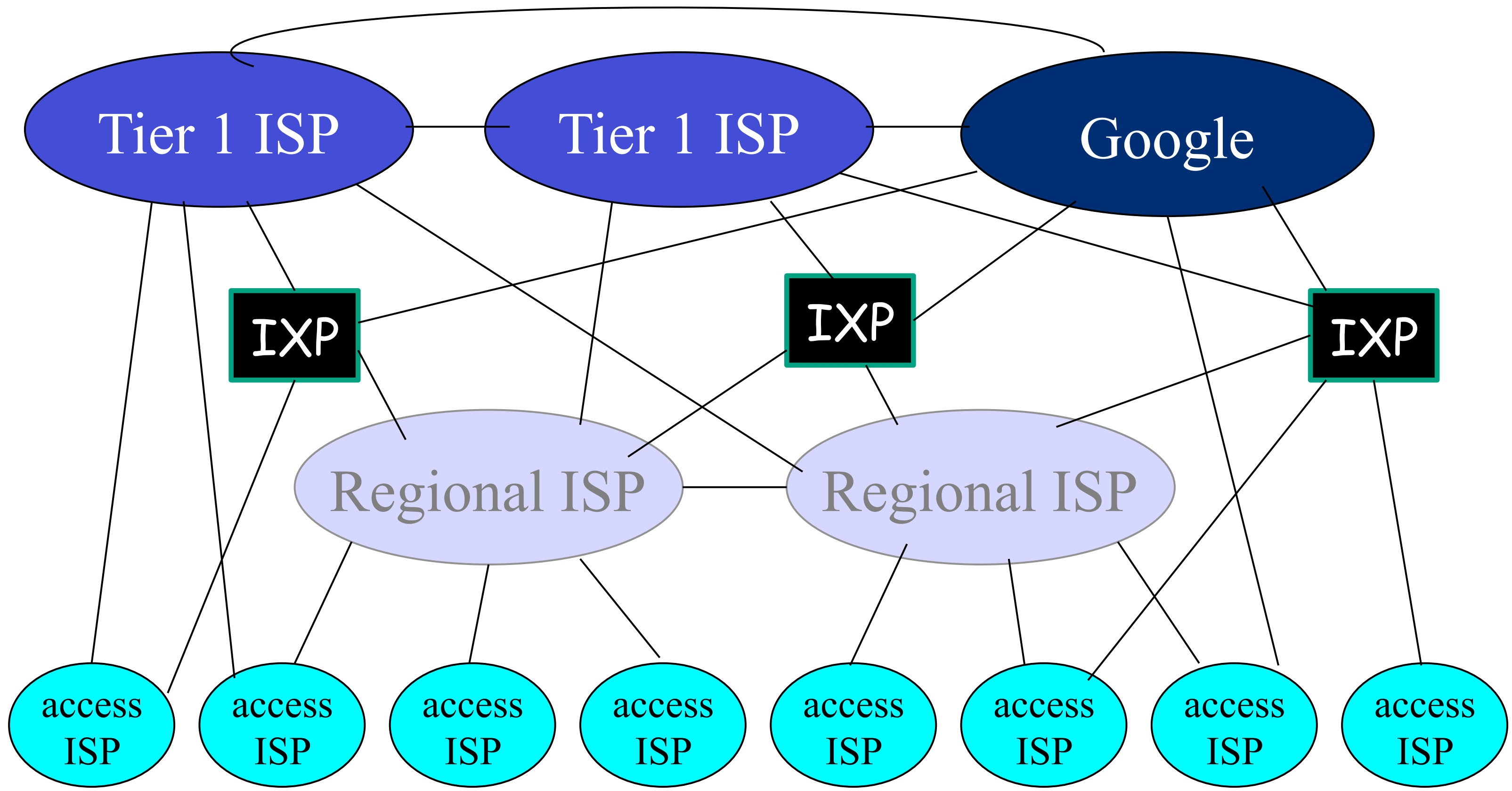


Internet structure: network of networks

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

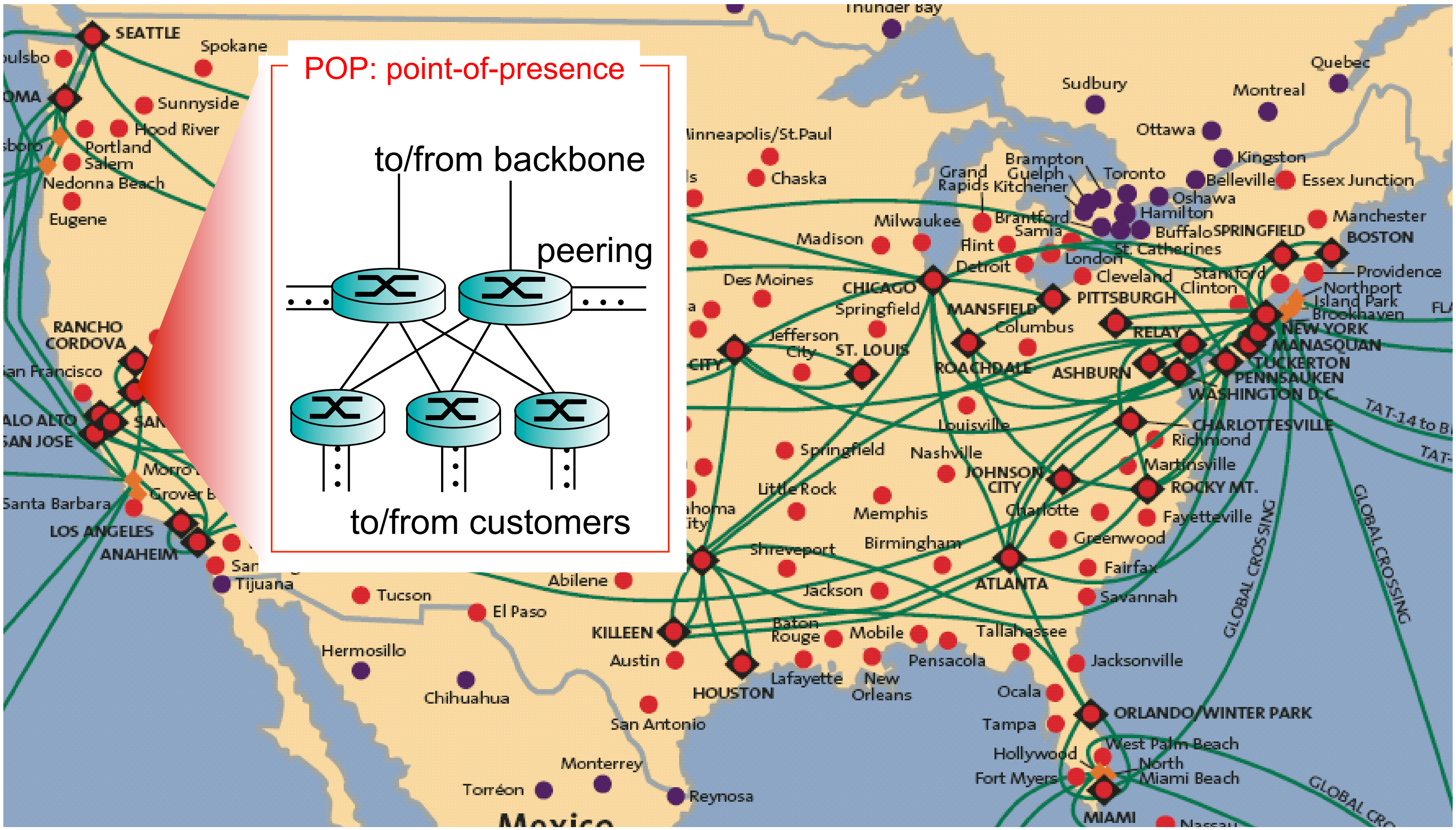


Internet structure: network of networks



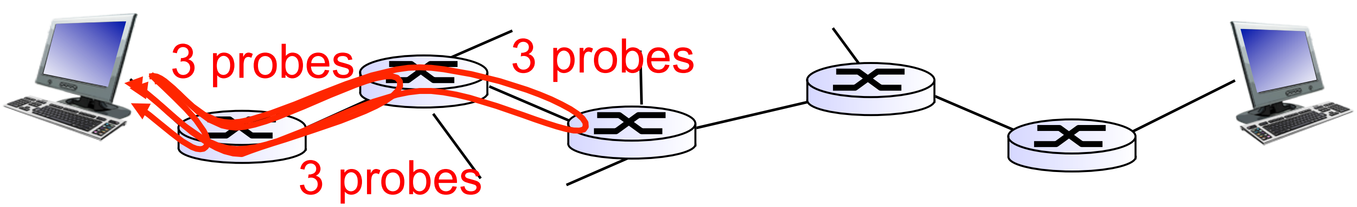
- at center: small # of well-connected large networks
  - "tier-1" commercial ISPs (e.g., Level 3, Sprint, AT&T, NTT), national & international coverage
  - content provider network (e.g, Google): private network that connects it data centers to Internet, often bypassing tier-1, regional ISPs

Tier-1 ISP: e.g., Sprint



"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 and routes

traceroute: from gaia.cs.umass.edu to www.eurecom.fr

Three 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)

More traceroute examples

```
Athina-Markopoulous-MacBook-Air-2:web athina$ traceroute gaia.cs.umass.edu
traceroute to gaia.cs.umass.edu (128.119.245.12), 64 hops max, 52 byte packets
 1  192.168.0.1 (192.168.0.1)  1.546 ms  0.247 ms  0.618 ms
 2  10.75.152.1 (10.75.152.1)  6.692 ms  7.636 ms  7.960 ms
 3  ip68-4-11-142.oc.oc.cox.net (68.4.11.142)  14.459 ms  8.553 ms  7.195 ms
 4  ip68-4-11-12.oc.oc.cox.net (68.4.11.12)  26.645 ms  8.021 ms  7.628 ms
 5  langbprj01-ae2.0.rd.la.cox.net (68.1.0.136)  8.452 ms  9.666 ms  9.866 ms
 6  lsan0.tr-cps.internet2.edu (206.223.123.199)  9.921 ms  11.280 ms  10.319 ms
 7  xe-0-2-0.0.sttl0.tr-cps.internet2.edu (64.57.20.223)  34.258 ms  34.985 ms  34.152 ms
 8  xe-1-1-0.0.chic0.tr-cps.internet2.edu (64.57.20.169)  87.729 ms  88.794 ms  88.357 ms
 9  198.71.47.62 (198.71.47.62)  112.777 ms  111.206 ms  111.823 ms
10  192.5.89.21 (192.5.89.21)  98.682 ms  98.637 ms  97.918 ms
11  nox300gw1-peer--207-210-142-242.nox.org (207.210.142.242)  98.917 ms  100.046 ms  99.847 ms
12  core1-rt-xe-0-0-0.gw.umass.edu (192.80.83.101)  100.235 ms  99.676 ms  98.883 ms
13  lgrc-rt-106-8-po-10.gw.umass.edu (128.119.0.233)  100.358 ms  100.123 ms  99.548 ms
14  128.119.3.32 (128.119.3.32)  101.201 ms  100.145 ms  99.514 ms
15  nscs1bbs1.cs.umass.edu (128.119.240.253)  101.423 ms  100.951 ms  103.533 ms
16  * * *
17  * * *
```

More traceroute examples

```
Athina-Markopoulous-MacBook-Air-2:web athina$ traceroute nestor.calit2.uci.edu
traceroute to nestor.calit2.uci.edu (128.195.185.109), 64 hops max, 52 byte packets
 1  302-wism-vl970.ucinet.uci.edu (169.234.0.1)  59.342 ms  27.768 ms  90.426 ms
 2  cs1-core--302-wism.ucinet.uci.edu (128.195.249.129)  1.325 ms  1.361 ms  1.254 ms
 3  325--cs1-core.ucinet.uci.edu (128.195.249.190)  1.051 ms  1.113 ms  1.035 ms
 4  nestor.calit2.uci.edu (128.195.185.109)  1.019 ms  1.053 ms  1.030 ms

Athina-Markopoulous-MacBook-Air-2:web athina$ traceroute www.google.com
traceroute: Warning: www.google.com has multiple addresses; using 74.125.224.178
traceroute to www.google.com (74.125.224.178), 64 hops max, 52 byte packets
 1  302-wism-vl970.ucinet.uci.edu (169.234.0.1)  2.994 ms  0.930 ms  1.018 ms
 2  cs1-core--302-wism.ucinet.uci.edu (128.195.249.129)  1.036 ms  1.003 ms  0.966 ms
 3  kazad-dum-vl123.ucinet.uci.edu (128.200.2.222)  1.286 ms  1.088 ms  1.234 ms
 4  dc-tus-agg2--uci-ge-1.cenic.net (137.164.24.49)  2.816 ms  2.306 ms  1.700 ms
 5  riv-core1--tus-agg2-10ge-2.cenic.net (137.164.47.79)  9.473 ms  6.731 ms  13.066 ms
 6  dc-lax-core1--riv-core1-10ge-2.cenic.net (137.164.46.57)  12.061 ms  9.388 ms  11.659 ms
 7  72.14.223.85 (72.14.223.85)  7.697 ms  7.713 ms  7.751 ms
 8  64.233.174.238 (64.233.174.238)  7.777 ms  9.668 ms  8.567 ms
 9  72.14.236.11 (72.14.236.11)  8.098 ms  8.008 ms  8.128 ms
10  lax02s01-in-f18.1e100.net (74.125.224.178)  8.130 ms  7.953 ms  8.101 ms
Athina-Markopoulous-MacBook-Air-2:web athina$
```

Chapter 1: roadmap

1.1 what *is* the Internet?

1.2 network edge

- end systems, access networks, links

1.3 network core

- packet switching, circuit switching, network structure

1.4 delay, loss, throughput in networks

1.5 protocol layers, service models

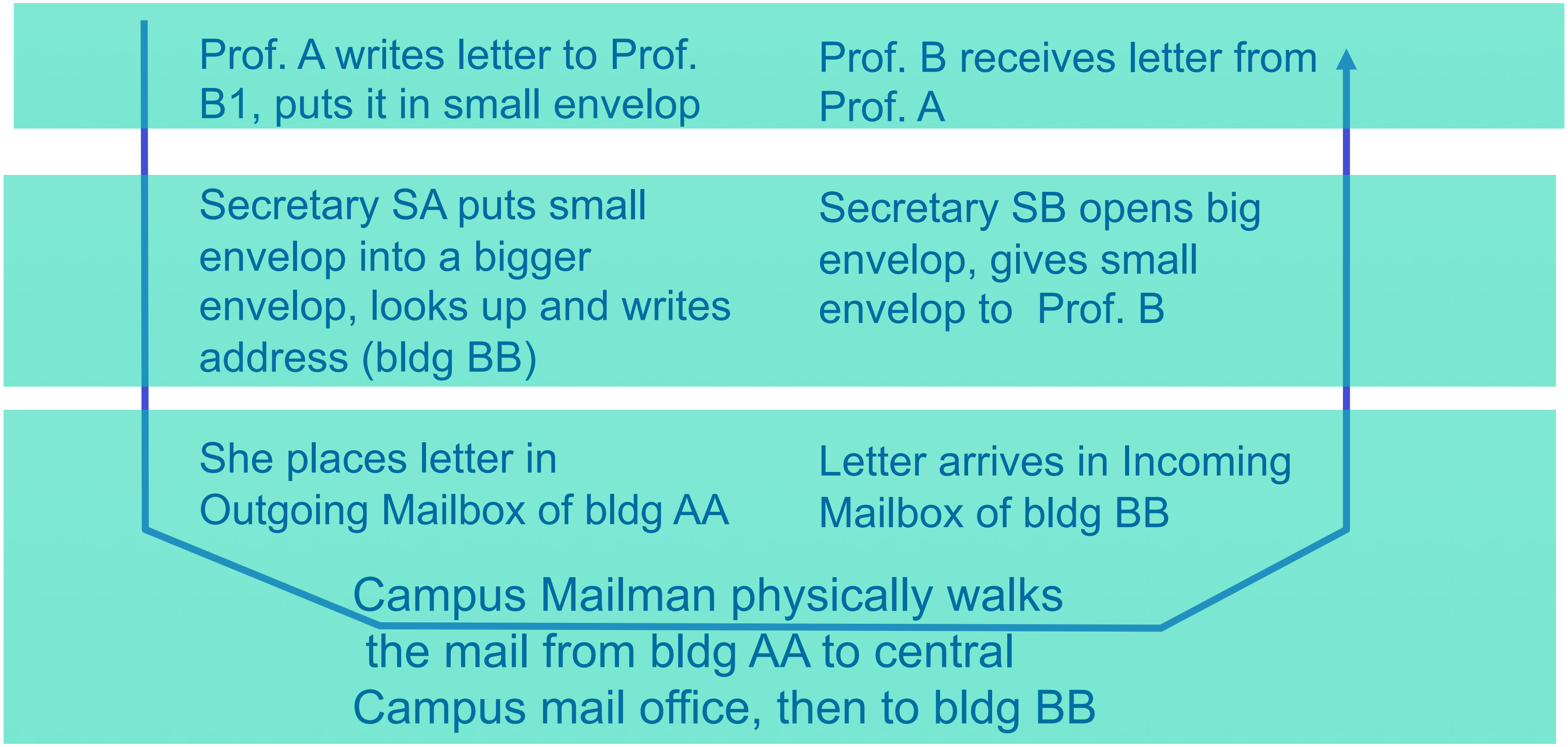
1.6 networks under attack: security

1.7 history

Dealing with Scale and Complexity

- The Internet is highly complex, in terms of …
  - Its sheer size (number of components)
  - The number of tasks it needs to manage: routing, congestion control, packet reordering, connection establishment …
  - Diversity of Components, Topology, Functionality,
- Tasks are structured through modularization
  - Divide and Conquer
  - Break down into smaller pieces
  - Create different functional layers

Layering of Campus Mail



layers: each layer implements a service

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

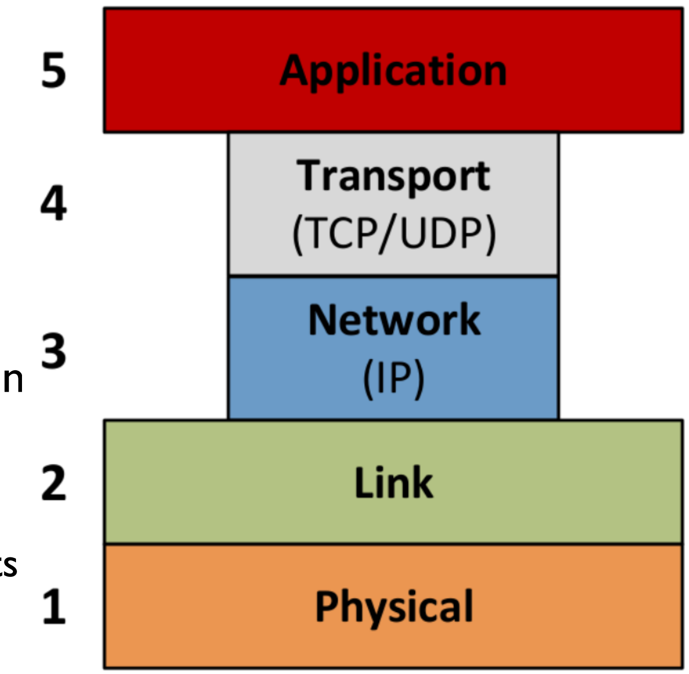
Why layering?

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 secretary, secretary's routine, mailman's routine, doesn't affect rest of system
- layering considered harmful?
  - duplication of functionality?
  - cross-layer optimization?

Internet protocol stack

- *Application layer:*
  - What we interact with:
- *Transport layer:*
  - process-process data transfer
  - End-to-end management: TCP, UDP
- *Network layer:*
  - routing of datagrams from source to destination
  - IP, routing protocols
- *Link Layer:*
  - data transfer between neighboring network elements
  - Ethernet, 802.111 (WiFi), PPP
- *physical:*
  - network medium (fiber, wireless,…)
  - bits on the wire

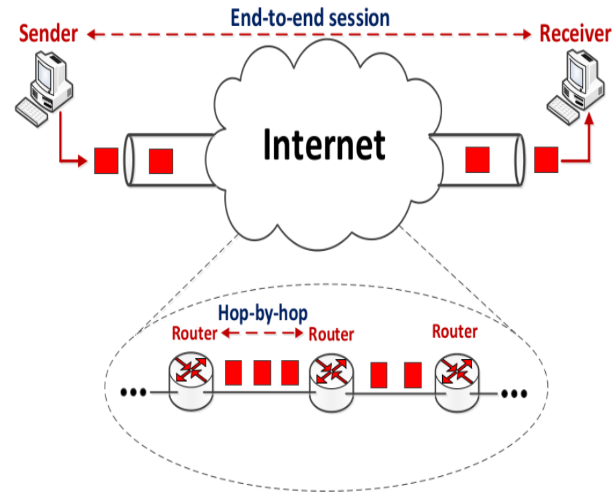


Transport & Network

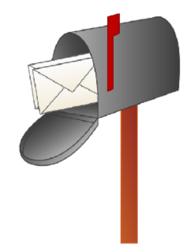
- ❑ "Thin waist"
  - Other layers: evolved dramatically
  - TCP/IP: Stayed mostly the same

- ❑ Transport layer
  - End-to-end
  - Connection-oriented in TCP

- ❑ Network layer
  - Hop-by-hop
  - Connectionless in IP



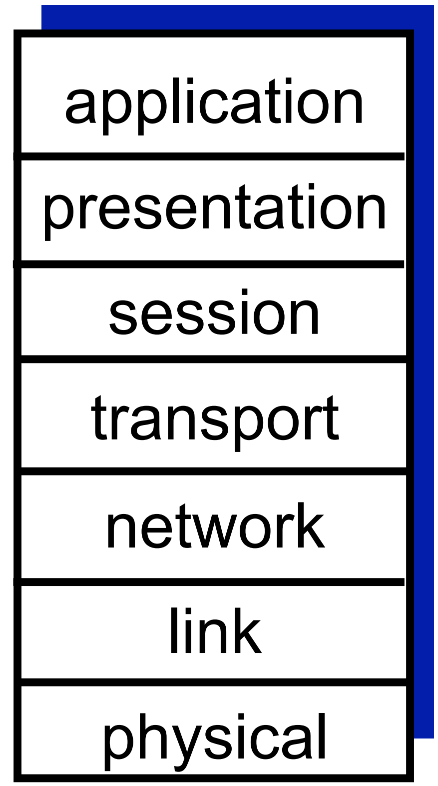
Connection-oriented



Connectionless

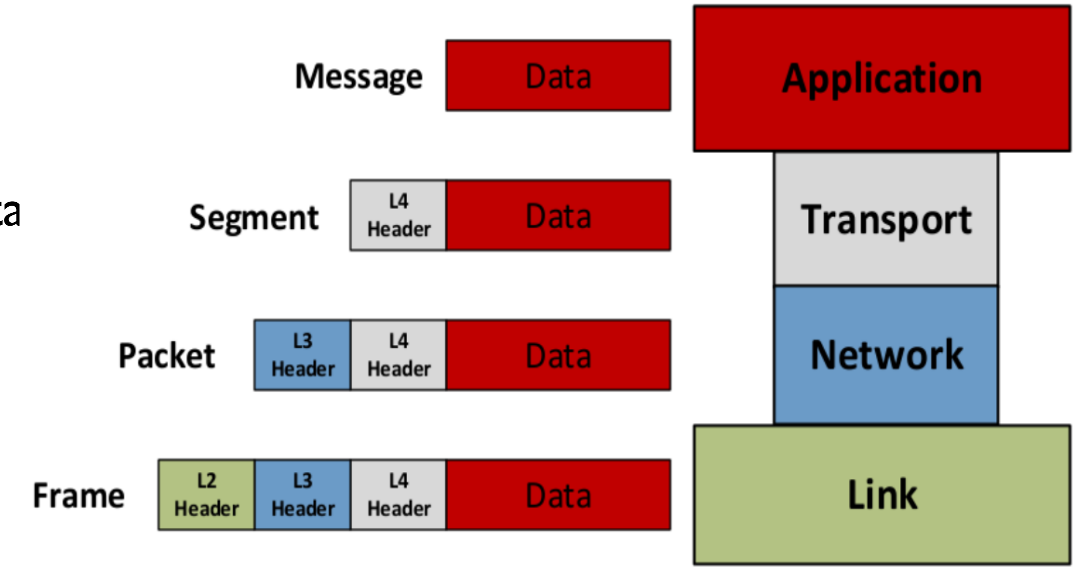
ISO/OSI reference model

- *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



Headers

- Encapsulation: augment data with headers
  - Payload: actual content
  - Header: identification and control information

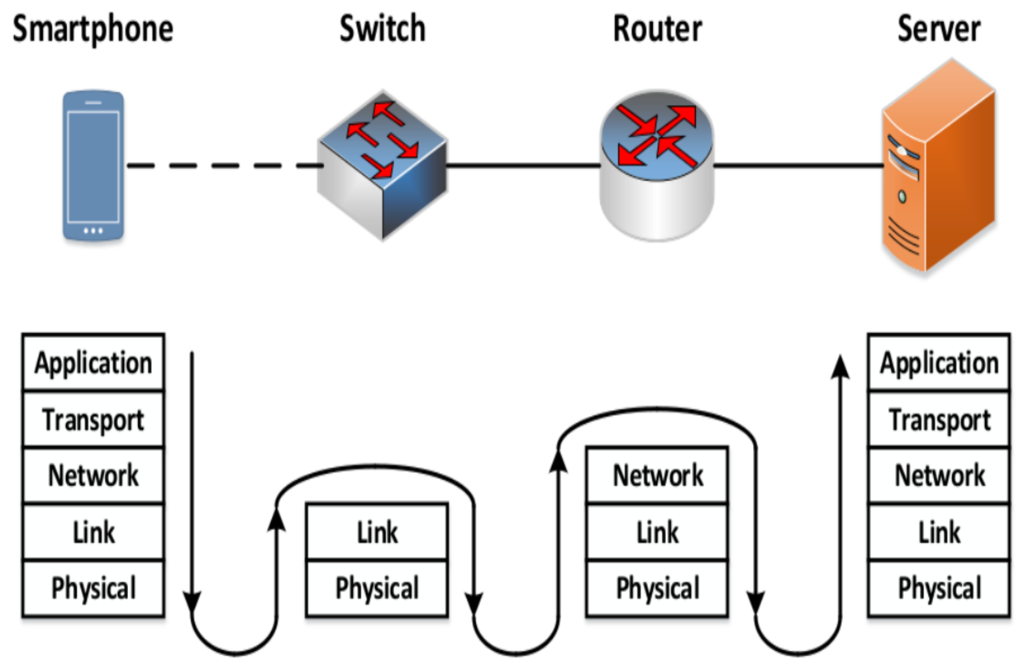


- This creates overhead. Why bother?
  - Allows us to distinguish messages
  - e.g.: Layer 3 header contains src & dst IP address of next hop
  - Essential for packet switching

"Understanding" Layers

- Different network elements process up to different layers

- End-hosts
  - Server, computer
  - Process all 5
- Routers
  - Up to 3
  - Have IP addresses
- Switches
  - Up to 2
  - Do not have or process IP



Encapsulation