Course on Computer Communication and Networks

Lecture 2
Chapter 1: Introduction:
Part B: Network structure, performance, security prelude

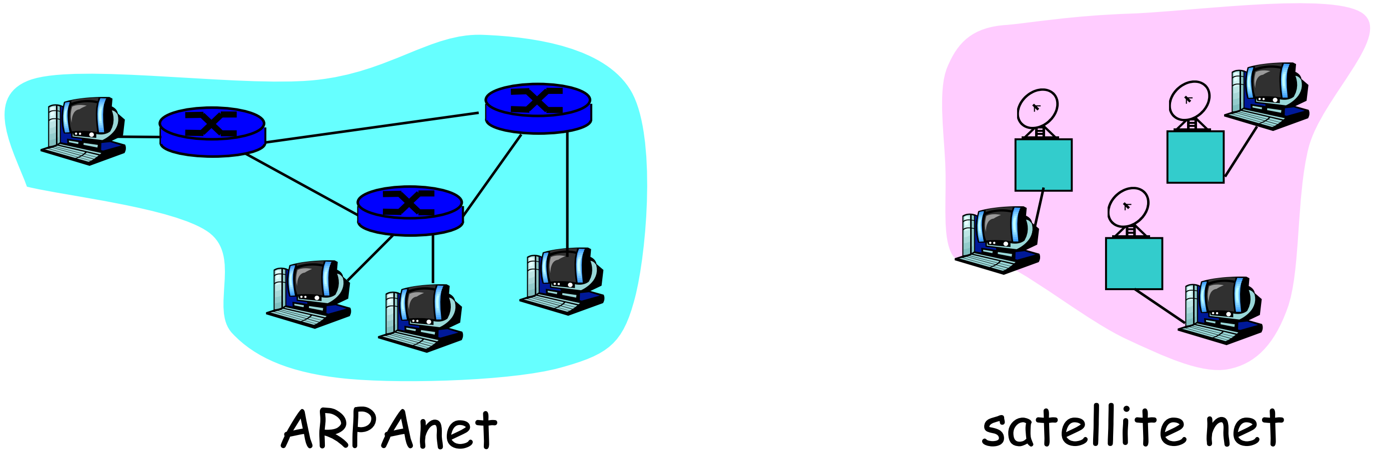
CTH EDA344/GU DIT 423

Based on the book Computer Networking: A Top Down Approach, Jim Kurose, Keith Ross, Addison-Wesley.

The Internet concept: bridging networks

1974: multiple unconnected nets

… differing in: addressing conventions, packet formats, routing, physical medium

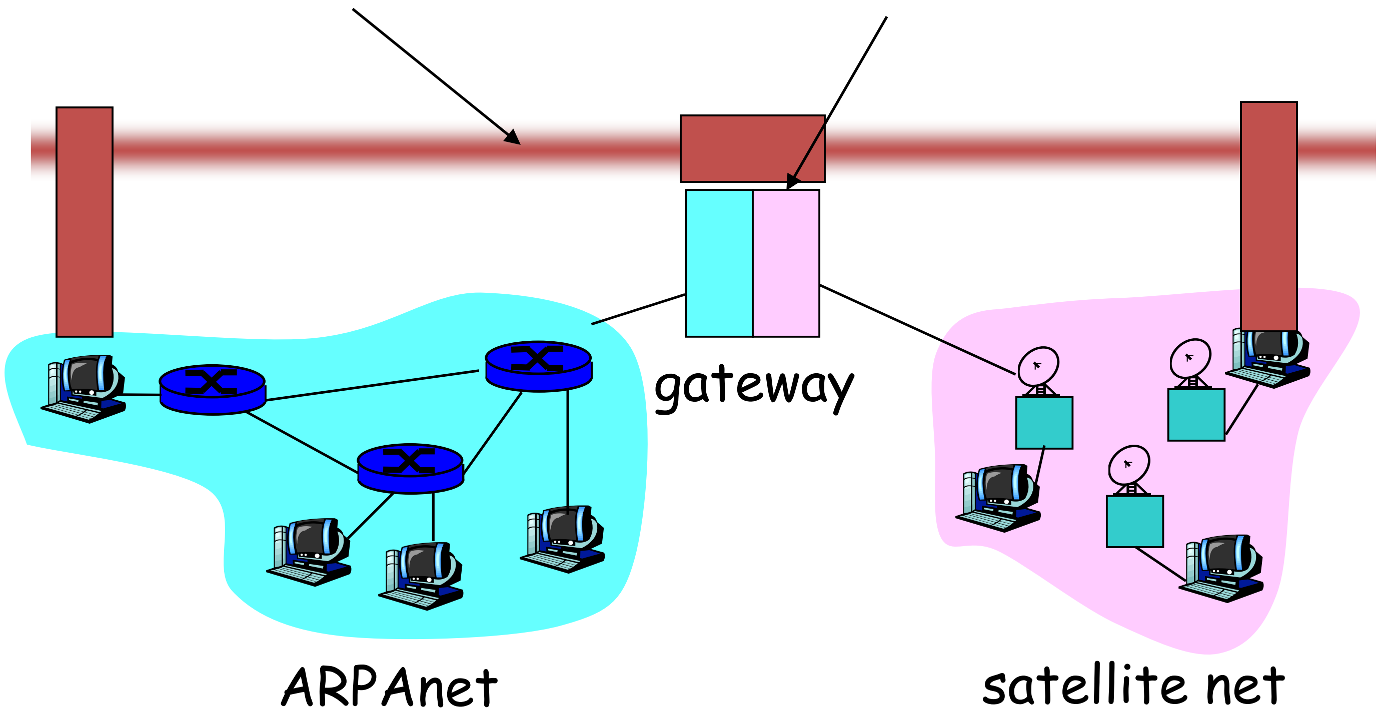


"A Protocol for Packet Network Intercommunication", V. Cerf, R. Kahn, IEEE Transactions on Communications, May, 1974, pp. 637-648.

The Internet: bridging networks

Internetwork layer (IP):
- ❒ internetwork appears as single, uniform entity, despite underlying local network heterogeneity
- ❒ network of networks

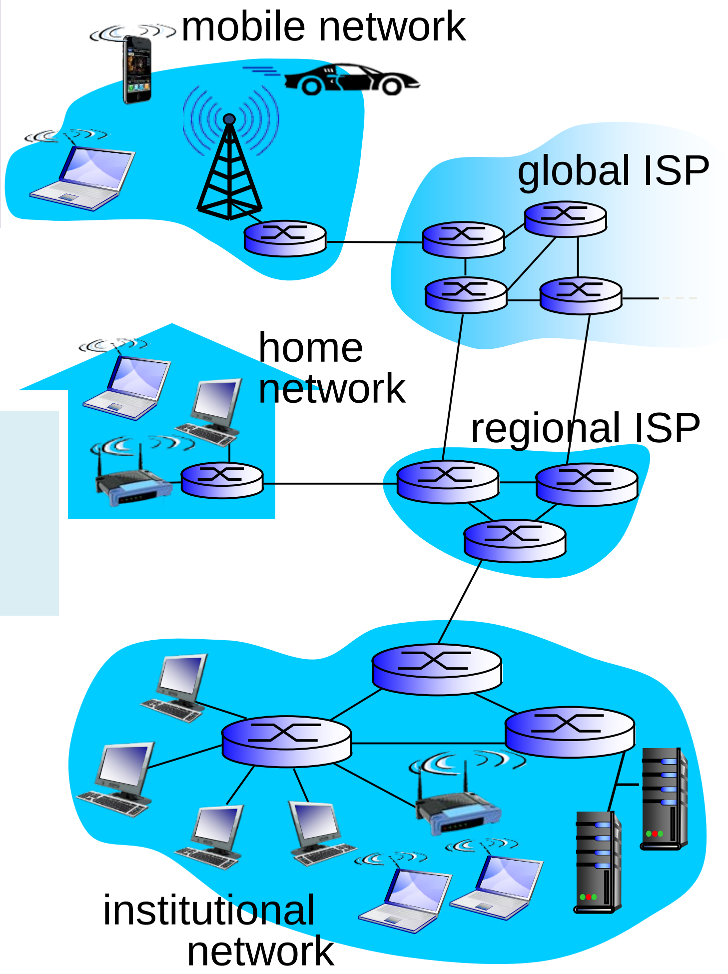
Gateway:
- "embed internetwork packets in local packet format"
- route (at inter-network level) to next gateway



A closer look at network structure:

network edge: hosts:
- run application programs e.g. Web, email, …
- … based on network services available

access networks:
- *connect end-hosts to the Internet*
- *through physical media:* wired, wireless links



network core:
- interconnected routers
- network of networks

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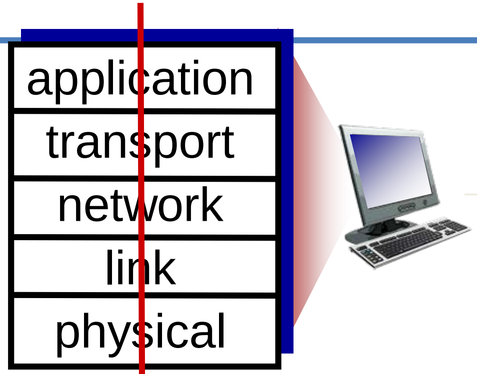

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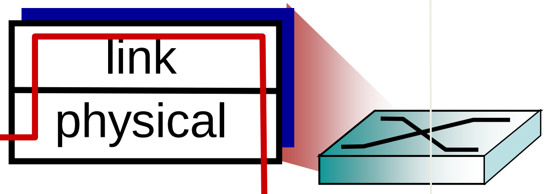


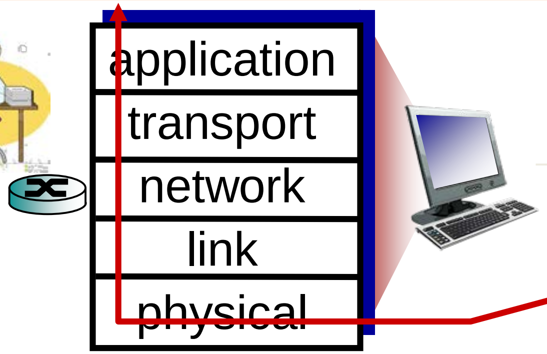
Types of communication service available by the transport layer @ Internet:

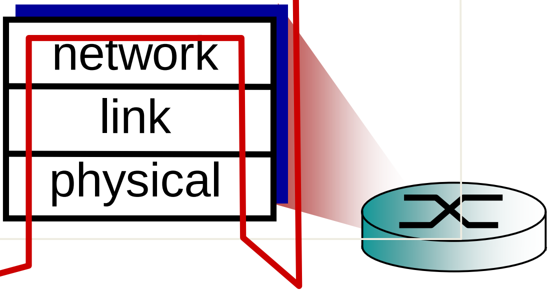
- **connection-oriented**: reliable, in-order data delivery (TCP)
- **connectionless**: "best effort", arbitrary order data-delivery (UDP)

Q: How & based on what "core" functionality?
(…main Q for the Internet….)


UDP


TCP





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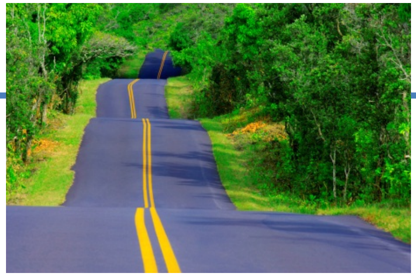
Roadmap



1. Zooming into core
   – Ways of data transfer
   – Routing
   – Performance: delays (& loss)
   – …. throughput
2. Network/Internet structure complemented:
   – access net, physical media
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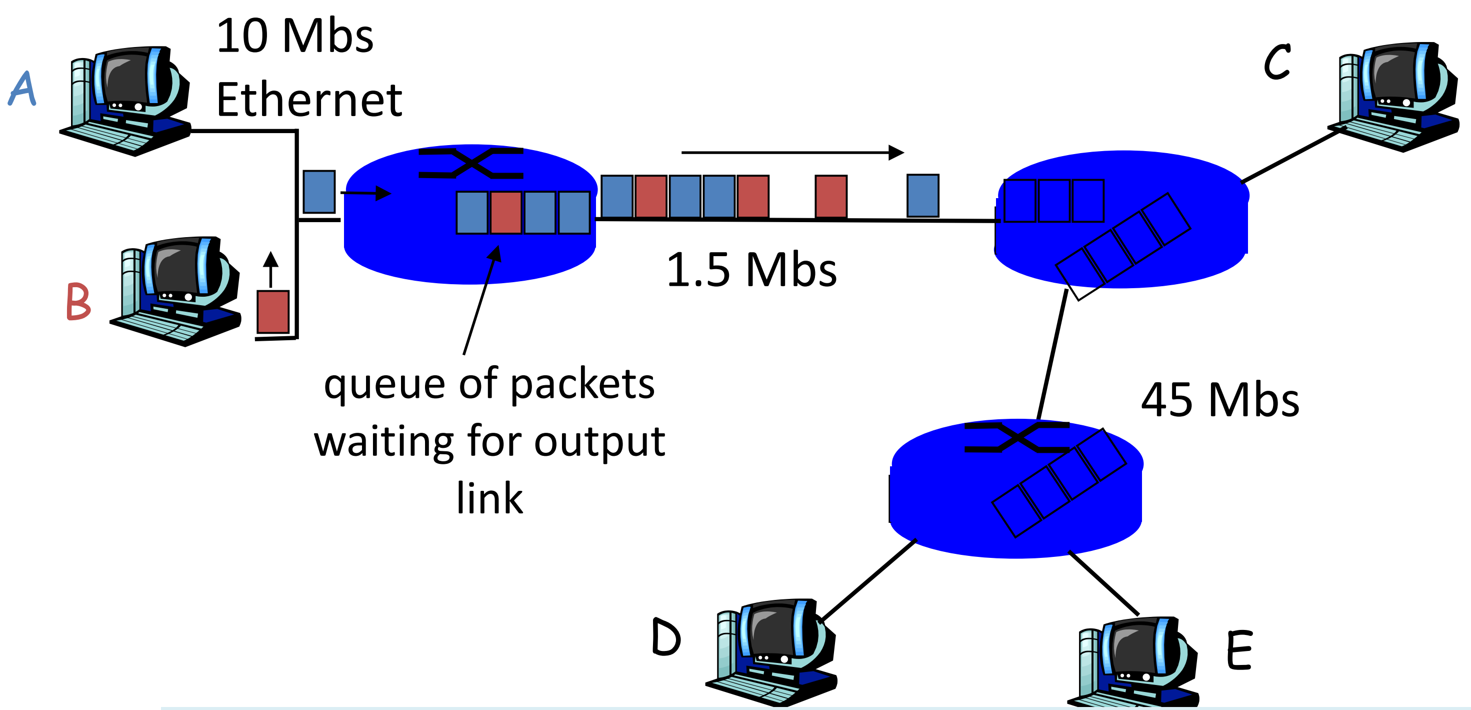
3. Security prelude

Network Core: how is data transferred through the net?

Packet Switching



Application messages divided into *packets*

- packets *share* network resources
- resources used *as needed*

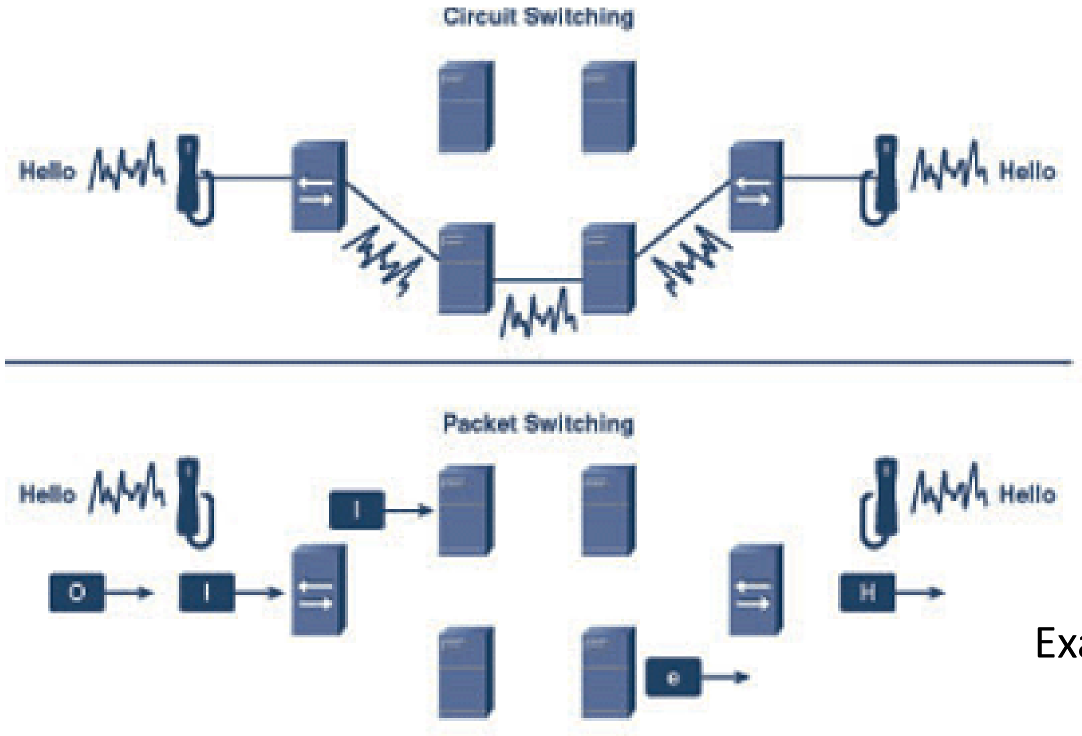
store and forward:

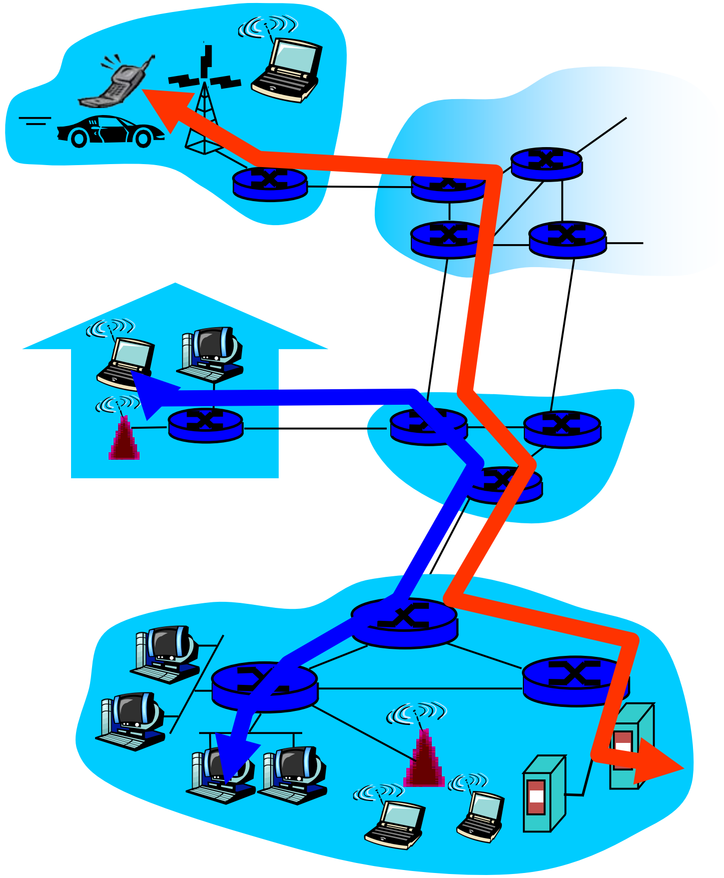
- packets move one hop at a time
  - transmit over link; wait their turn at next link

Alternative Core: Circuit Switching
(analogue telephony)

End-end resources dedicated for "call"

- dedicated resources (link bandwidth, switch capacity): no sharing
- circuit-like (guaranteed) latency bound
- call setup required





Example video for Circuit vs packet switching
http://www.youtube.com/watch?v=Dq1zpiDN9k4&feature=related

Packet switching versus circuit switching

Packet switching allows more users to use the network!

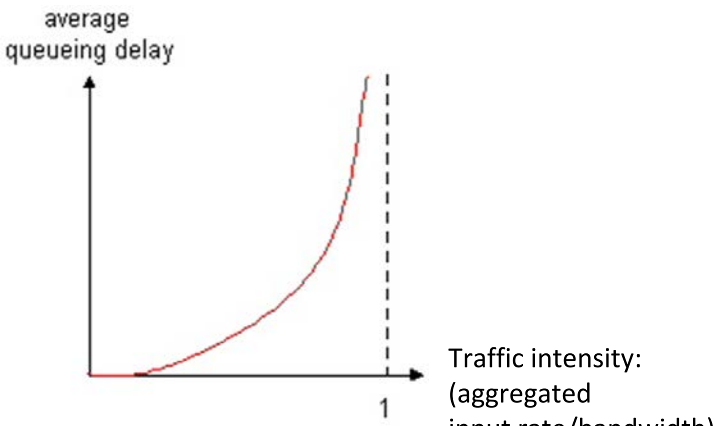
Q: what happens with > 35 users? Still circuit-like behavior?

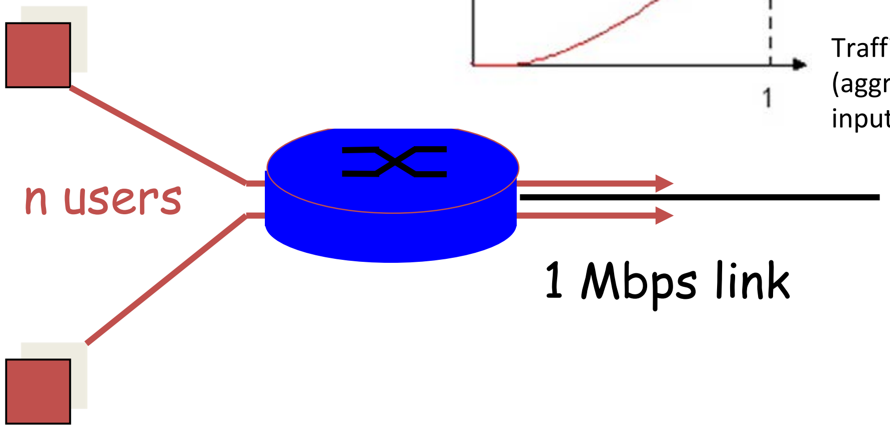
- 1 Mbit link
- each user/connection:
  - 100Kbps when "active"
  - active 10% of time (bursty behaviour)
- **circuit-switching** how many users/connections can be multiplexed?:
  - 10
- **packet switching**

  with n= 35 users:

  P(active simultaneously k > 10 , i.e. some needs to wait) < 0.0004

  ⇒ almost all of the time, same queuing behaviour as in circuit switching)

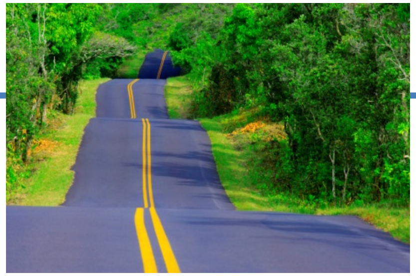




Hint: The probability of *k* out of *n* users active (p=0.1 in our example)

$$f(k;n,p) = \Pr(X = k) = \binom{n}{k} p^k (1-p)^{n-k}$$

Roadmap



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(Can we combine the benefits of CS & PS?)

Routing and network-core main design issue

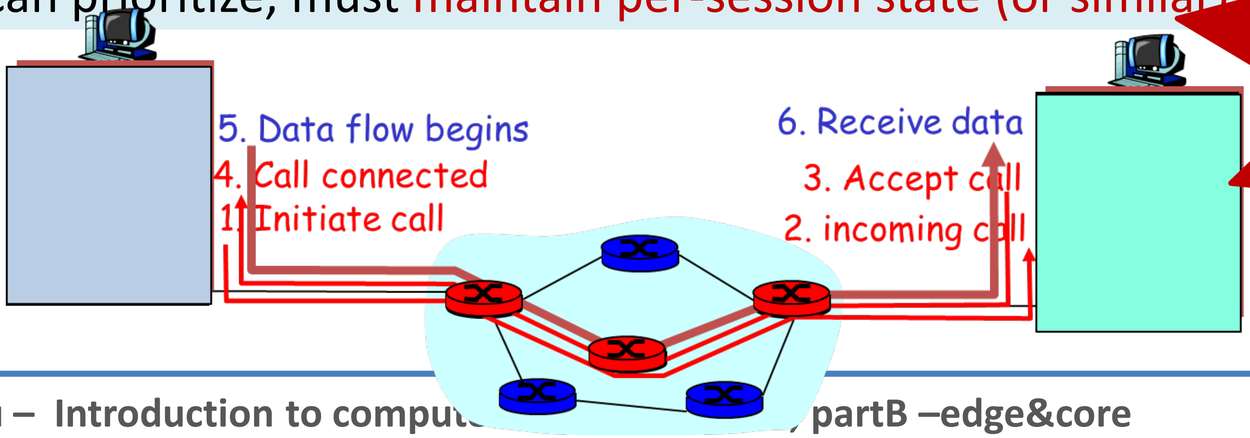
What is routing's role?

find routes from source to destination

1. path selection algorithms
2. Important design issue/type of service offered at network layer:
   - **Option 1: datagram network**:
     - *destination address* determines next hop
     - routes may change during session
   - **Option 2: virtual circuit network: resource reservation+sharing!!**
     - path determined at *call setup*, remains fixed thru session
     - *combining packet-switching with circuit switching behaviour*
     - routers can prioritize, must maintain per-session state (or similar)

Simple to implement & maintain (Internet main approach)

Expensive, but better to provide guarantees (Internet's new concerns; more to appear soon at a lecture near you…)



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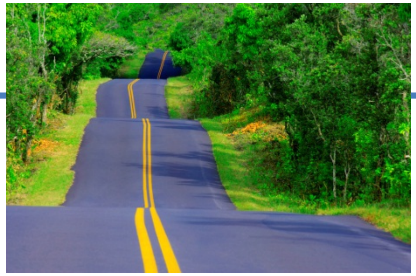

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Delays (latencies) in packet-switched networks

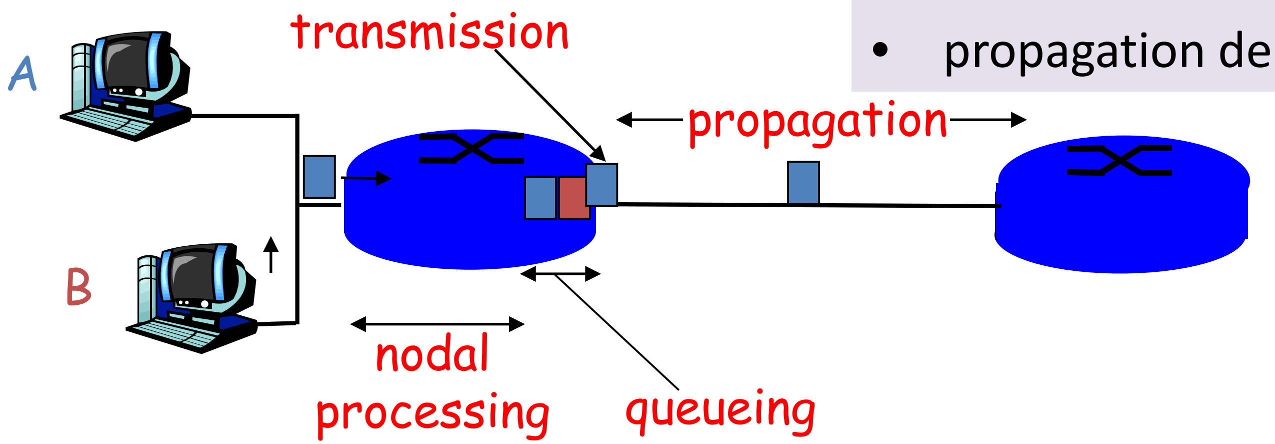
- 1. nodal processing:
  - check bit errors
  - determine output link
- 2. queuing
  - time waiting at output link for transmission
  - depends on congestion level of router

3. Transmission delay:

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

4. Propagation delay:

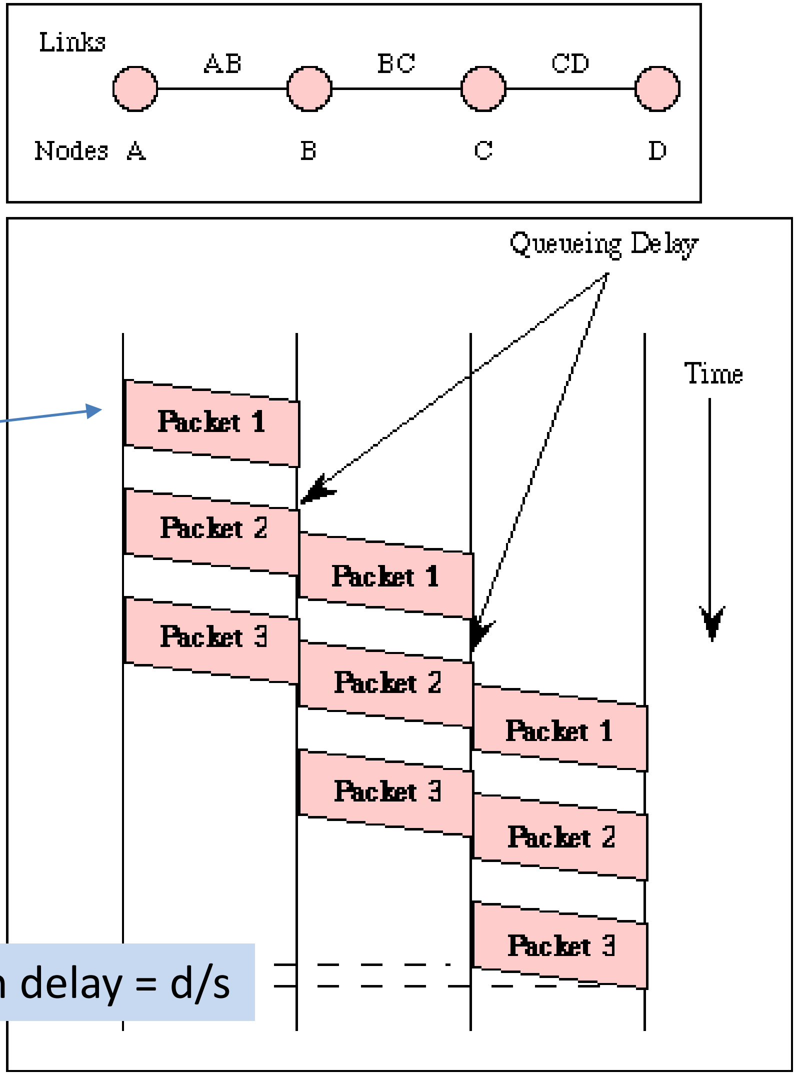
- d = length of physical link
- s = propagation speed in medium (~$2x10^8$ m/sec)
- propagation delay = d/s



Visualize delays: packet switching

store and forward behavior visualization

time to send bits into link = L/R



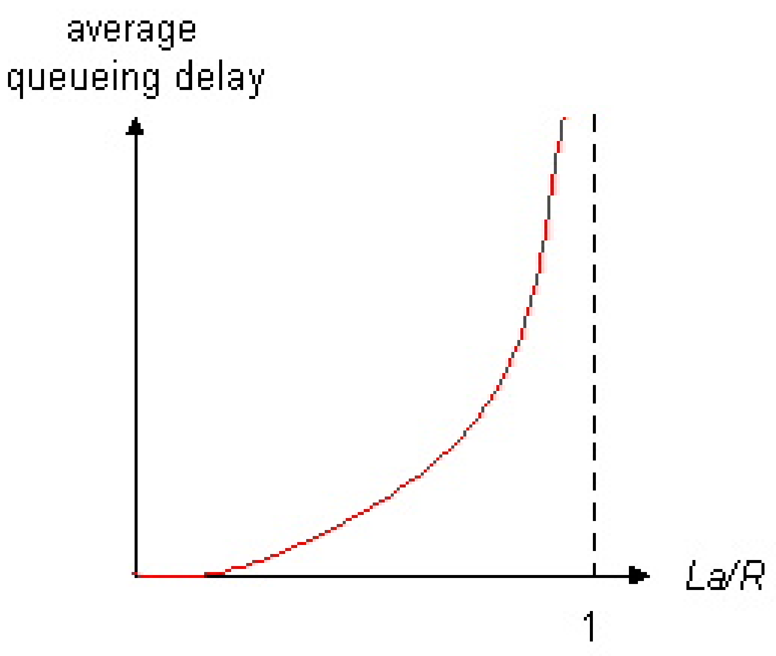
propagation delay = d/s

fig. Gorry Fairhurst

Queueing delay (revisited) …

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

traffic intensity = La/R

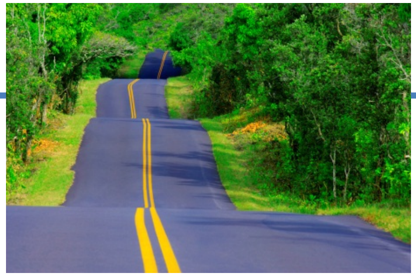


- La/R ~ 0: average queueing delay small
- La/R -> 1: delays become large
- La/R > 1: more "work" arriving than can be serviced, average delay infinite! Queues may grow unlimited, packets can be lost

La/R ~ 0

La/R is 1 or more

Roadmap



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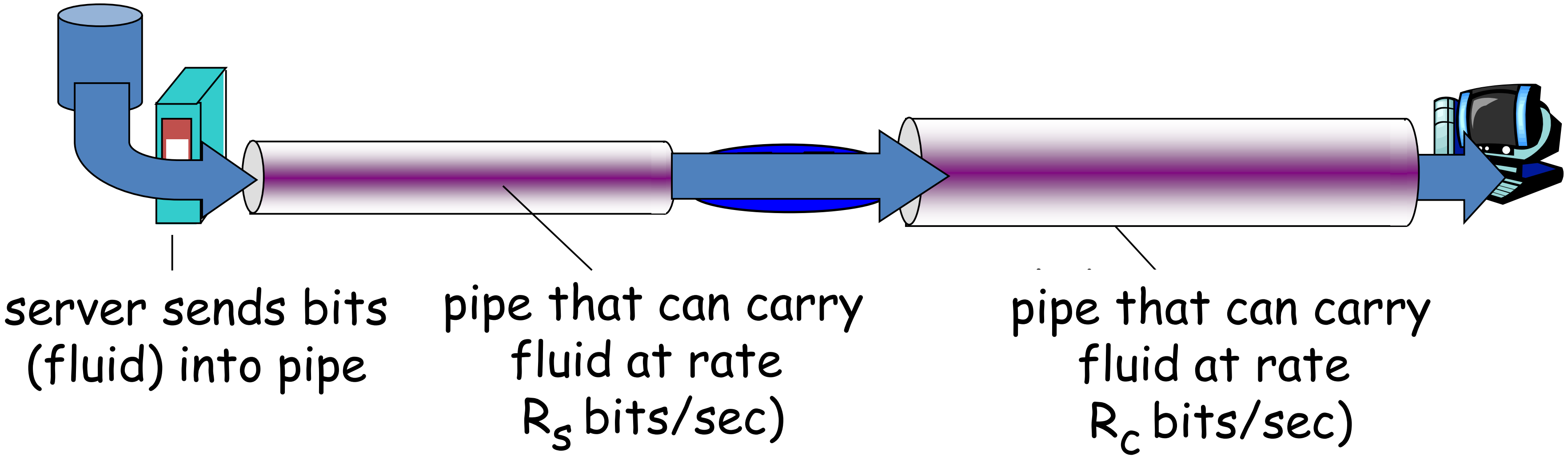
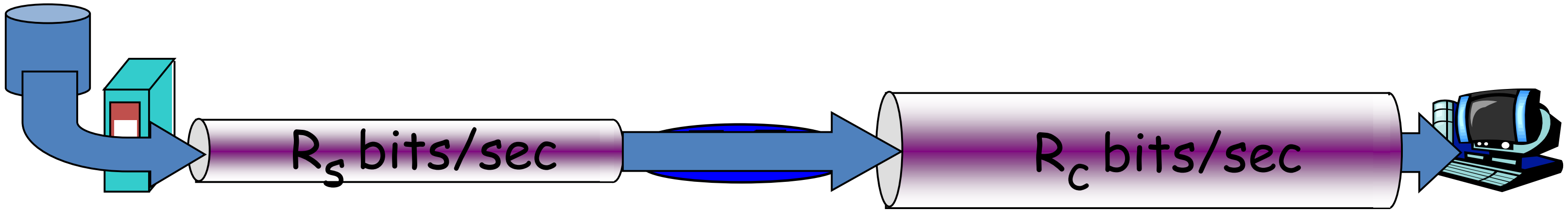
Throughput

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

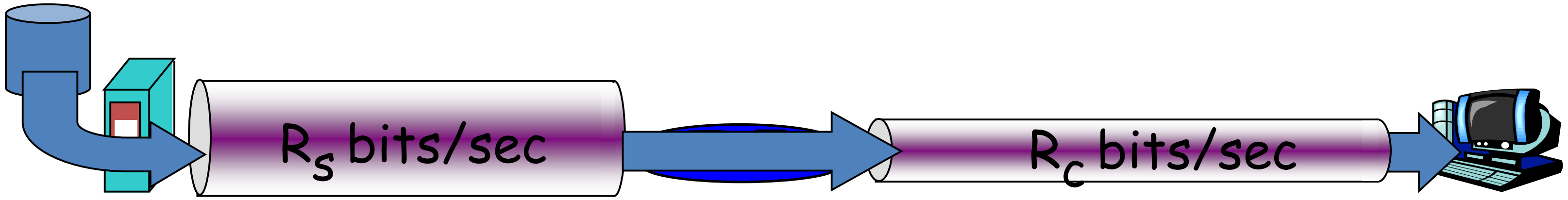


Throughput (more)

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



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

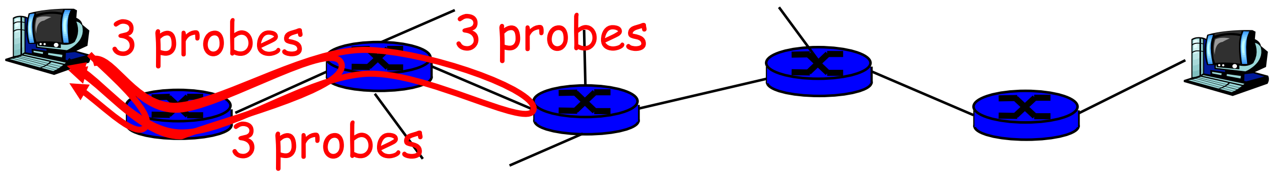


bottleneck link

link on end-end path that constrains end-end throughput

… "Real" Internet delays and routes (1)…

- 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 (2)…

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

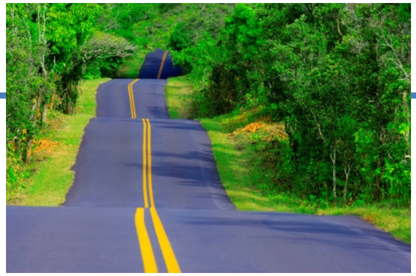
Three delay measurements from
gaia.cs.umass.edu to cs-gw.cs.umass.edu

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 reponse (probe lost, router not replying)

Roadmap



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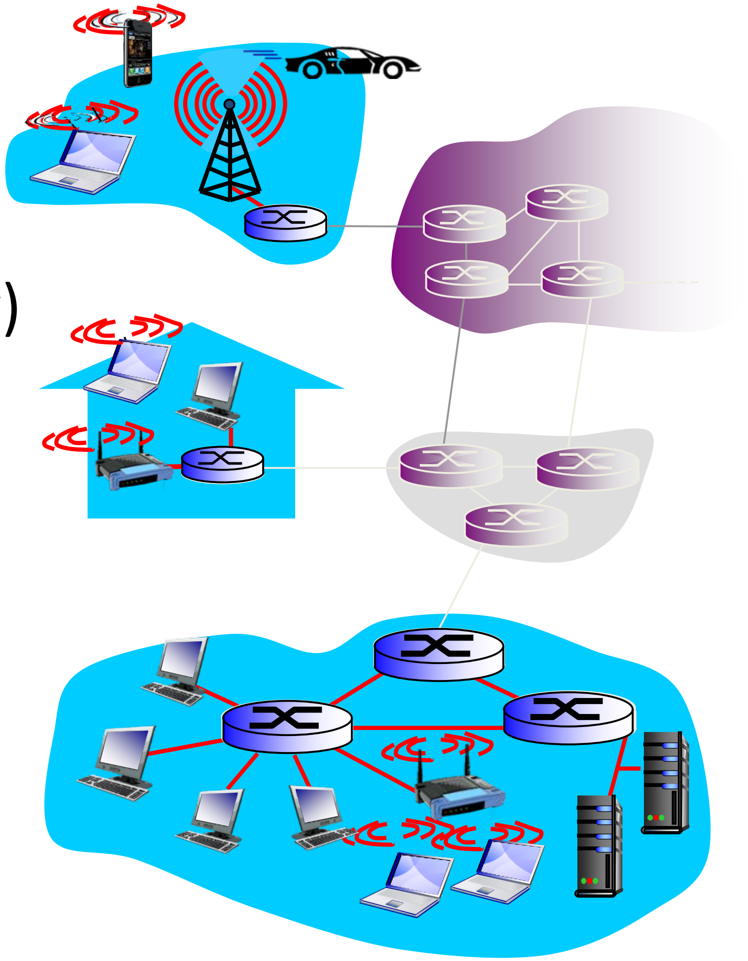
Access networks and physical media

Q: How to connect end systems to first router?

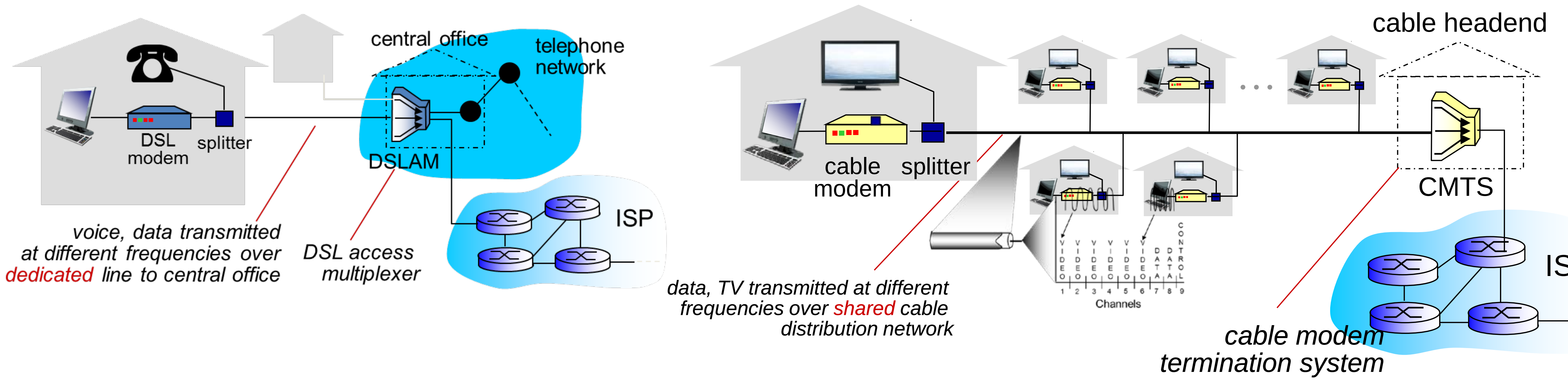
- residential access nets
- institutional access networks (school, company)

keep in mind:

- bandwidth (bits per second)?
- shared or dedicated?



Access nets:
digital subscriber line (DSL) & cable network



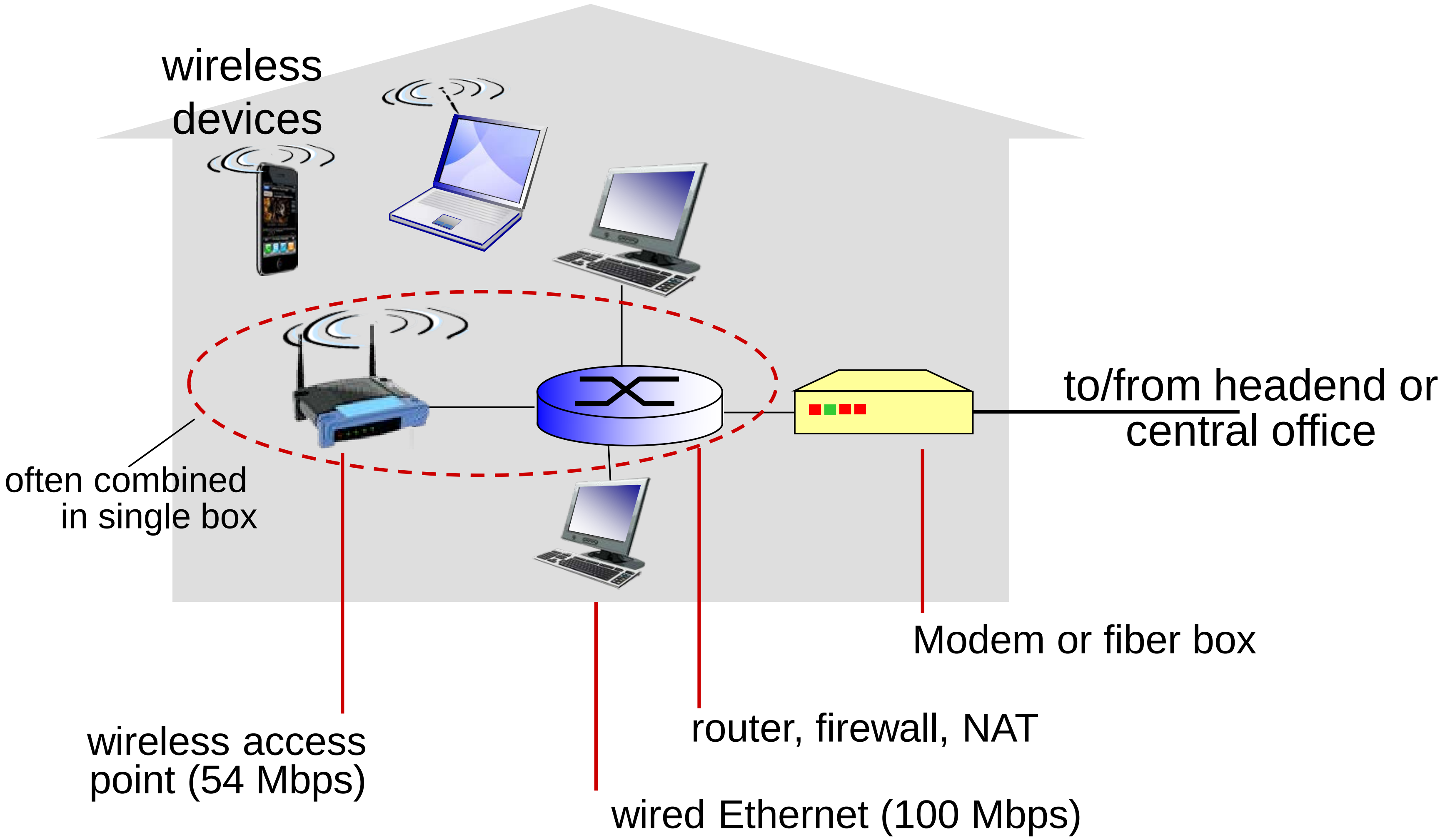
use *existing* telephone line to central office DSLAM

- Multiplexing data/voice over DSL phone line to Internet/telephone net
- typically < 1 Mbps upstream, < 10 Mbps downstream

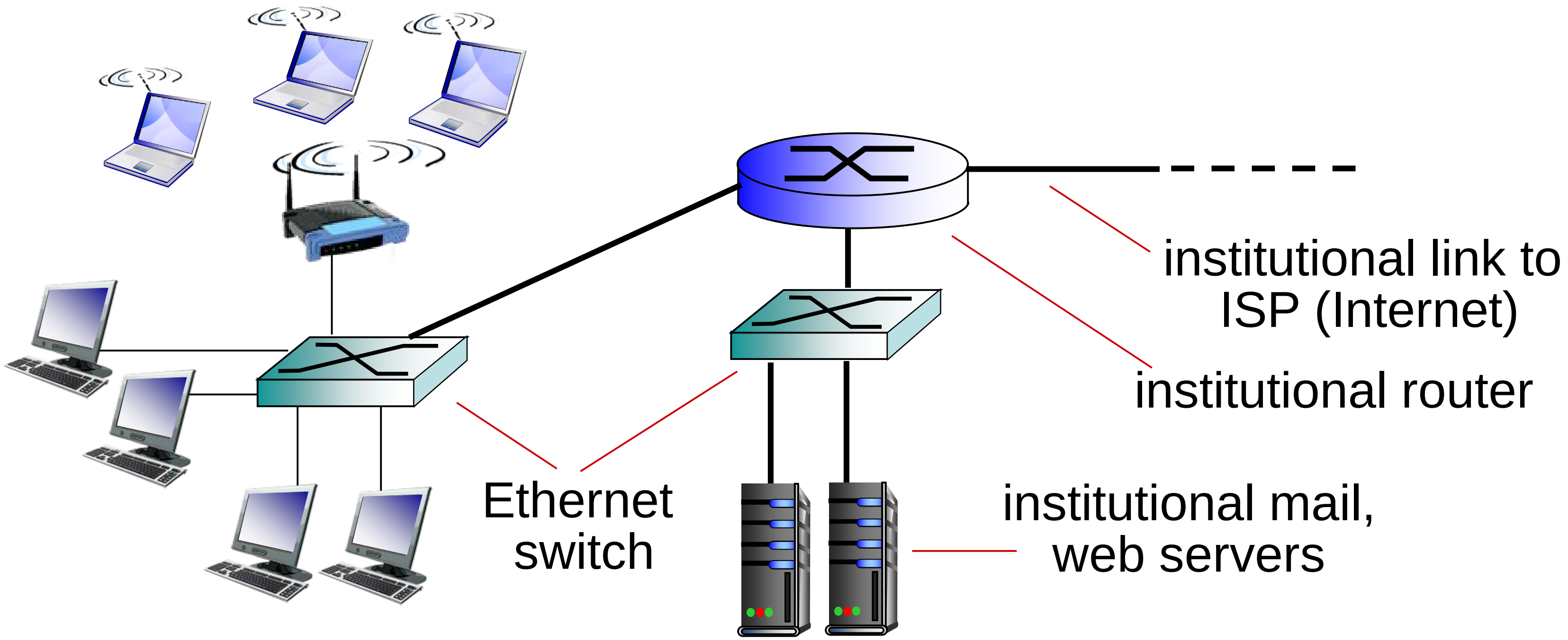
(HFC: hybrid fiber coax) network of cables, attaches homes to ISP router

- ca 2 Mbps upstream, 30Mbps downstream, homes *share access network* to cable headend
- unlike DSL, which has dedicated access to central office

Access net: home network



Enterprise access networks (Ethernet)

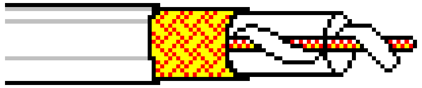


- typically used in companies, universities, etc
- 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates

Guided physical Media: coax, fiber, twisted pair

Coaxial cable:

- wire (signal carrier) within a wire (shield)
- broadband: multiple channels multiplexed on cable (HFC, cable TV)

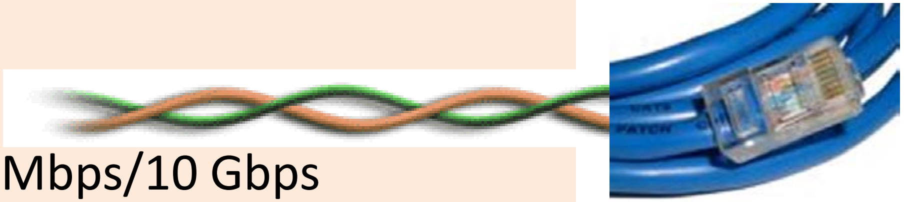


Fiber optic cable:

- low attenuation: fewer repeaters
- low error rate: light pulses immune to electromagnetic noise
- high-speed operation: e.g., 10-100 Gps

Twisted Pair (TP)

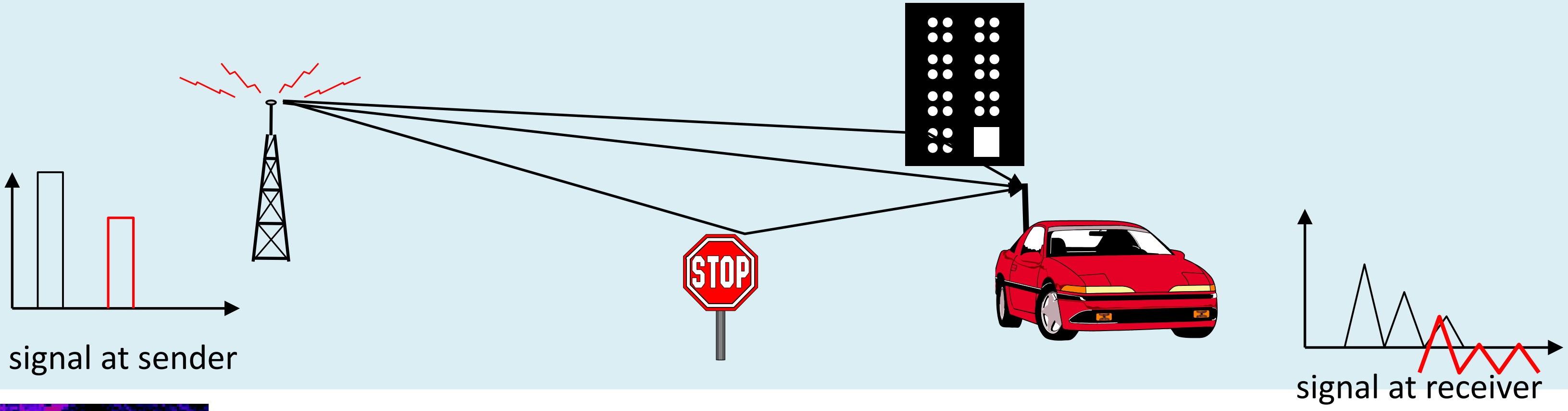
- two insulated copper wires
  - Category 3: traditional phone wires, 10 Mbps Ethernet
  - Category 5/6: more twists, higher insulation: 100-1000 Mbps/10 Gbps

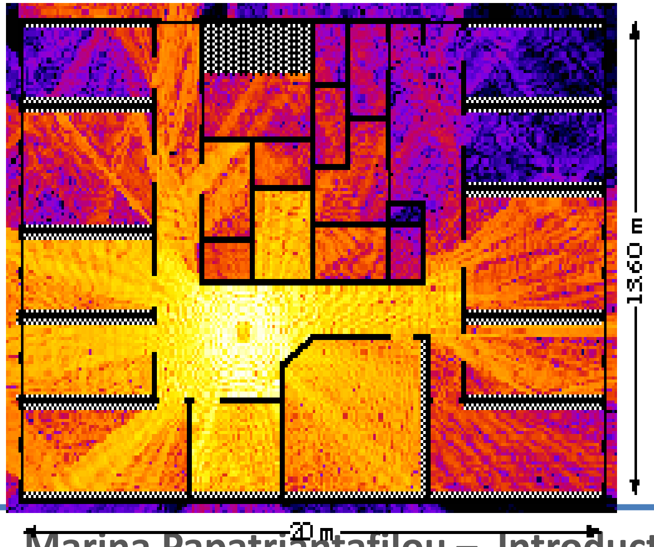


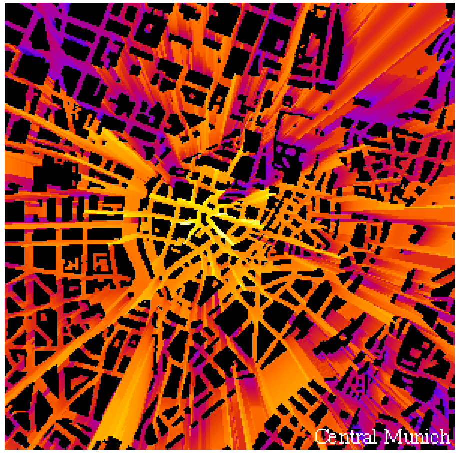
Unguided Physical media: Radio
Properties: Attenuation, Multipath propagation

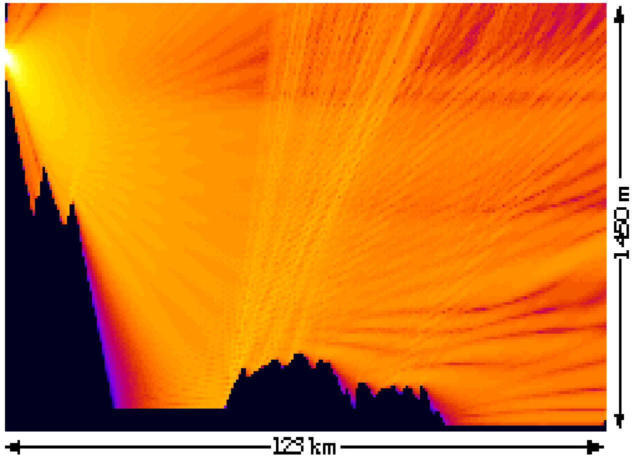
radio links (Mbps): terrestrial microwave, LAN/WiFi, wide-area/cellular, satellite

Signal can fade with distance, can get obstructed, can take many different paths between sender and receiver due to reflection, scattering, diffraction



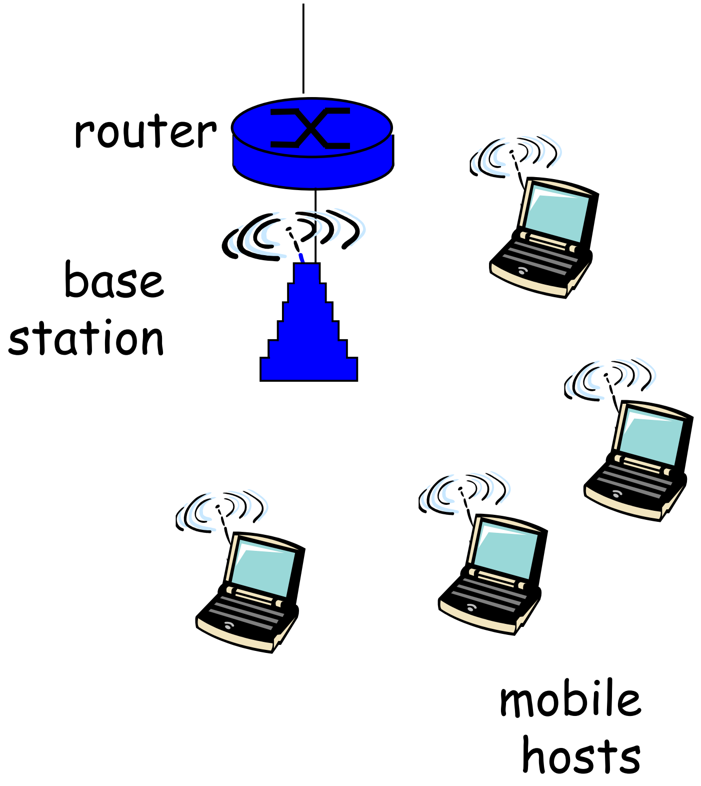




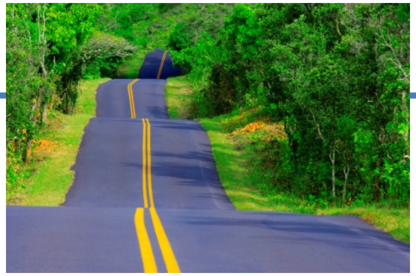


Wireless access networks

- "adhoc" or via base station aka "access point"
- wireless LANs (10's m)
  - 802.11 (WiFi): ca 10-50 Mbps
- wider-area wireless access (10's km)
  - provided by telco operator
  - ~1-10 Mbps over cellular system
  - 3G, 4G, 5G evolving (for IoT)



Roadmap



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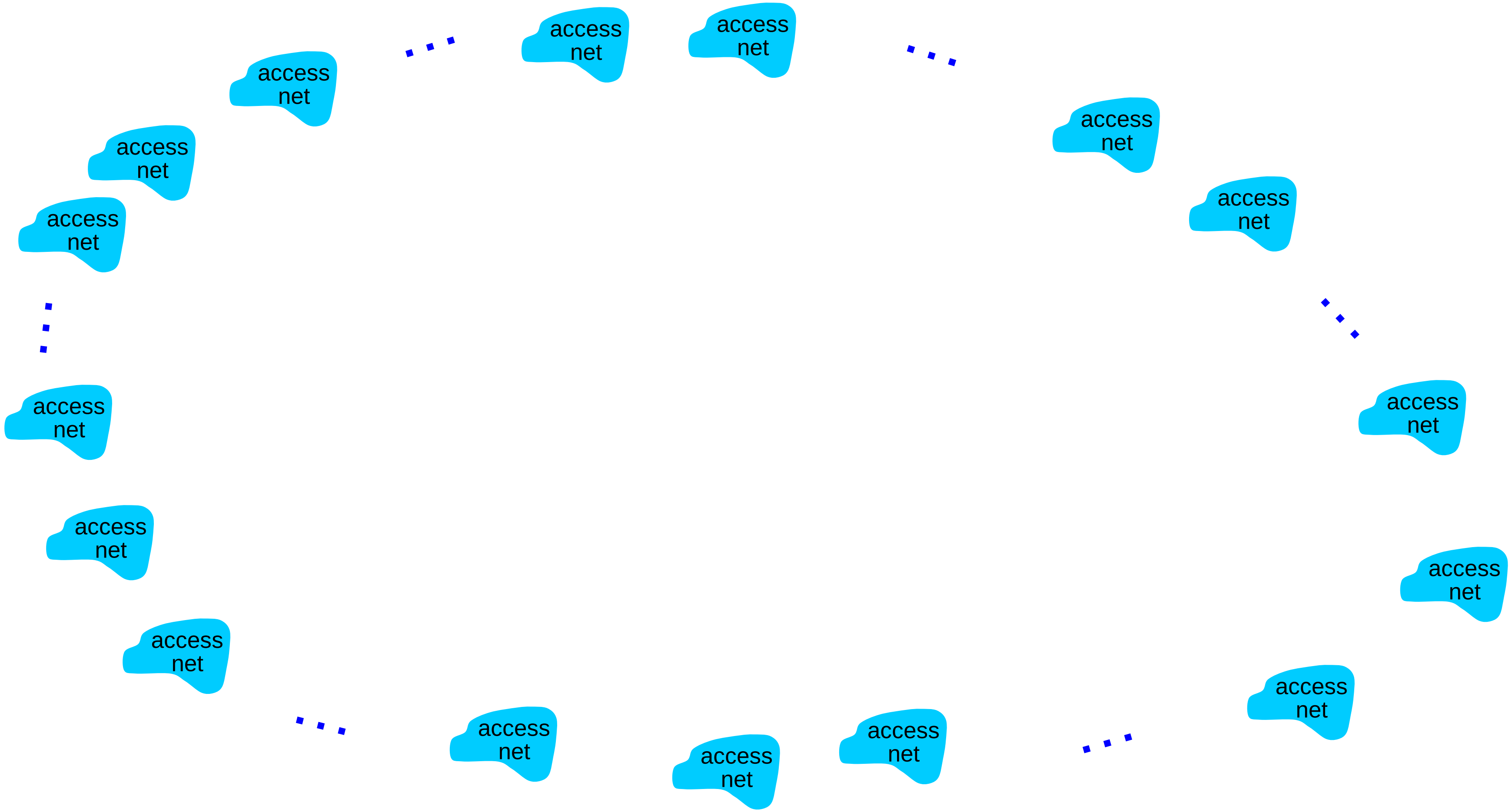
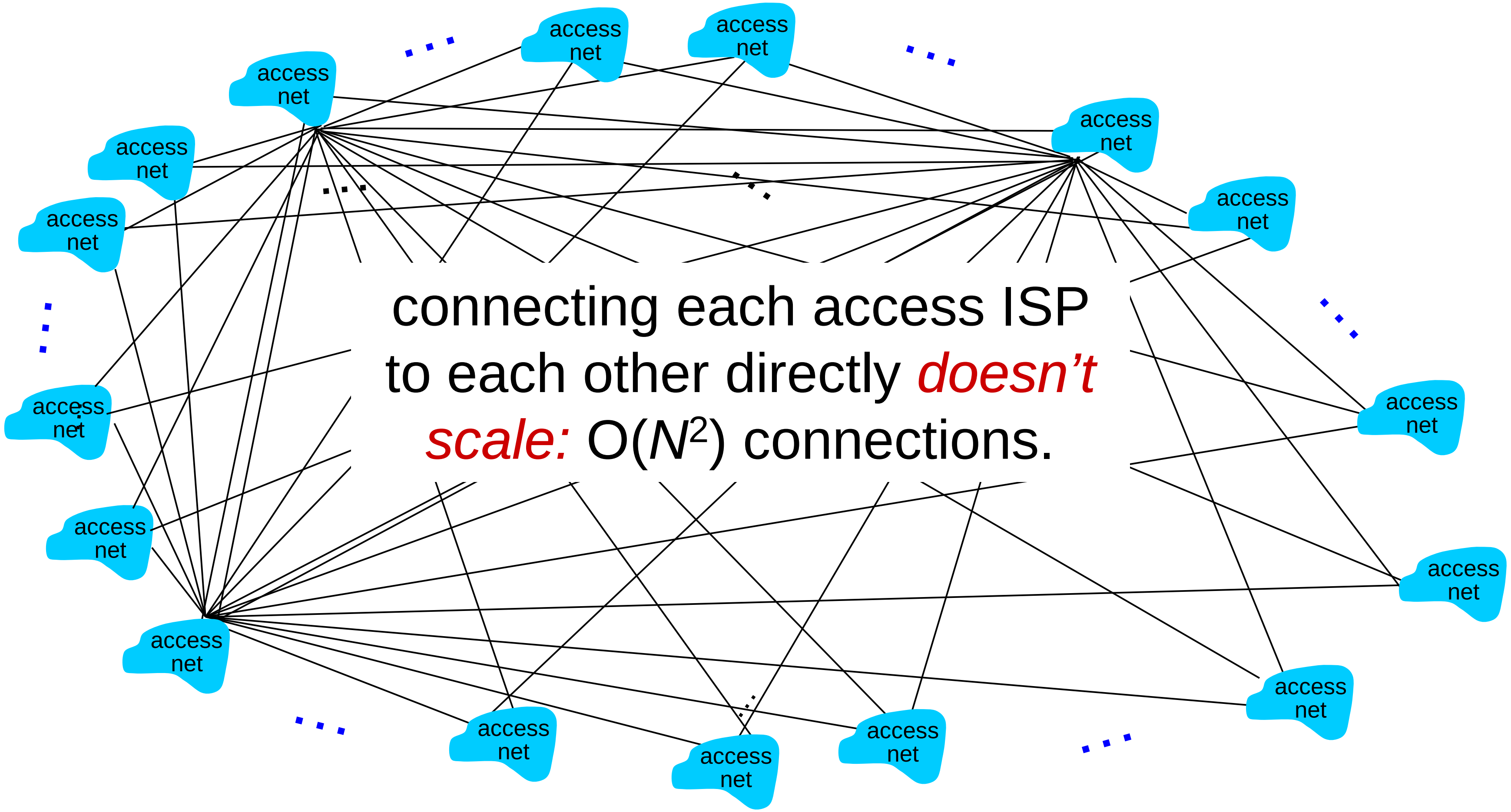
Internet structure: network of networks

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



Internet structure: network of networks

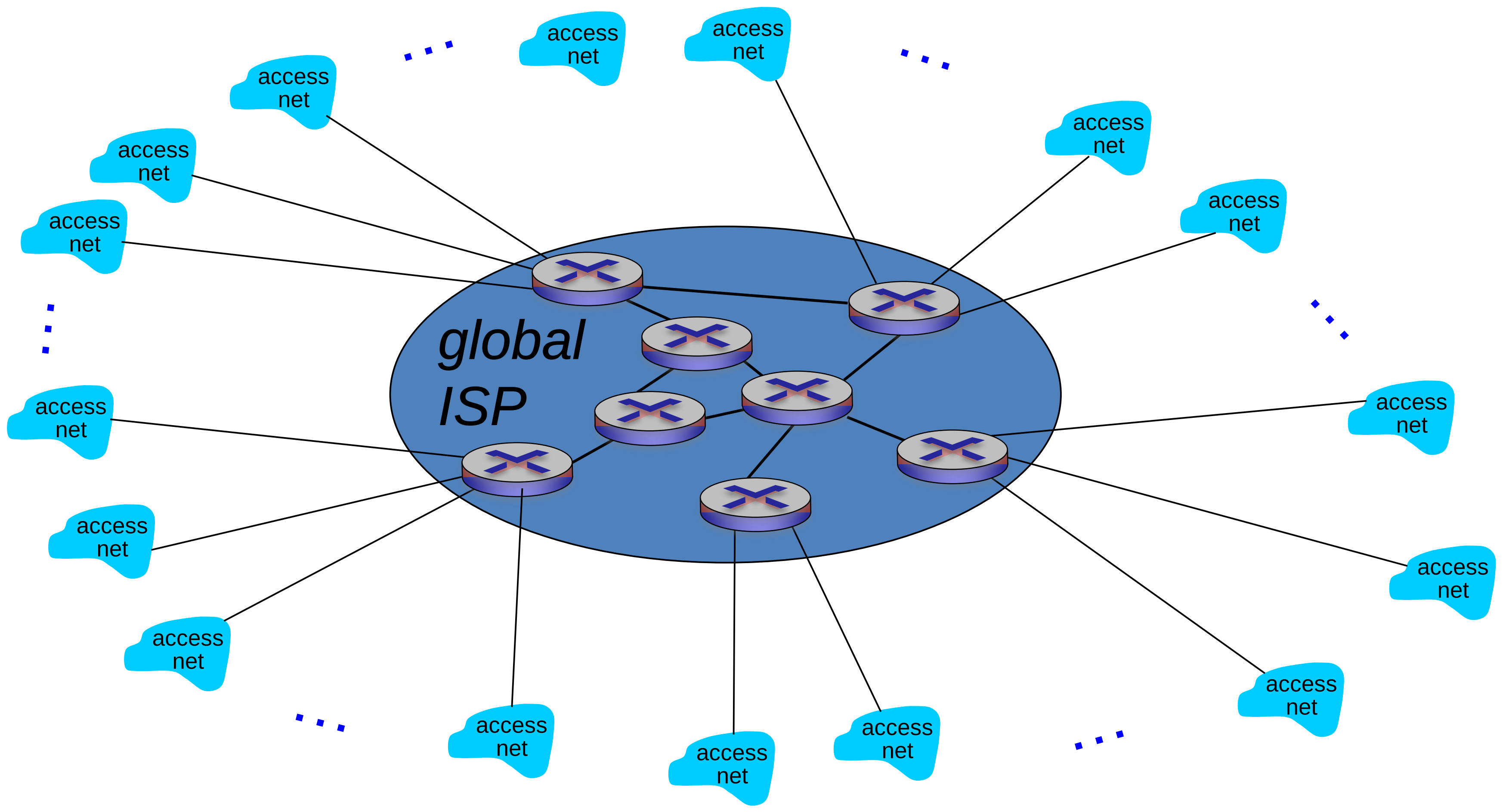
Option: connect each access ISP to every other access ISP?



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

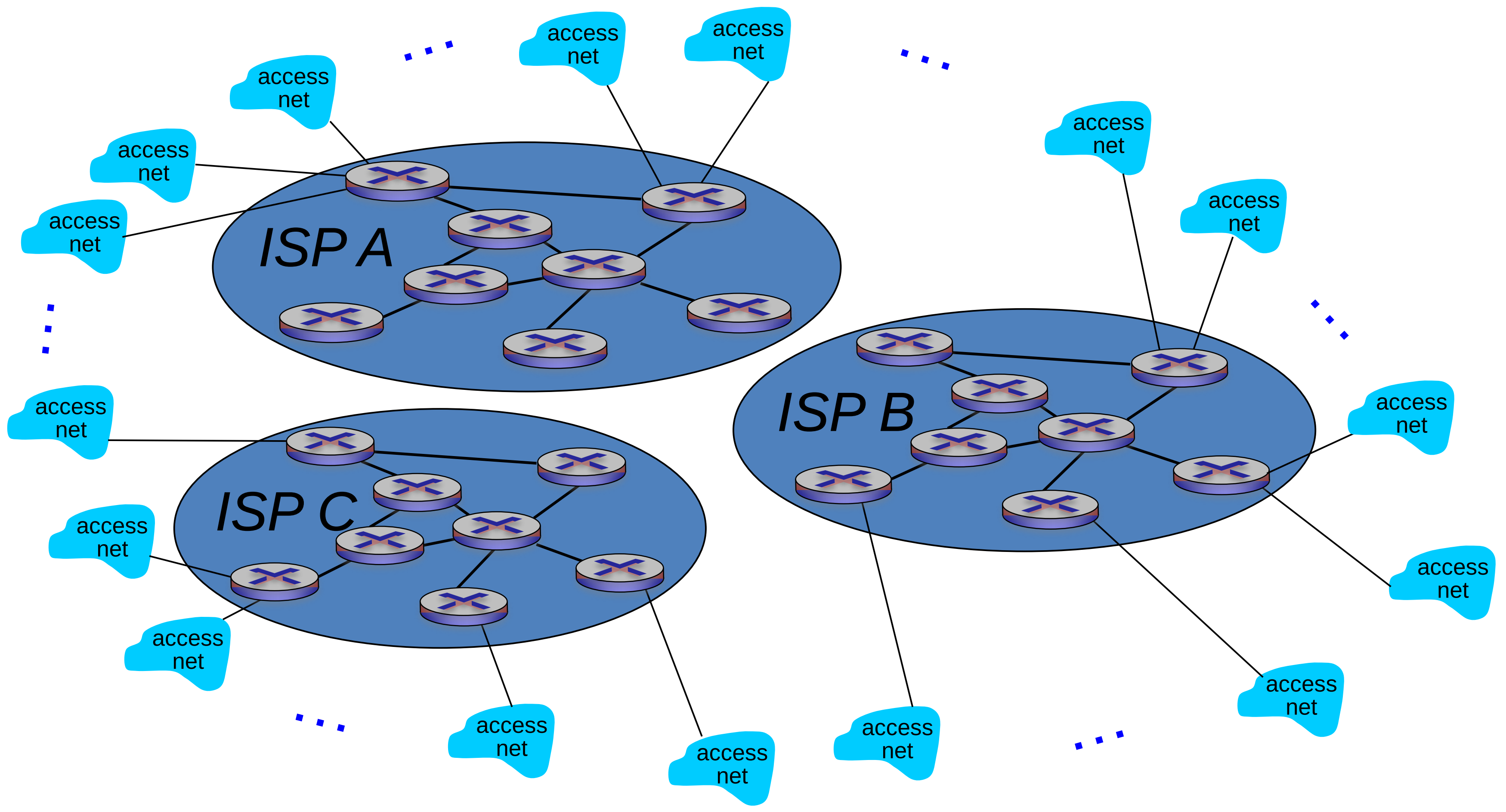
Internet structure: network of networks

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



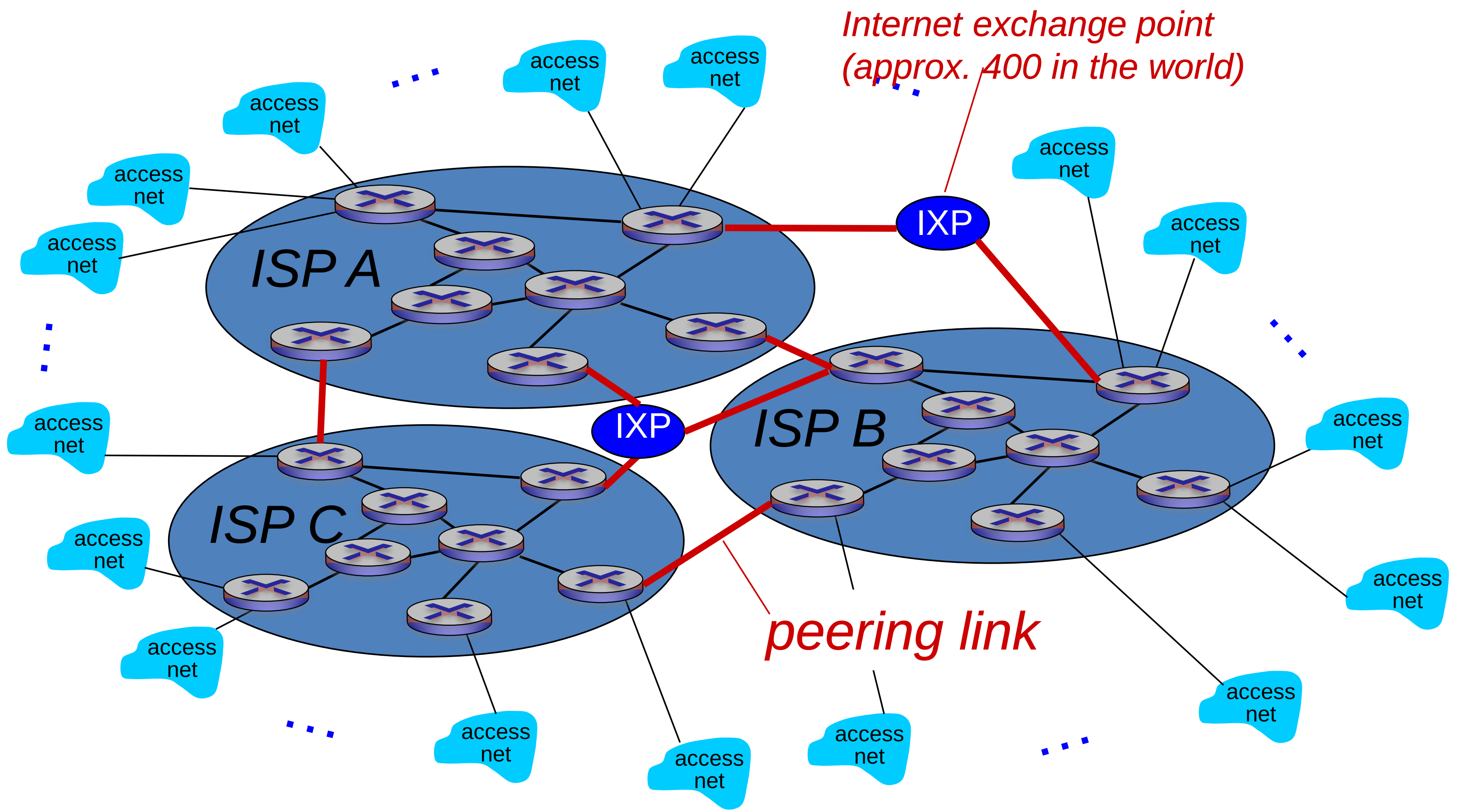
Internet structure: network of networks

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



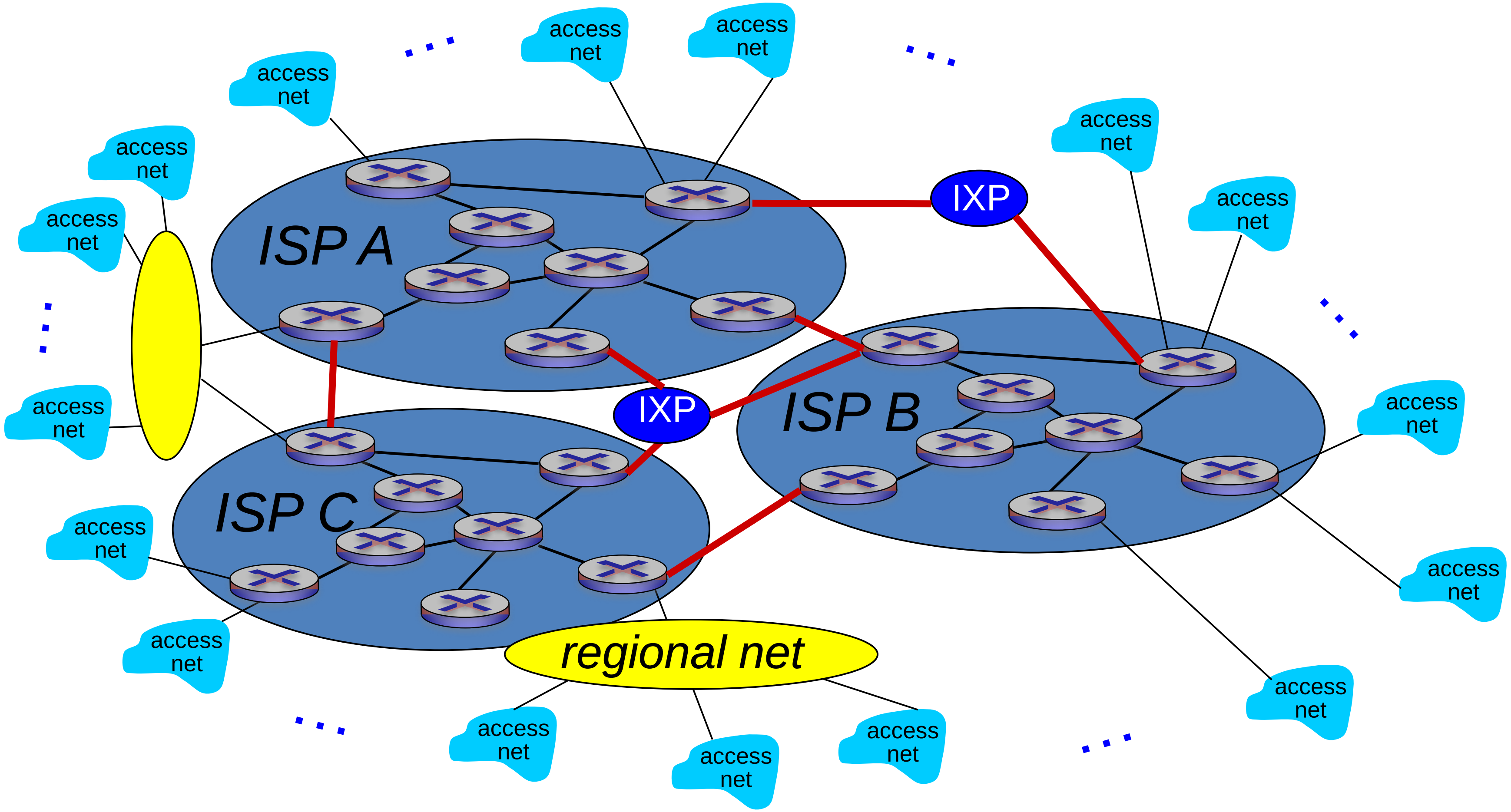
Internet structure: network of networks

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



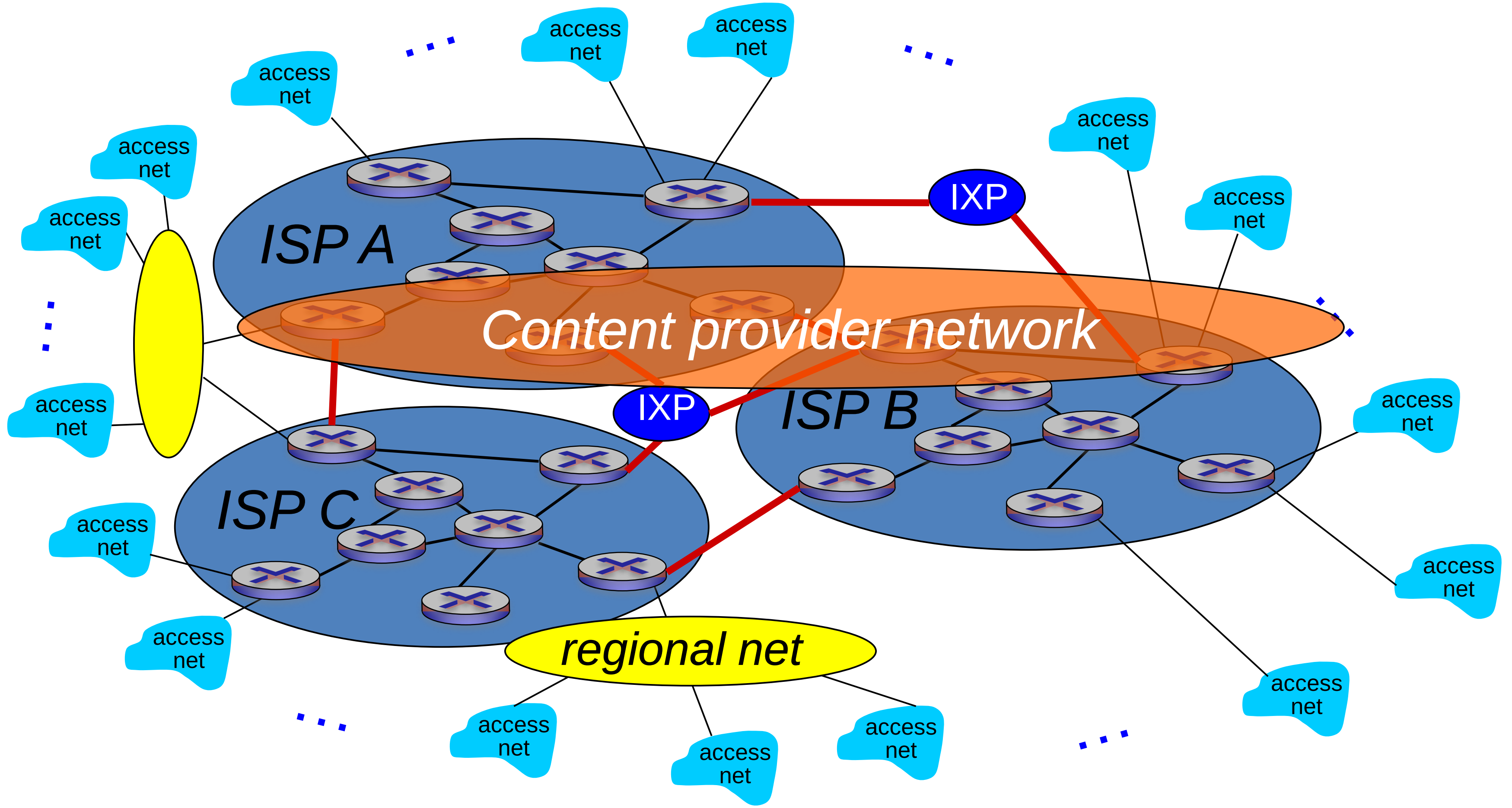
Internet structure: network of networks

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

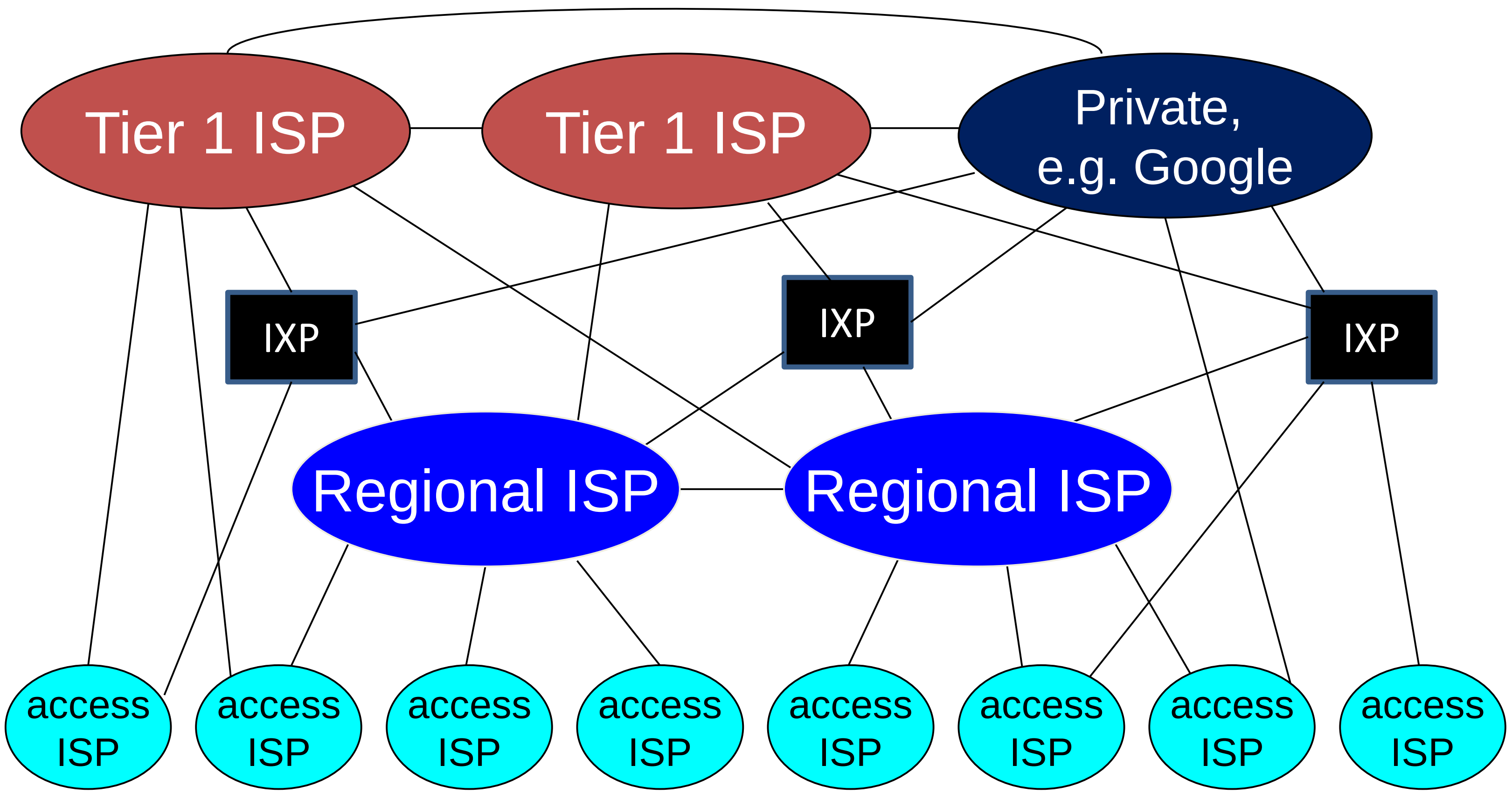


Internet structure: network of networks

… 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

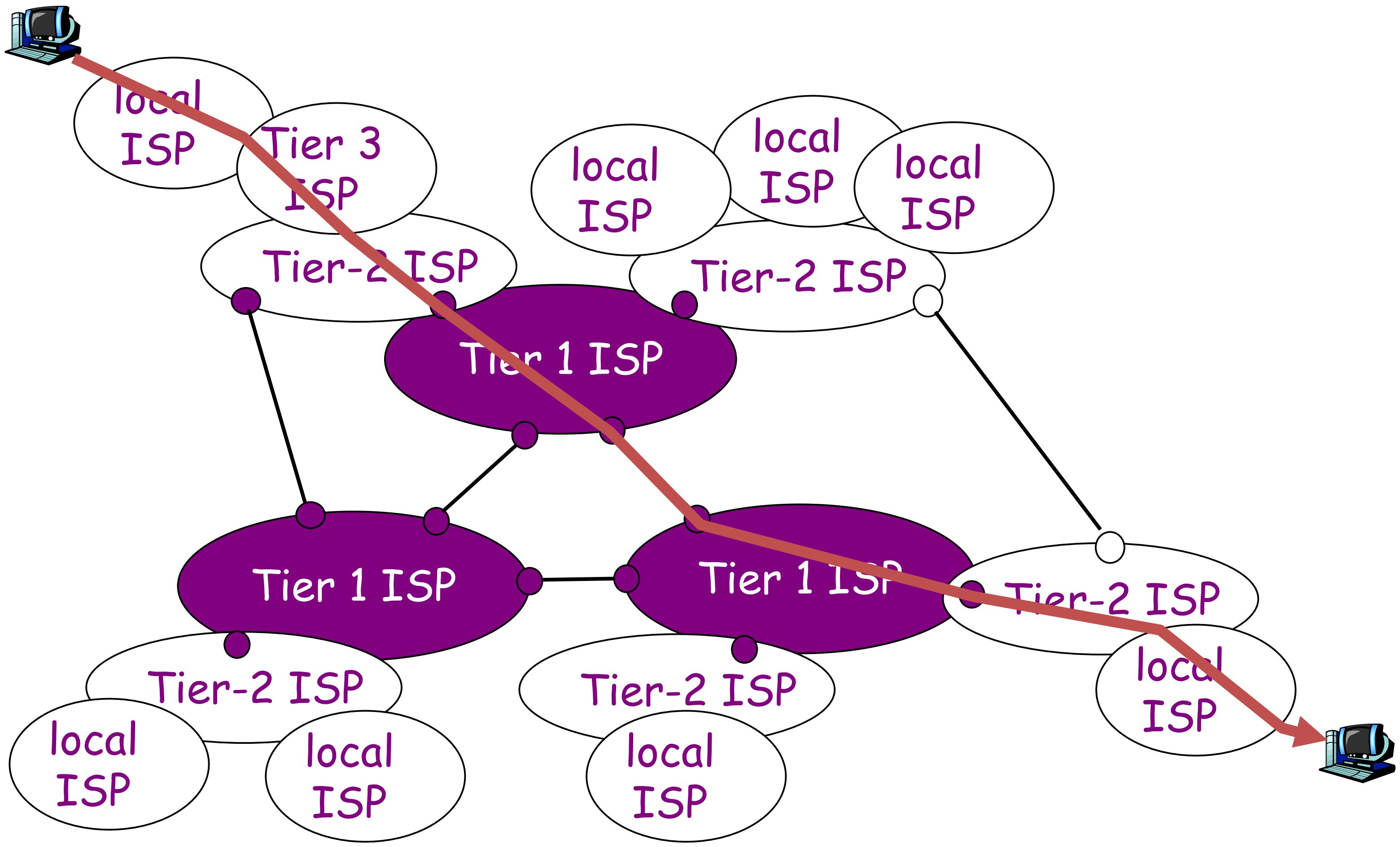


at center: small # of well-connected large networks

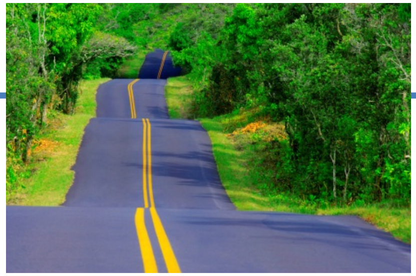
- "tier-1" commercial ISPs (e.g., Level 3, Sprint, AT&T, NTT, Telia), national & international coverage
- content provider network (e.g., Google): private network that connects its (but this might change soon) data centers to Internet, often bypassing tier-1, regional ISPs

Internet structure: network of networks

A packet passes through many networks … (Food for thought: implications/requirements?)



Roadmap



1. Zooming into core
   – Ways of data transfer
   – Routing
   – Performance: delays, …
   – …. throughput, loss
2. Network/Internet structure complemented:
   – access net, physical media
   – backbones, NAPs, ISPs
3. Security prelude

Network Security Prelude

- The field of network security is about:
  - how adversaries can attack computer networks
  - how we can defend networks against attacks (mitigation)
  - how to design architectures that are immune to attacks (prevention)
- 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 can put malware into hosts via Internet

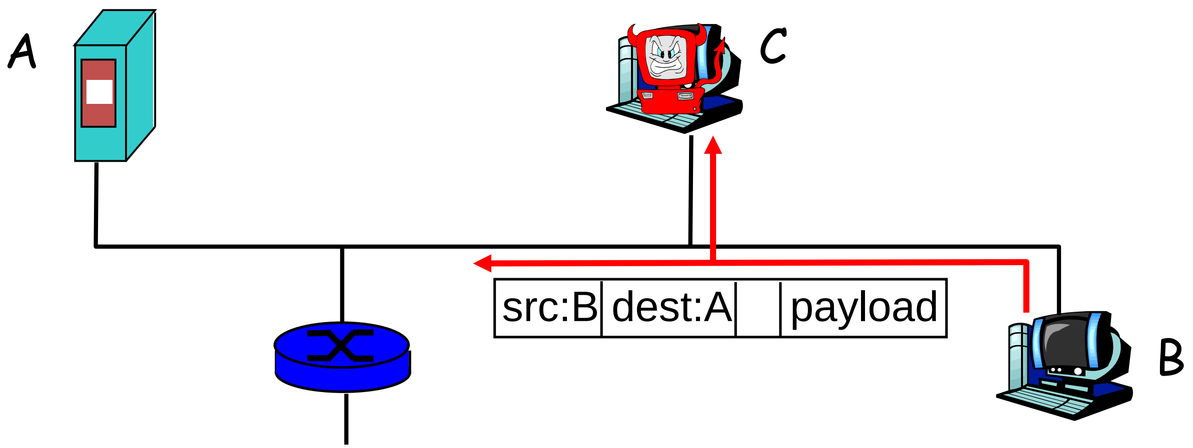
- Malware can get in host from a virus, worm, or trojan horse.
- Spyware malware can record keystrokes, web sites visited, upload info to collection site.
- Infected host can be enrolled in a botnet, used for spam and DDoS attacks.
- Malware is often self-replicating: from an infected host, seeks entry into other hosts

Bad guys can sniff packets

Packet sniffing:

– Shared/broadcast medium (shared Ethernet, wireless)

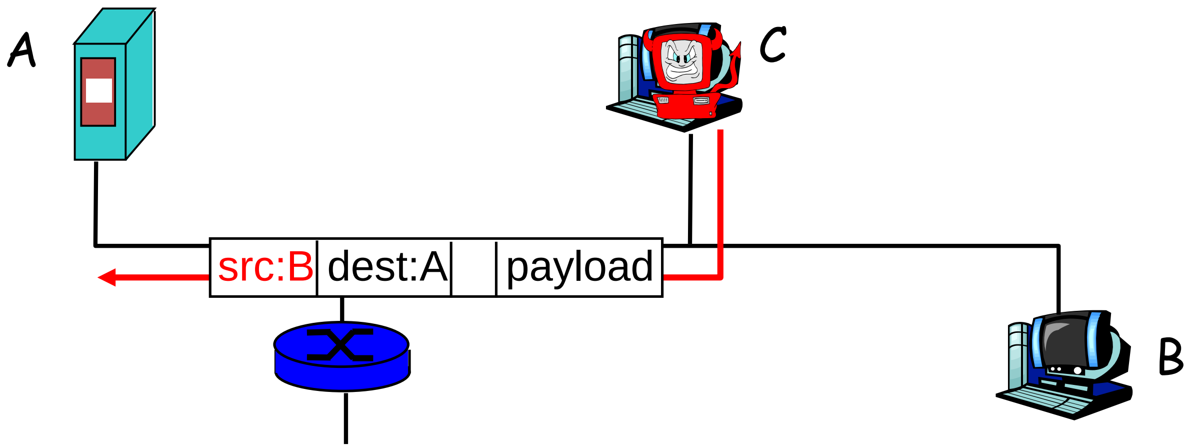
– promiscuous network interface reads/records all packets passing by



- Wireshark software used for end-of-chapter labs is a (free) packet-sniffer
- NOTE: be aware that it is inappropriate to use outside the scope of the lab

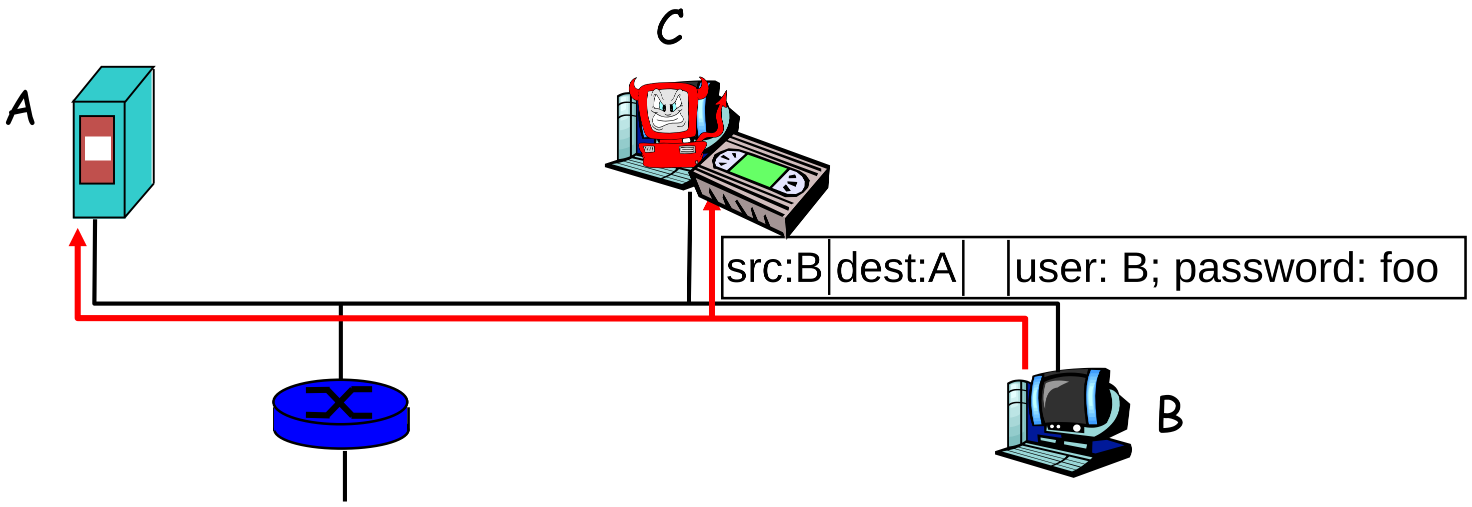
Bad guys can use false source addresses

- *IP spoofing:* send packet with false source address



Bad guys can record and playback

- *record-and-playback*: sniff sensitive info (e.g., password), and use later
  - password holder *is* that user from system point of view



Chapter 1: Summary

Covered a "ton" of material!

- what's the Internet
- what's a protocol?
- protocol layers, service models

- network edge (types of service)
- network core (ways of transfer, routing)

- performance, delays, loss

- access net, physical media
- backbones, NAPs, ISPs

- Security concerns

- (history: read more in corresponding section, interesting & fun ☺)

In order to have:

- context, overview, "feeling " of networking
- A point of reference for context in the focused discussions to come

Reading instructions (incl.next lecture)

1. Kurose Ross book

Careful	**Quick**
6/e, 7/e: 1.3, 1.4, 1.5	the rest

Extra Reading (optional)
Computer and Network Organization: An Introduction,
by Maarten van Steen and Henk Sips, Prentice Hall
(very good introductory book for non-CSE students)

Review questions

Review questions from Kurose-Ross book, chapter 1 (for basic study)

- 6/e, 7/e: R11, R12, R13, R16, 17, R18, R19, R20, R21, R22, R23, R24, R25, R28.

Extra questions, for further study: delay analysis in packet switched networks:

http://www.comm.utoronto.ca/~jorg/teaching/ece466/material/466-SimpleAnalysis.pdf