CS 3205 COMPUTER NETWORKS

JAN-MAY 2020

LECTURE 2,3: 14TH 21ST JAN 2020

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

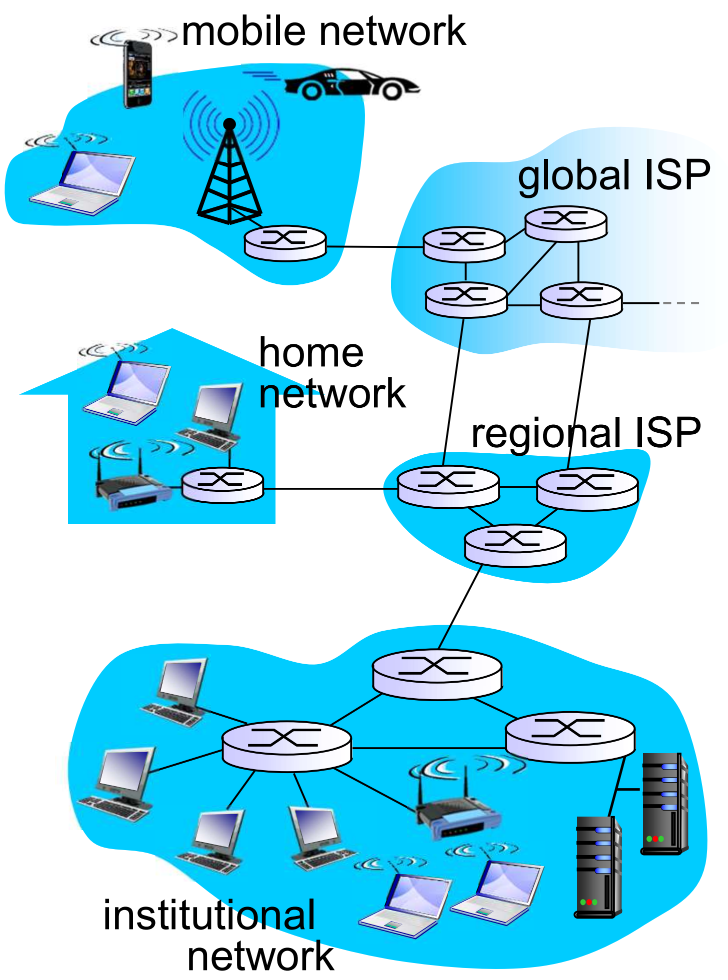
1.5 protocol layers, service models

1.6 networks under attack: security

1.7 history

A closer look at network structure:

- *network edge:*
  - hosts: clients and servers
  - servers often in data centers
- *access networks, physical media:* wired, wireless communication links
- *network core:*
  - interconnected routers
  - network of networks



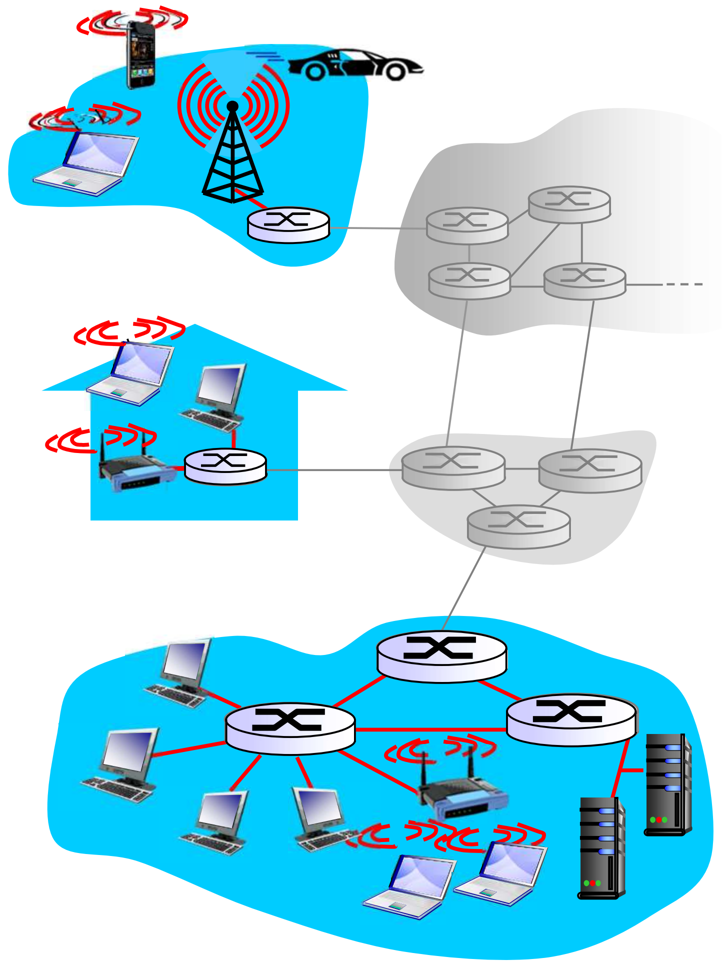
Access networks and physical media

Q: How to connect end systems to edge router?

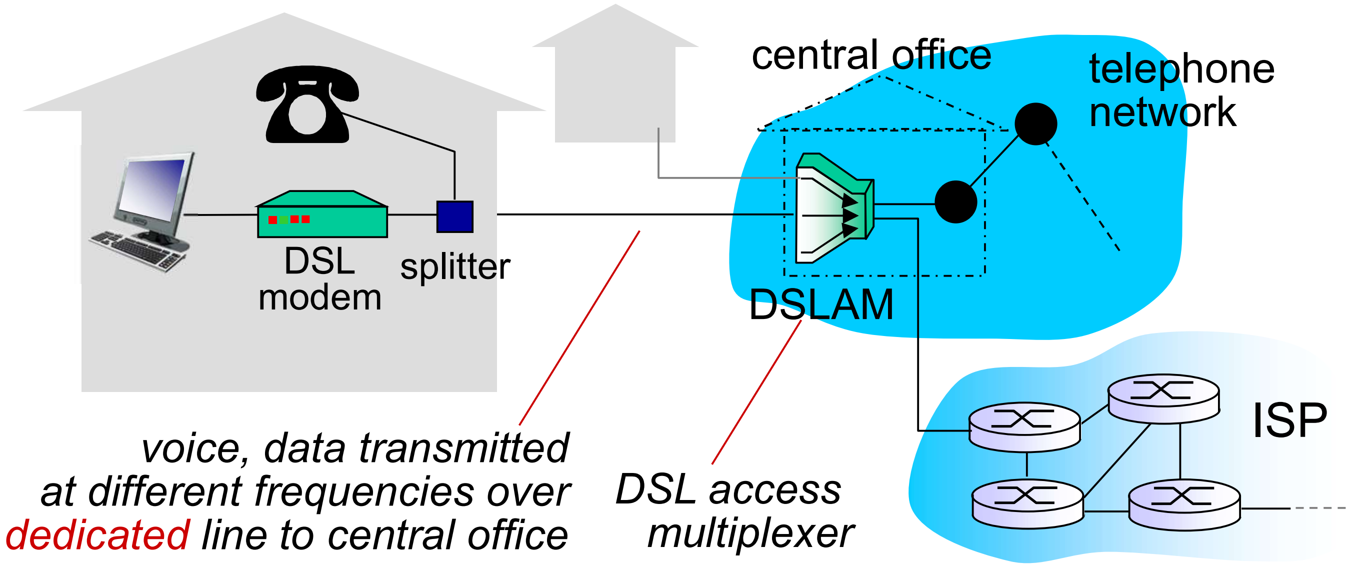
- residential access nets
- institutional access networks (school, company)
- mobile access networks

keep in mind:

- bandwidth (bits per second) of access network?
- shared or dedicated?



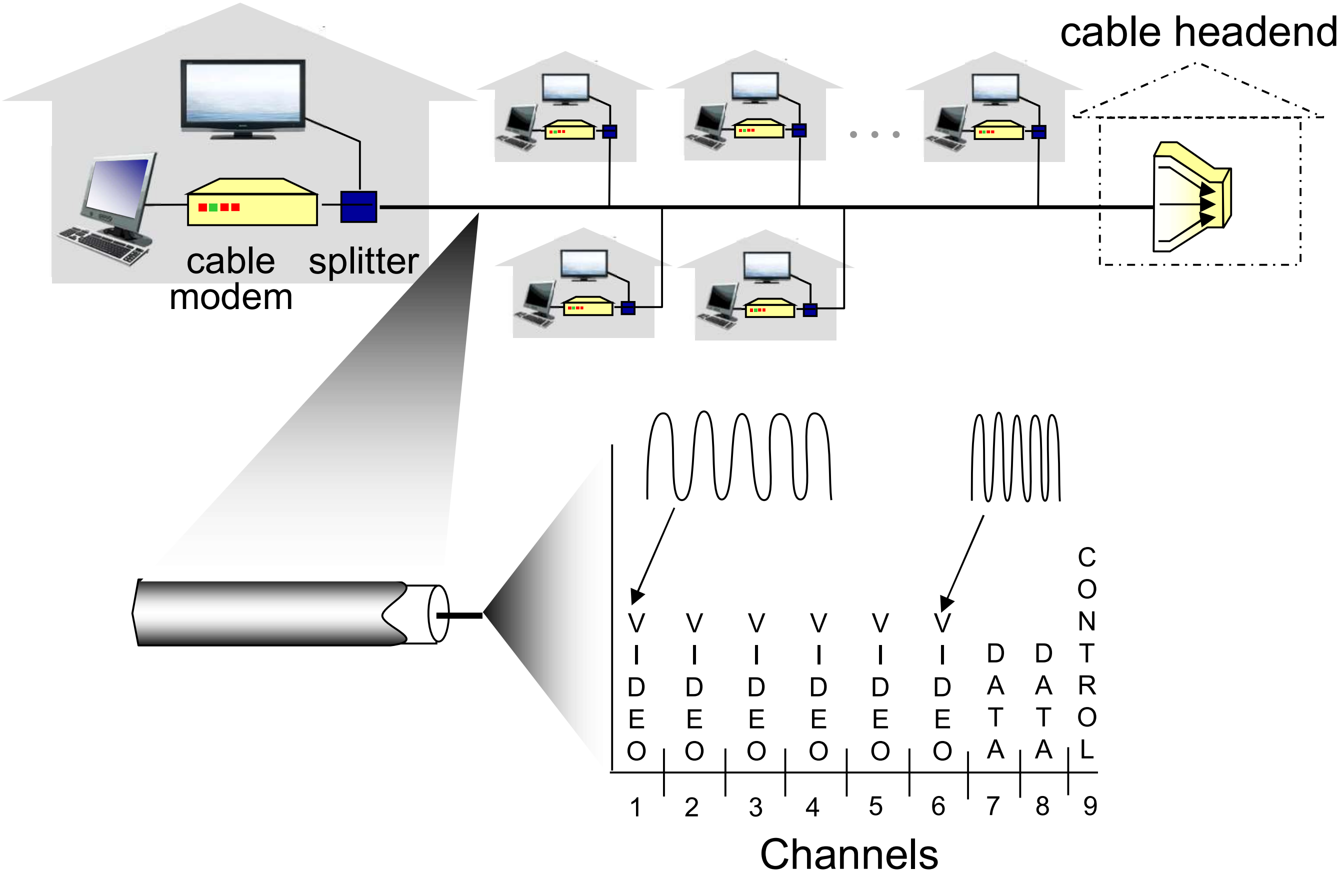
Access net: digital subscriber line (DSL)



- use *existing* telephone line to central office DSLAM
  - data over DSL phone line goes to Internet
  - voice over DSL phone line goes to telephone net
- < 2.5 Mbps upstream transmission rate (typically < 1 Mbps)
- < 24 Mbps downstream transmission rate (typically < 10 Mbps)

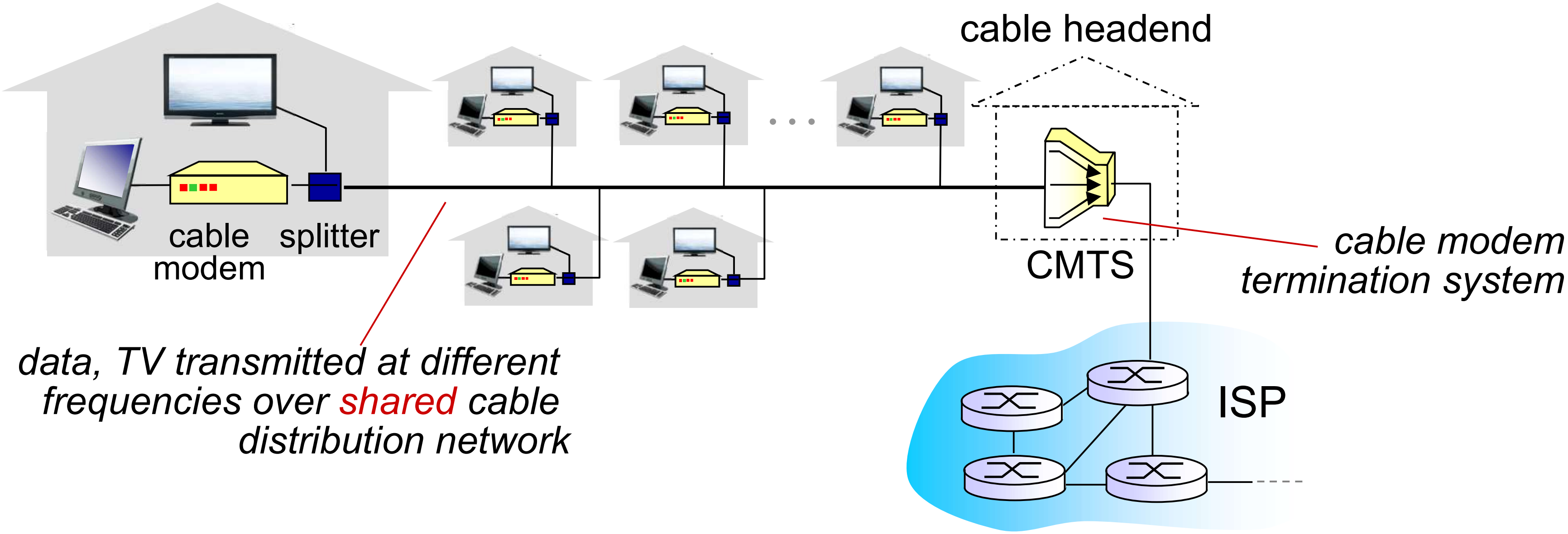
DSLAM- Digital Subscriber Line Access Multiplexer
BRAS – Broadband Remote Access Server

Access net: cable network



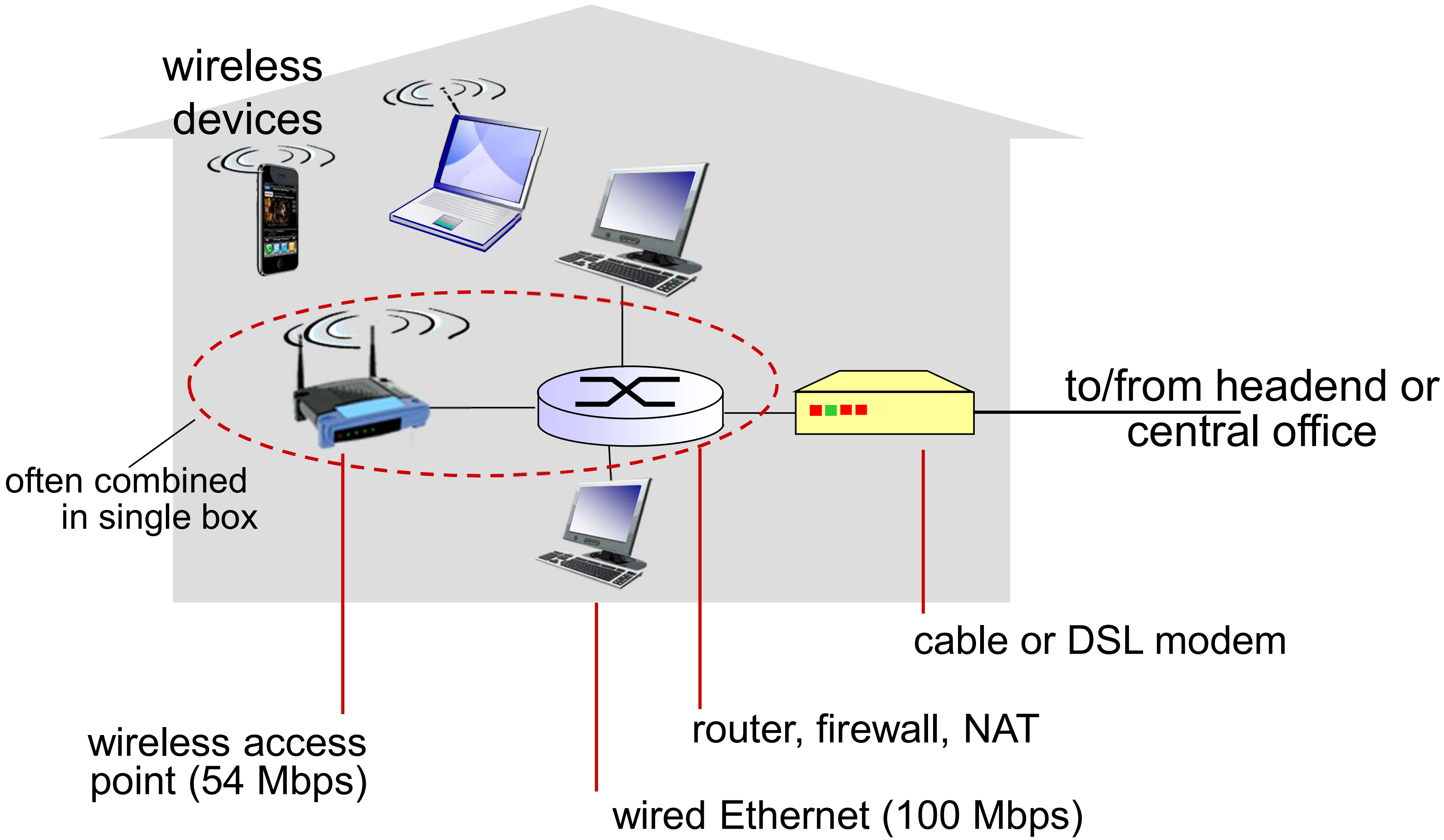
frequency division multiplexing: different channels transmitted in different frequency bands

Access net: cable network



- HFC: hybrid fiber coax
  - asymmetric: up to 30Mbps downstream transmission rate, 2 Mbps upstream transmission rate
- network of cable, fiber attaches homes to ISP router
  - homes *share access network* to cable headend
  - unlike DSL, which has dedicated access to central office
- Data Over Cable Service Interface Specification (DOCSIS) is a set of standards for transferring data by CATV and cable modems.

Access net: home network

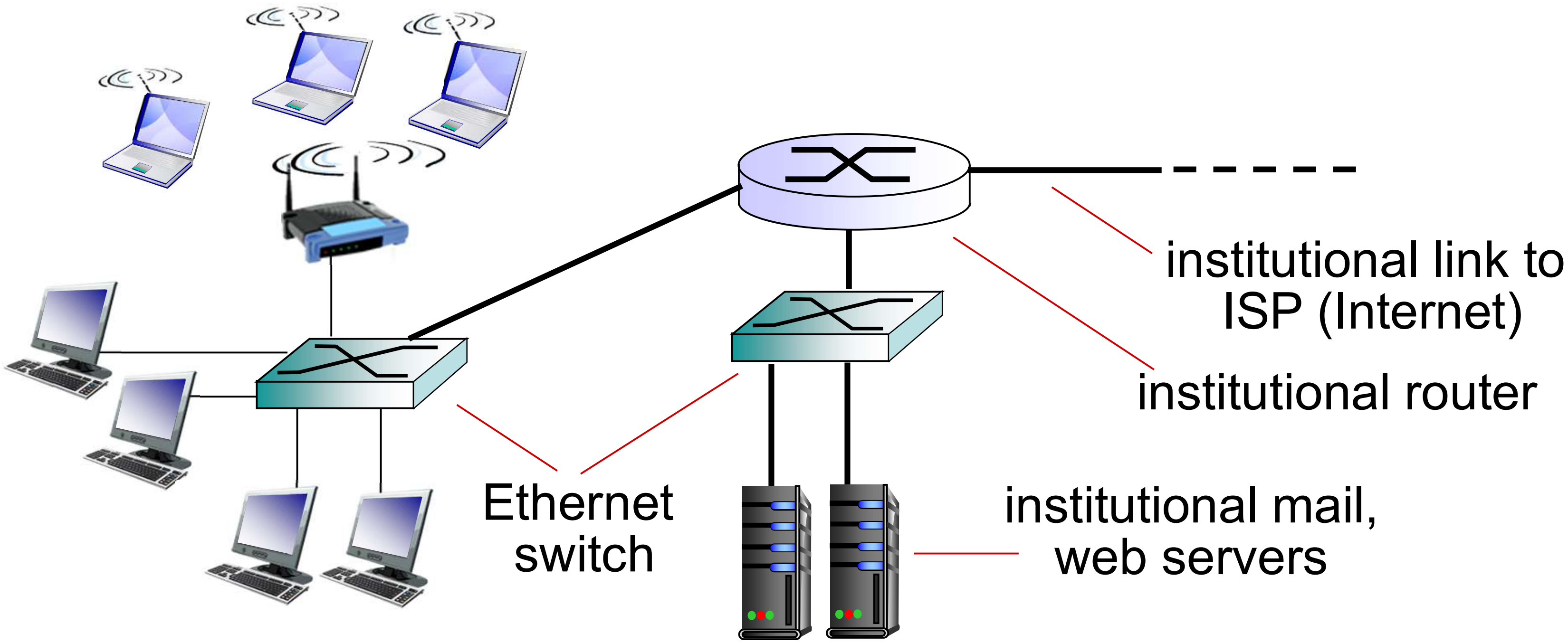


Access net: home network – WLAN Standards

IEEE Standard	802.11a	802.11b	802.11g	802.11n	802.11ac	802.11ax
Year Released	1999	1999	2003	2009	2014	2019
Frequency	5Ghz	2.4GHz	2.4GHz	2.4Ghz & 5GHz	2.4Ghz & 5GHz	2.4Ghz & 5GHz
Maximum Data Rate	54Mbps	11Mbps	54Mbps	600Mbps	1.3Gbps	10-12Gbps

http://www.ieee802.org/11/ - Web site for 802.11 related information

Enterprise access networks (Ethernet)



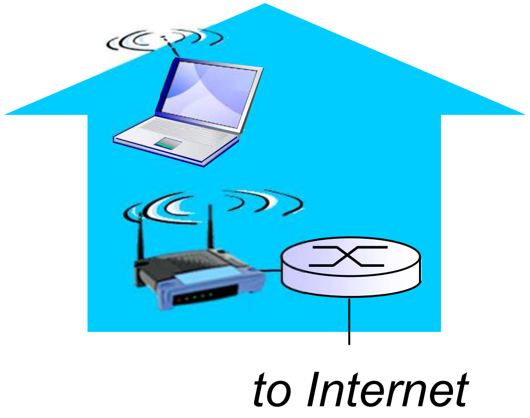
- typically used in companies, universities, etc
- 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates
- today, end systems typically connect into Ethernet switch

Wireless access networks

- shared *wireless* access network connects end system to router
  - via base station aka "access point"

wireless LANs:

- within building (100 ft)
- 802.11b/g (WiFi): 11, 54 Mbps transmission rate



wide-area wireless access

- provided by telco (cellular) operator, 10's km
- between 1 and 10 Mbps
- 3G, 4G: LTE

Wireless - Wide Area Networks

Table 1.7 Performance Evolution of 3GPP Standards

Standard	3GPP Release	Peak Downlink Speed	Peak Uplink Speed	Latency
GPRS	Release 97/99	40–80kbps	40–80kbps	600–700ms
EDGE	Release 4	237–474kbps	237kbps	350–450ms
UMTS (WCDMA)	Release 4	384kbps	384kbps	<200ms
HSDPA/UMTS	Release 5	1800kbps	384kbps	<120ms
HSPA	Release 6	3600–7200kbps	2000kbps	<100ms
HSPA+	Release 7 and 8	28–42Mbps	11.5Mbps	<80ms
LTE	Release 8	173–326Mbps	86Mbps	<30ms

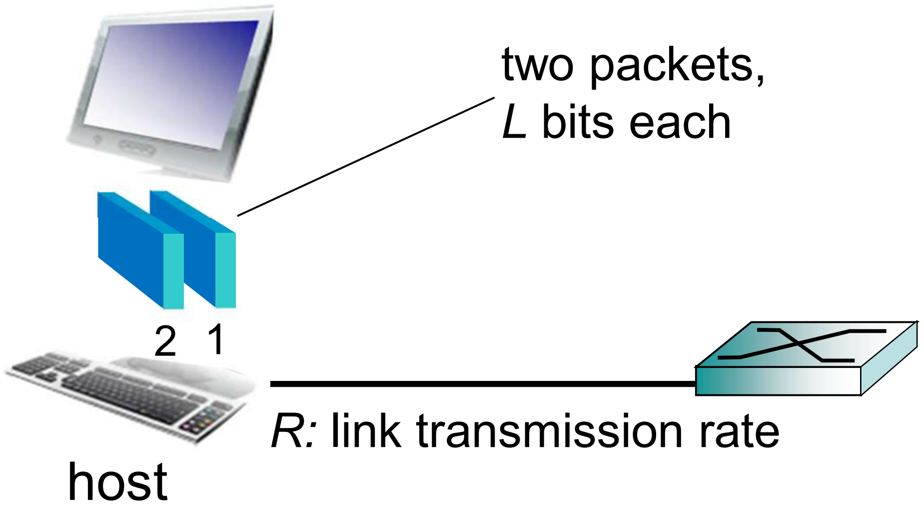
	LTE	LTE-Advanced	LTE-Adv. Pro	5G
	2008........................	..2012........................	..2015........................	..2018
3GPP Release	8 & 9	10 to 12	13 & 14	15
Theoretical maximum (DL) speed	**300Mbps**	**>1Gbps**	**>3Gbps**	**>10Gbps**
Latency	**≈50ms**	**10ms**	**2ms**	**1ms**
Channel bandwidth	Up to 20MHz	Up to 20MHz	Up to 20MHz	Up to 500MHz
Carriers	1	5	32	16 (LTE+NR)
Antennas(MIMO)	4	8	32	64 to 256

Basic characteristics of mobile networks

Host: sends *packets* of data

host sending function:

- takes application message
- breaks into smaller chunks, known as *packets*, of length *L* bits
- transmits packet into access network at *transmission rate R*
  - link transmission rate, aka link *capacity, aka link bandwidth*



$$\text{packet transmission delay} = \text{time needed to transmit } L\text{-bit packet into link} = \frac{L \text{ (bits)}}{R \text{ (bits/sec)}}$$

Physical media

- bit: propagates between transmitter/receiver pairs
- physical link: what lies between transmitter & receiver
- guided media:
  - signals propagate in solid media: copper, fiber, coax
- unguided media:
  - signals propagate freely, e.g., radio

twisted pair (TP)

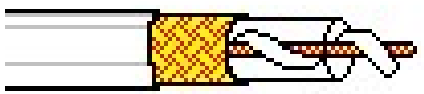
- two insulated copper wires
  - Category 5: 100 Mbps, 1 Gpbs Ethernet
  - Category 6: 10Gbps

If you are interested to know in detail the workings of Ethernet - visit
https://www.hardwaresecrets.com/how-gigabit-ethernet-works/
https://en.wikipedia.org/wiki/Ethernet_over_twisted_pair

Physical media: coax, fiber

coaxial cable:

- two concentric copper conductors
- bidirectional
- broadband:
  - multiple channels on cable
  - HFC (Hybrid Fiber Coxial) (Combining optical and coaxial)



fiber optic cable:

- glass fiber carrying light pulses, each pulse a bit
- high-speed operation:
  - high-speed point-to-point transmission (e.g., 10's-100's Gpbs transmission rate)
- low error rate:
  - repeaters spaced far apart
  - immune to electromagnetic noise

For more info: https://www.ppc-online.com/blog/what-is-coaxial-cable-and-how-is-it-used

Physical media: radio

- signal carried in electromagnetic spectrum
- no physical "wire"
- bidirectional
- propagation environment effects:
  - reflection
  - obstruction by objects
  - interference

radio link types:

- terrestrial microwave
  - e.g. up to 45 Mbps channels
- LAN (e.g., WiFi)
  - 11Mbps, 54 Mbps
- wide-area (e.g., cellular)
  - 3G/4G/5G cellular: ~ few Mbps/ Gbps
- satellite
  - Kbps to 45Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus low altitude

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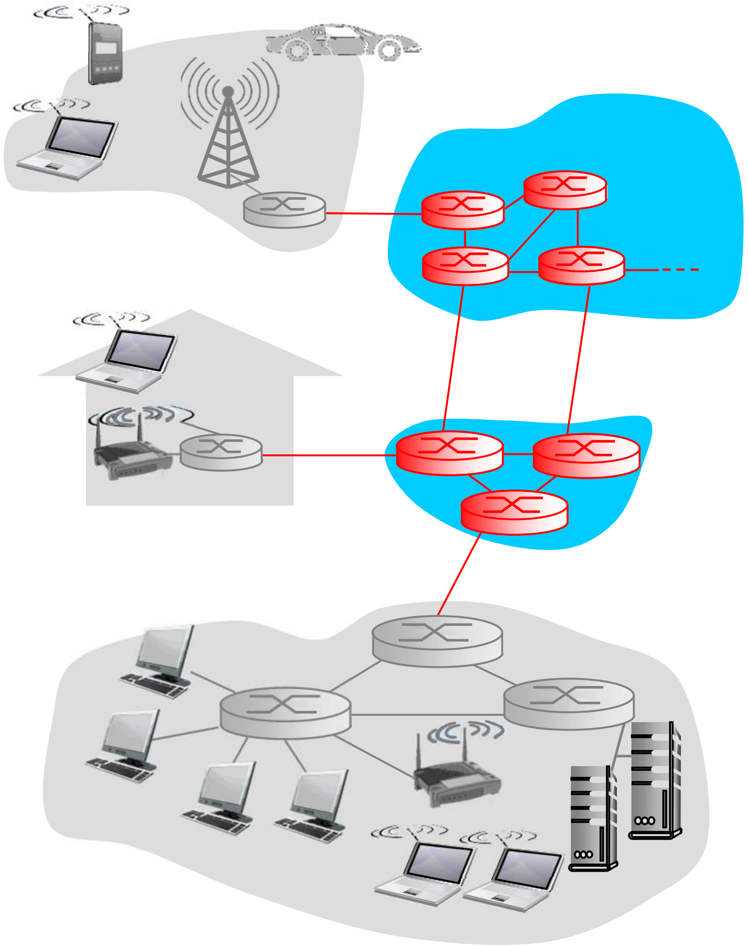
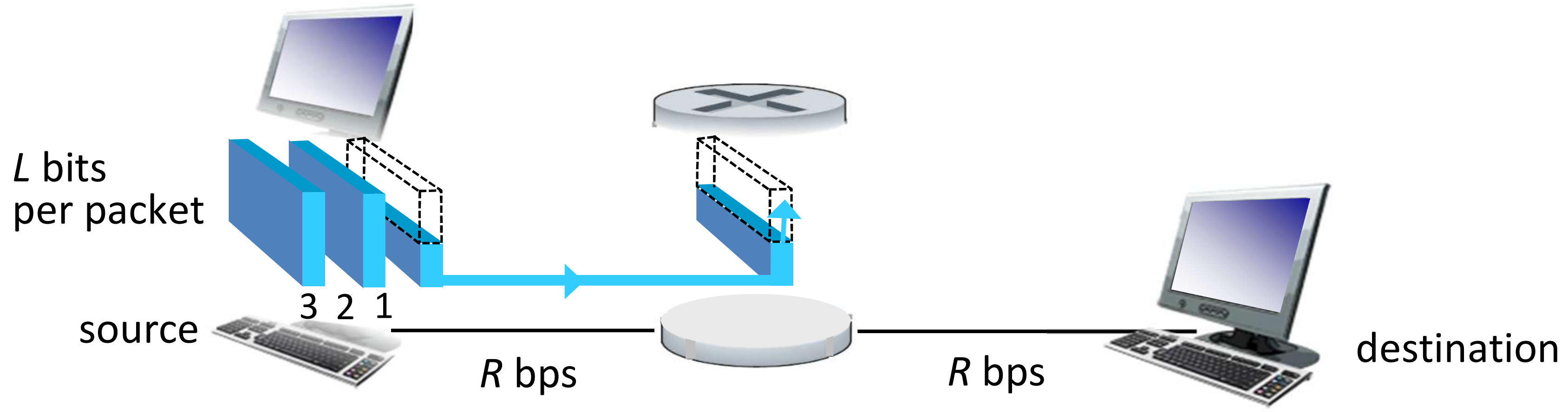
The network core

- 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



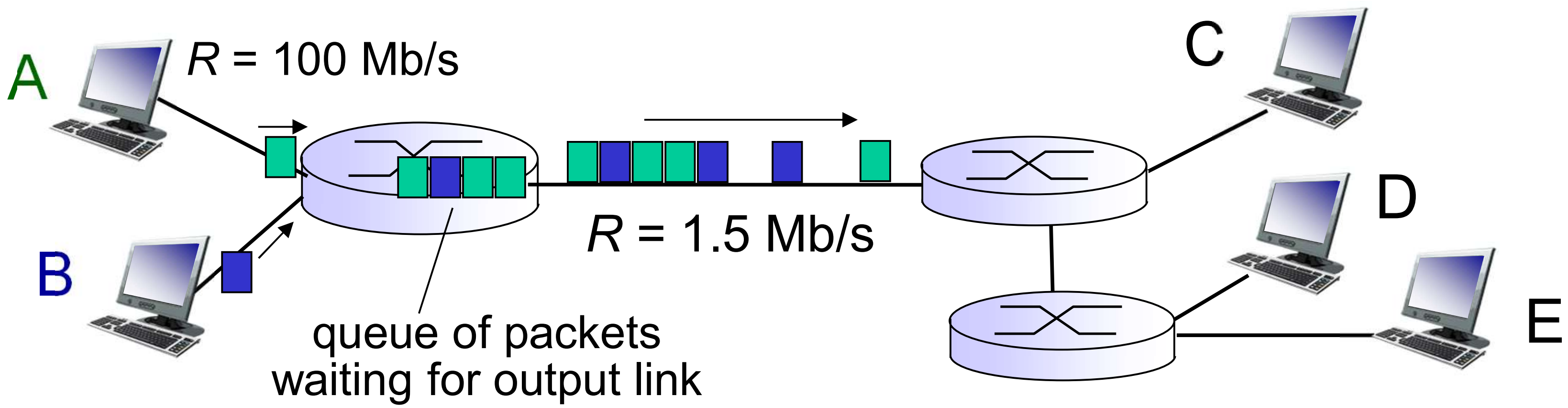
- takes L/R seconds to transmit (push out) L-bit packet into link at R bps
- *store and forward:* entire packet must arrive at router before it can be transmitted on next link
- end-end delay = $2L/R$ (assuming zero propagation delay)

more on delay shortly …

one-hop numerical example:

- L = 7.5 Mbits
- R = 1.5 Mbps
- one-hop transmission delay = 5 sec

Packet Switching: queueing delay, loss



queuing and loss:

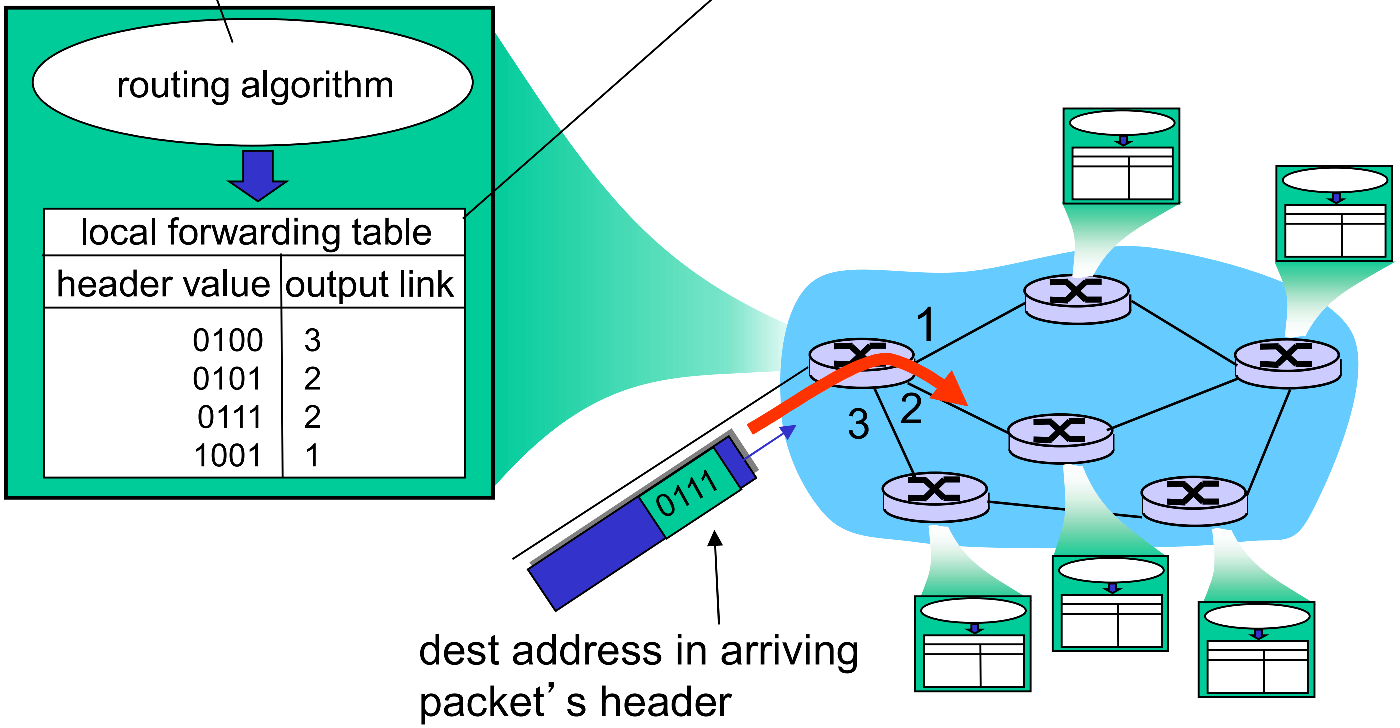
- If arrival rate (in bits) to link exceeds transmission rate of link for a period of time:
  - packets will queue, wait to be transmitted on link
  - packets can be dropped (lost) if memory (buffer) fills up

Two key network-core functions

routing: determines source-destination route taken by packets

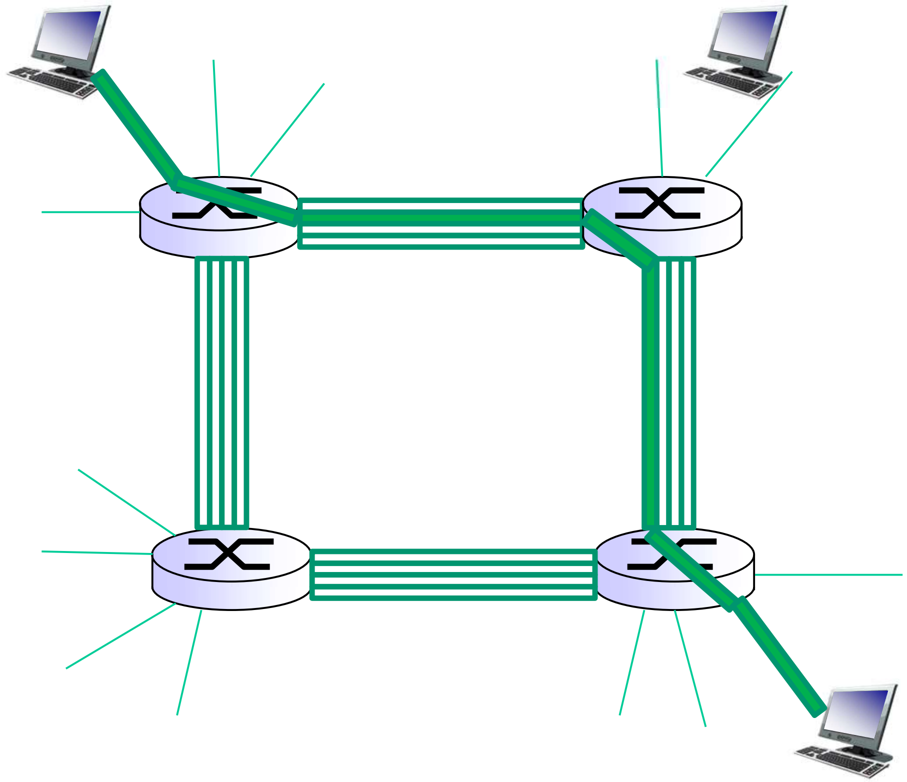
- *routing algorithms*

forwarding: move packets from router's input to appropriate router output



Alternative core: circuit switching

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

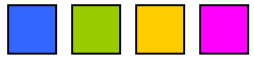


- In diagram, each link has four circuits.
  - call gets 2nd circuit in top link and 1st circuit in right link.
- dedicated resources: no sharing
  - circuit-like (guaranteed) performance
- circuit segment idle if not used by call *(no sharing)*
- Commonly used in traditional telephone networks

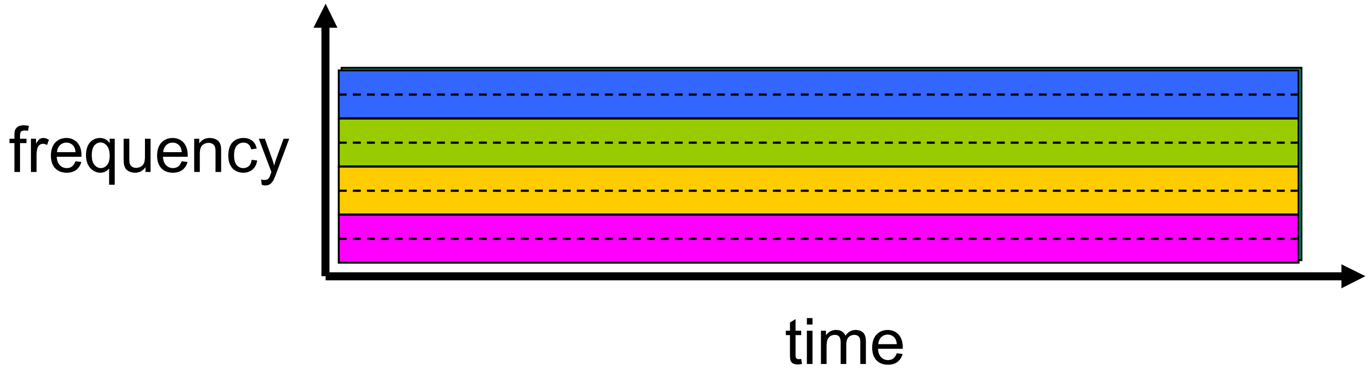
Circuit switching: FDM versus TDM

Example:

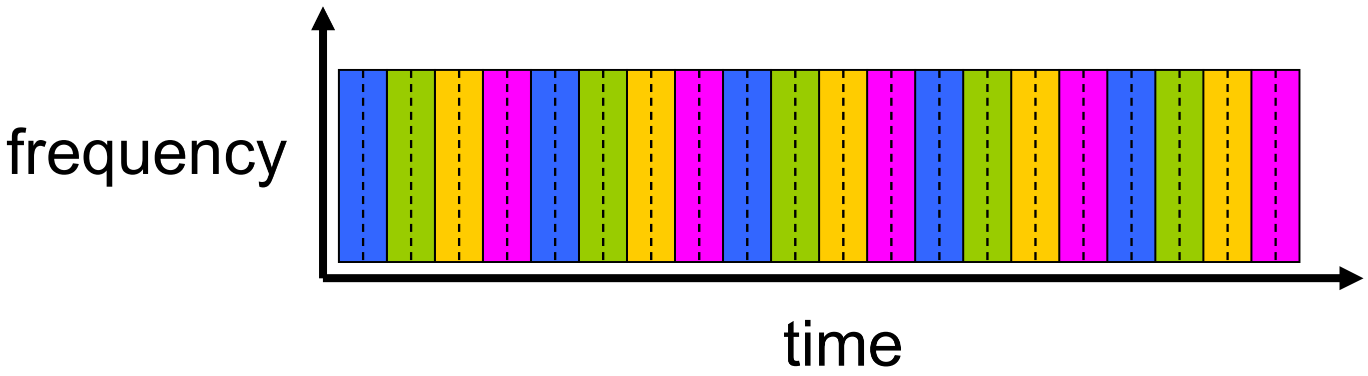
4 users



FDM



TDM

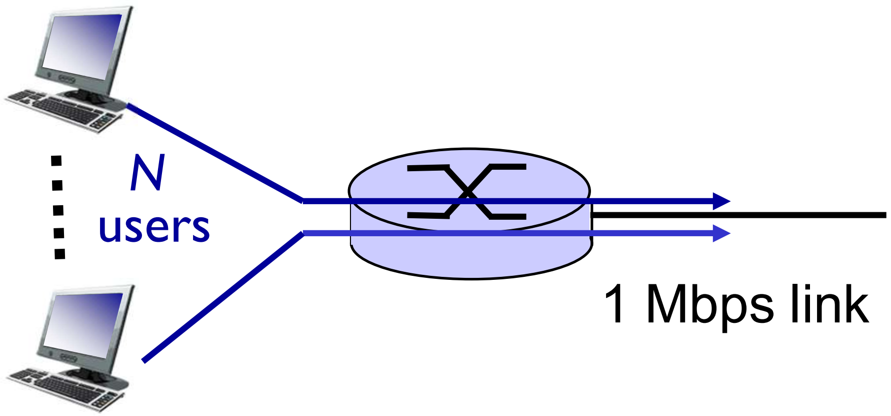


Packet switching versus circuit switching

packet switching allows 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 ?

Packet switching versus circuit switching

A Numerical example

Suppose users share a 3 Mbps link. Also suppose each user requires 150 kbps when transmitting, but each user transmits only 10 percent of the time. (See the discussion of packet switching versus circuit switching in Section 1.3.)

a. When circuit switching is used, how many users can be supported?

b. For the remainder of this problem, suppose packet switching is used. Find the probability that a given user is transmitting.

c. Suppose there are 120 users. Find the probability that at any given time, exactly n users are transmitting simultaneously. (*Hint*: Use the binomial distribution.)

d. Find the probability that there are 21 or more users transmitting simultaneously.

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 (chapter 7)

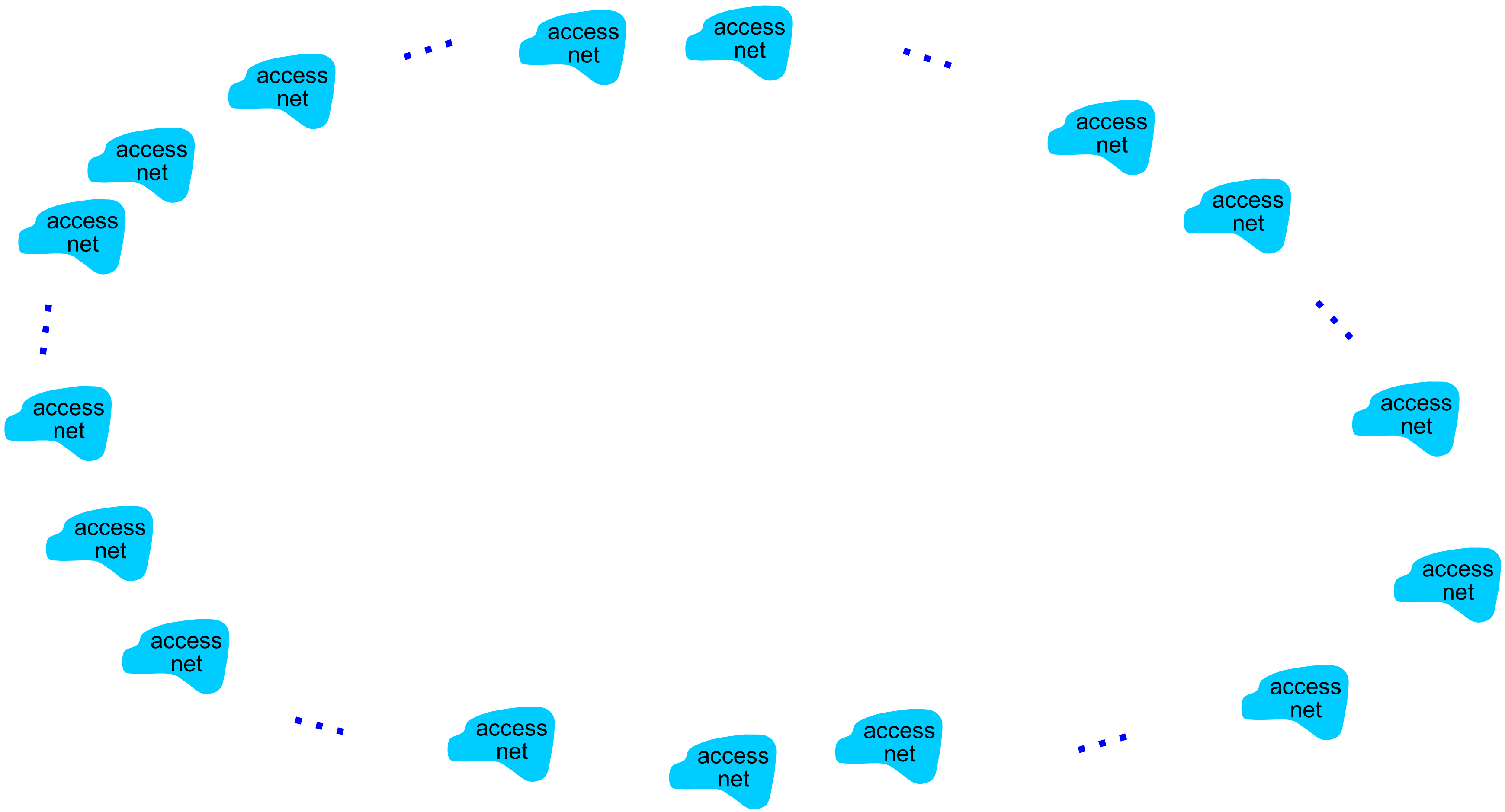
Q: human analogies of reserved resources (circuit switching) versus on-demand allocation (packet-switching)?

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

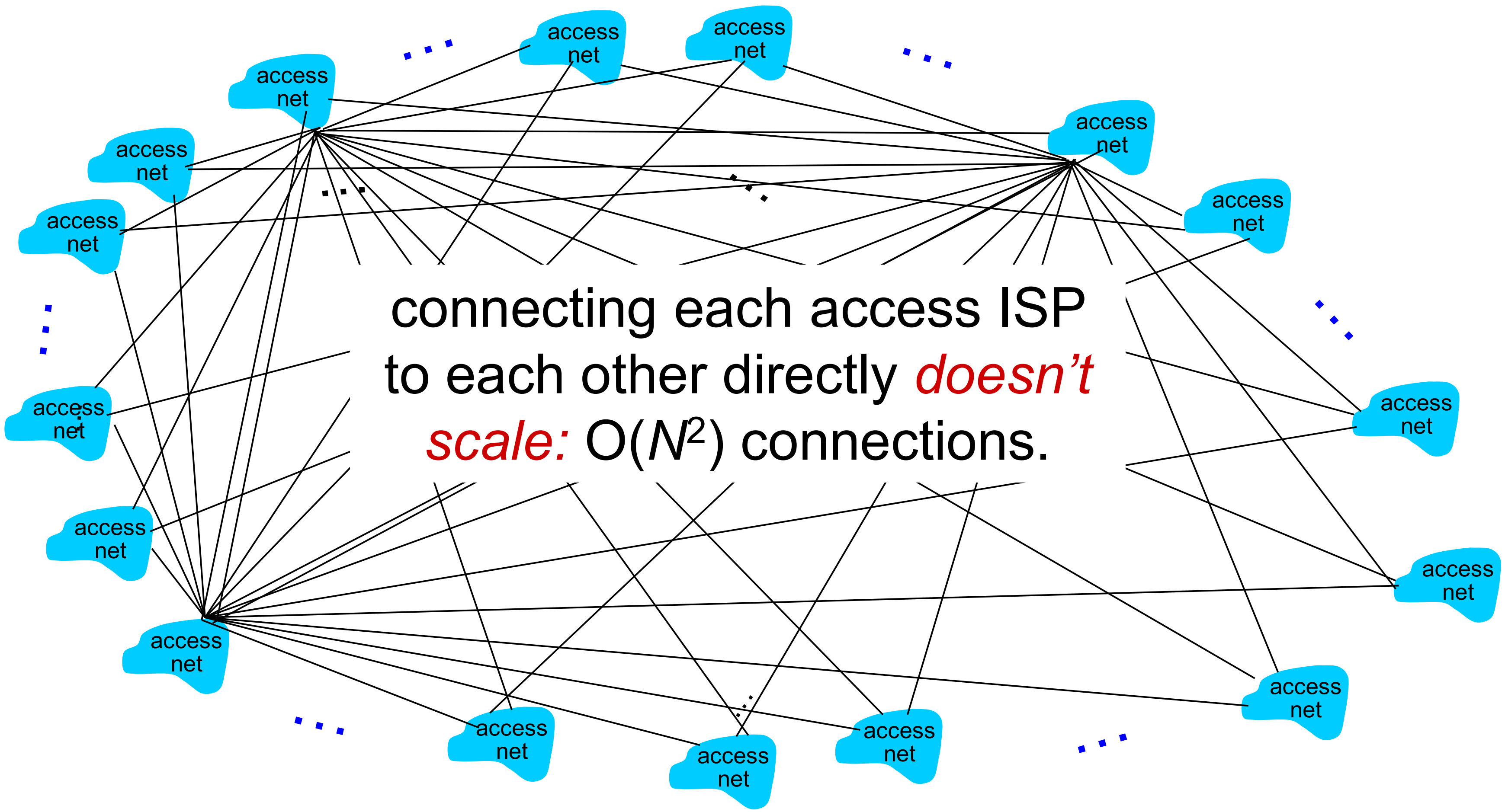
Internet structure: network of networks

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



Internet structure: network of networks

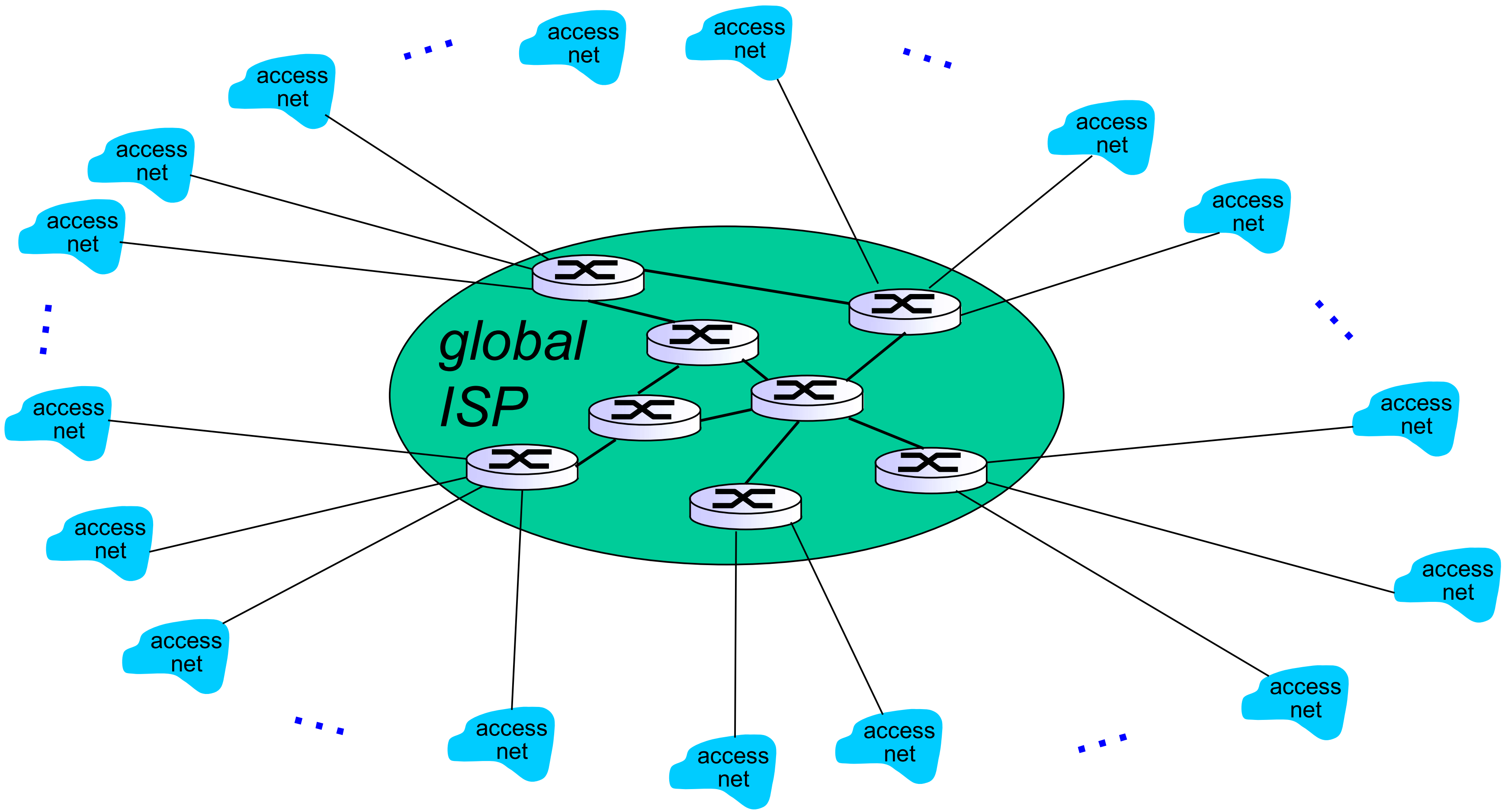
Option: connect each access ISP to every other access ISP?



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

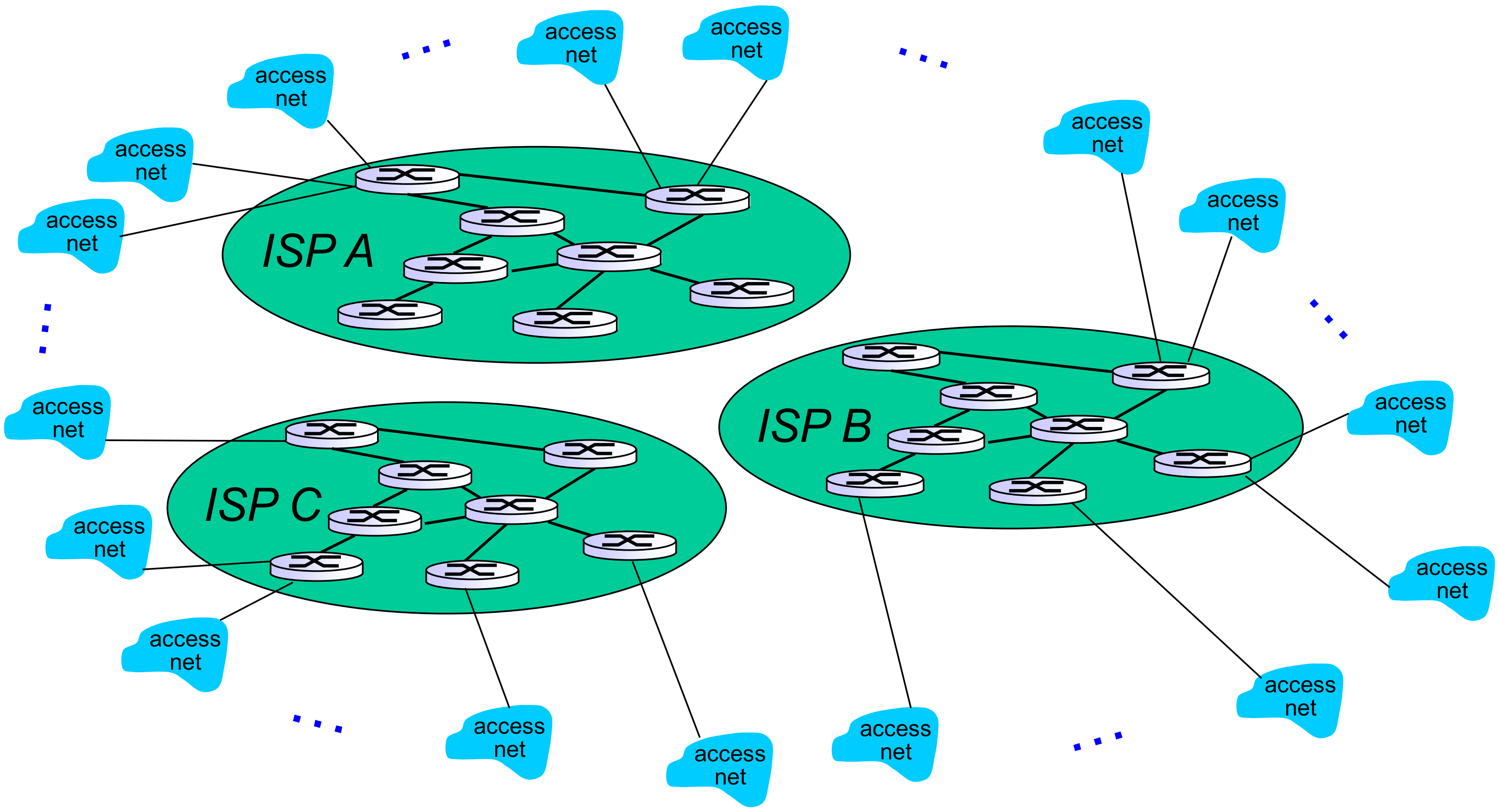
Internet structure: network of networks

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



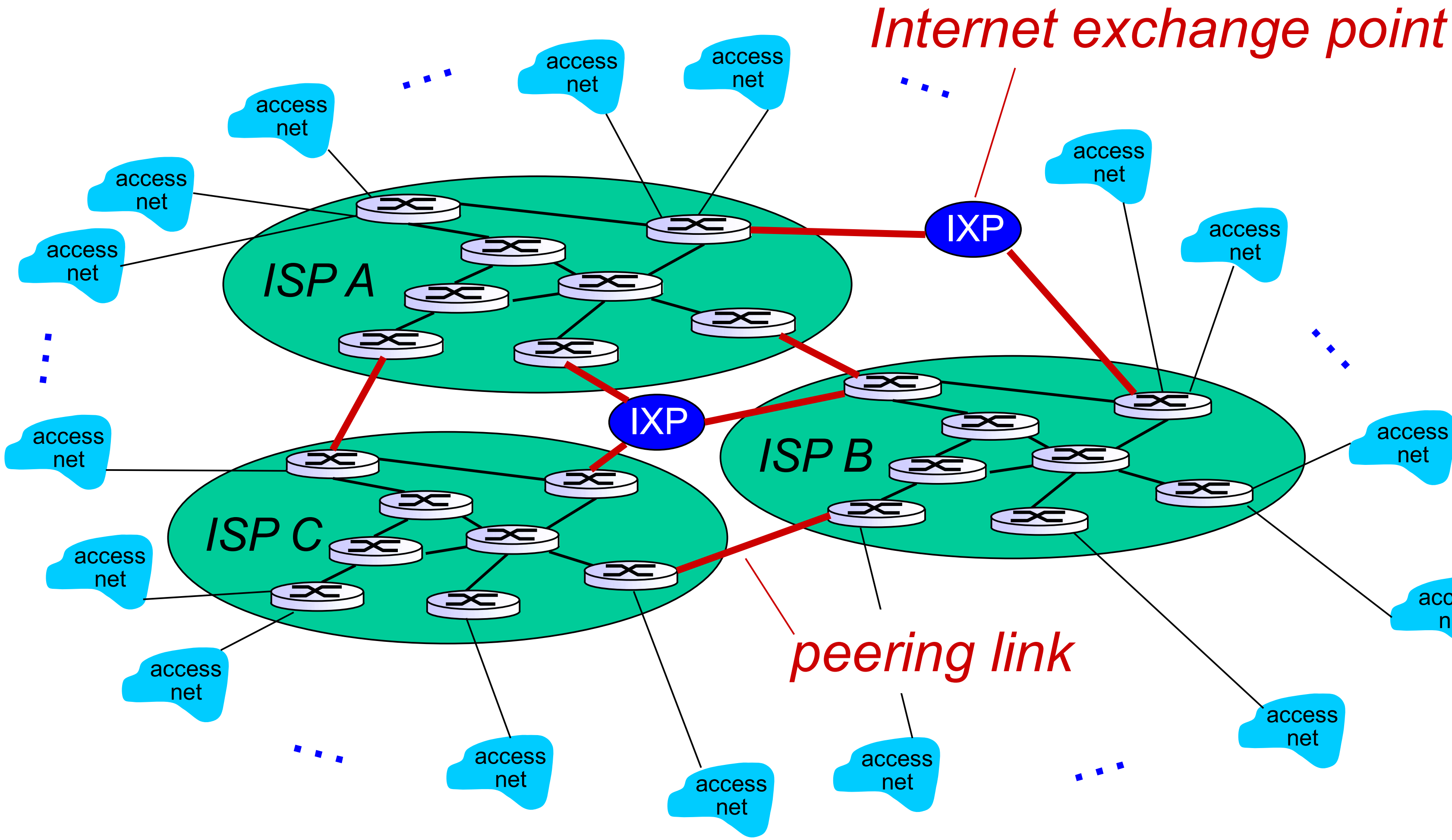
Internet structure: network of networks

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



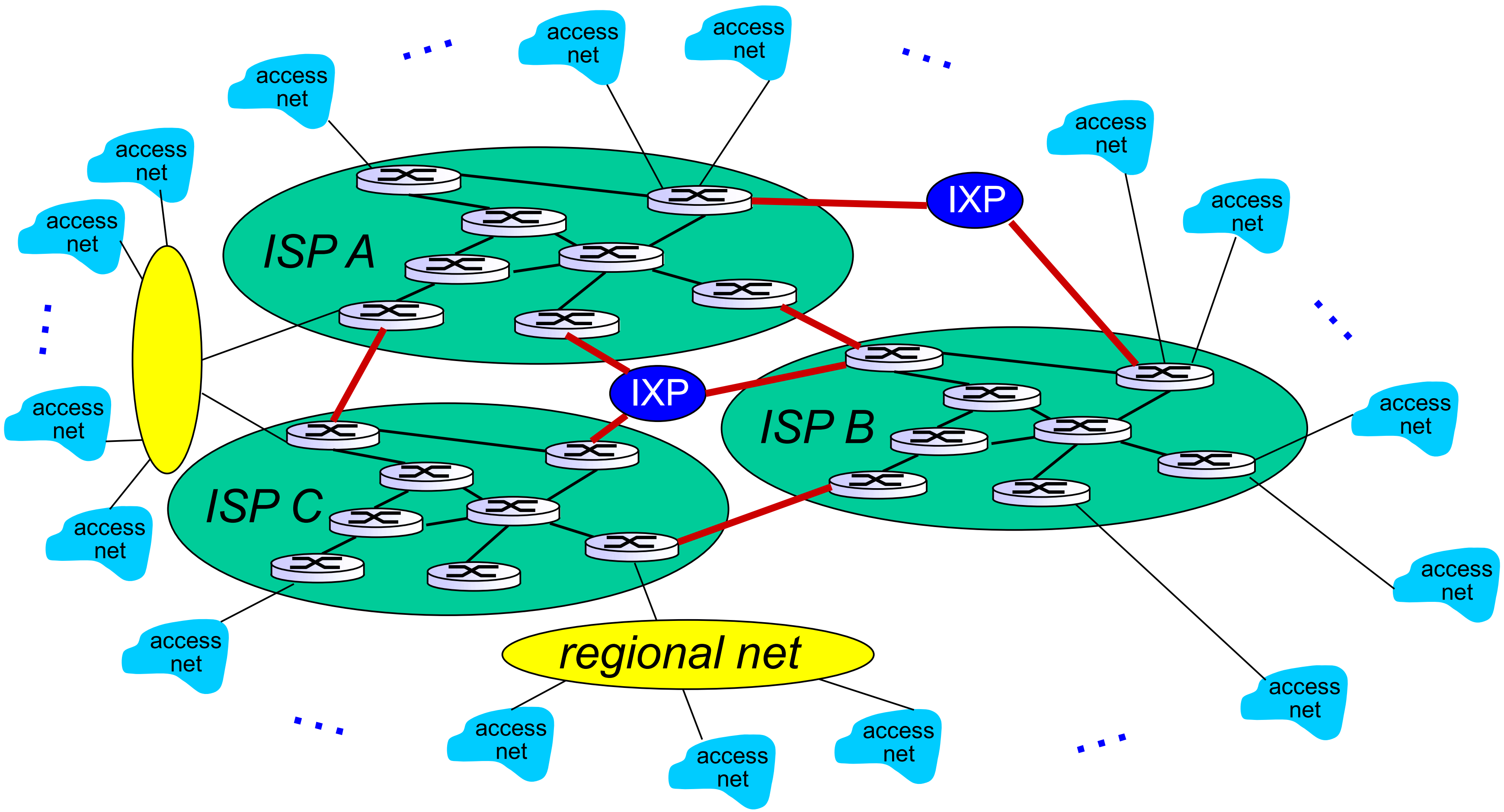
Internet structure: network of networks

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



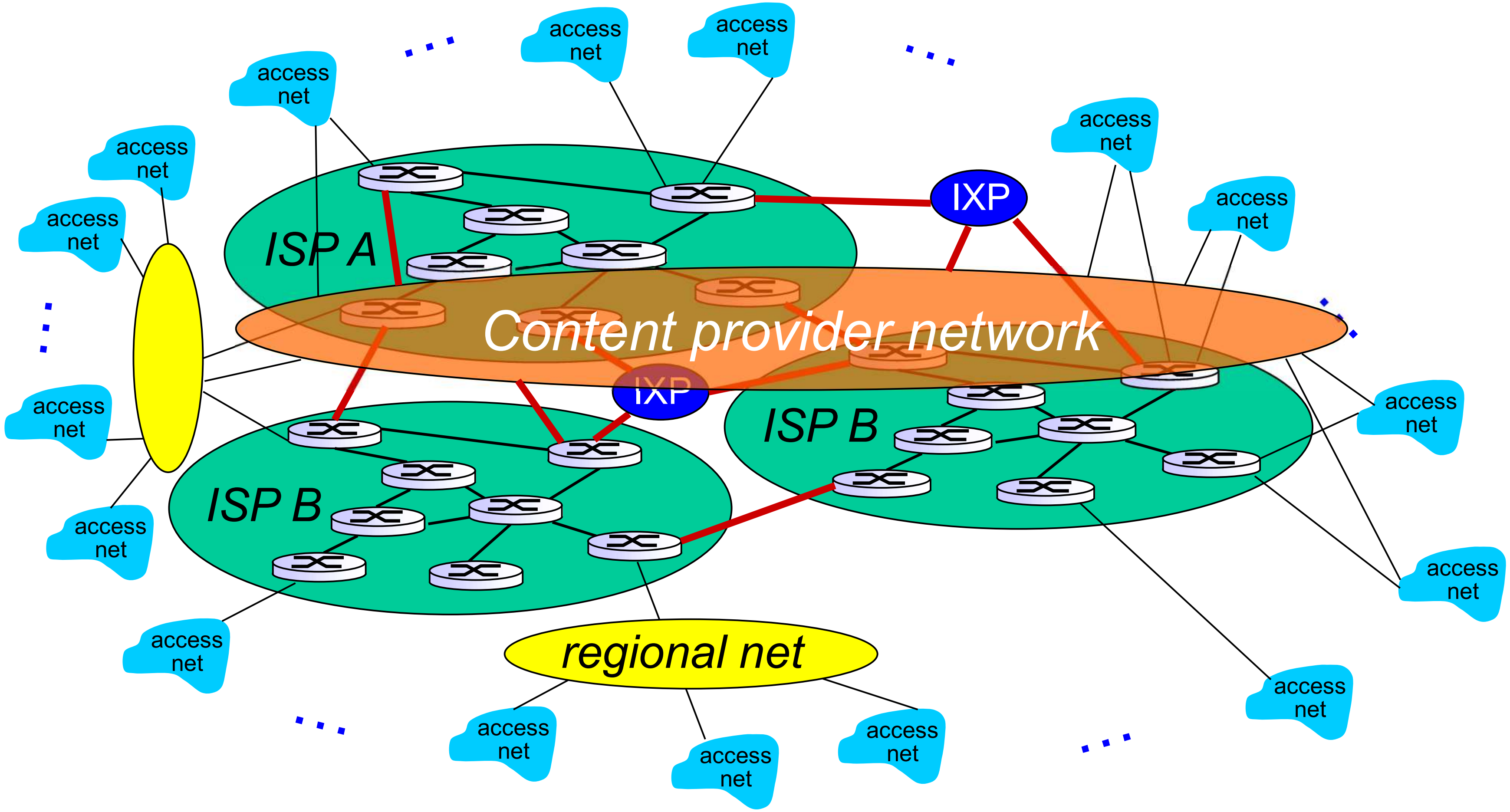
Internet structure: network of networks

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

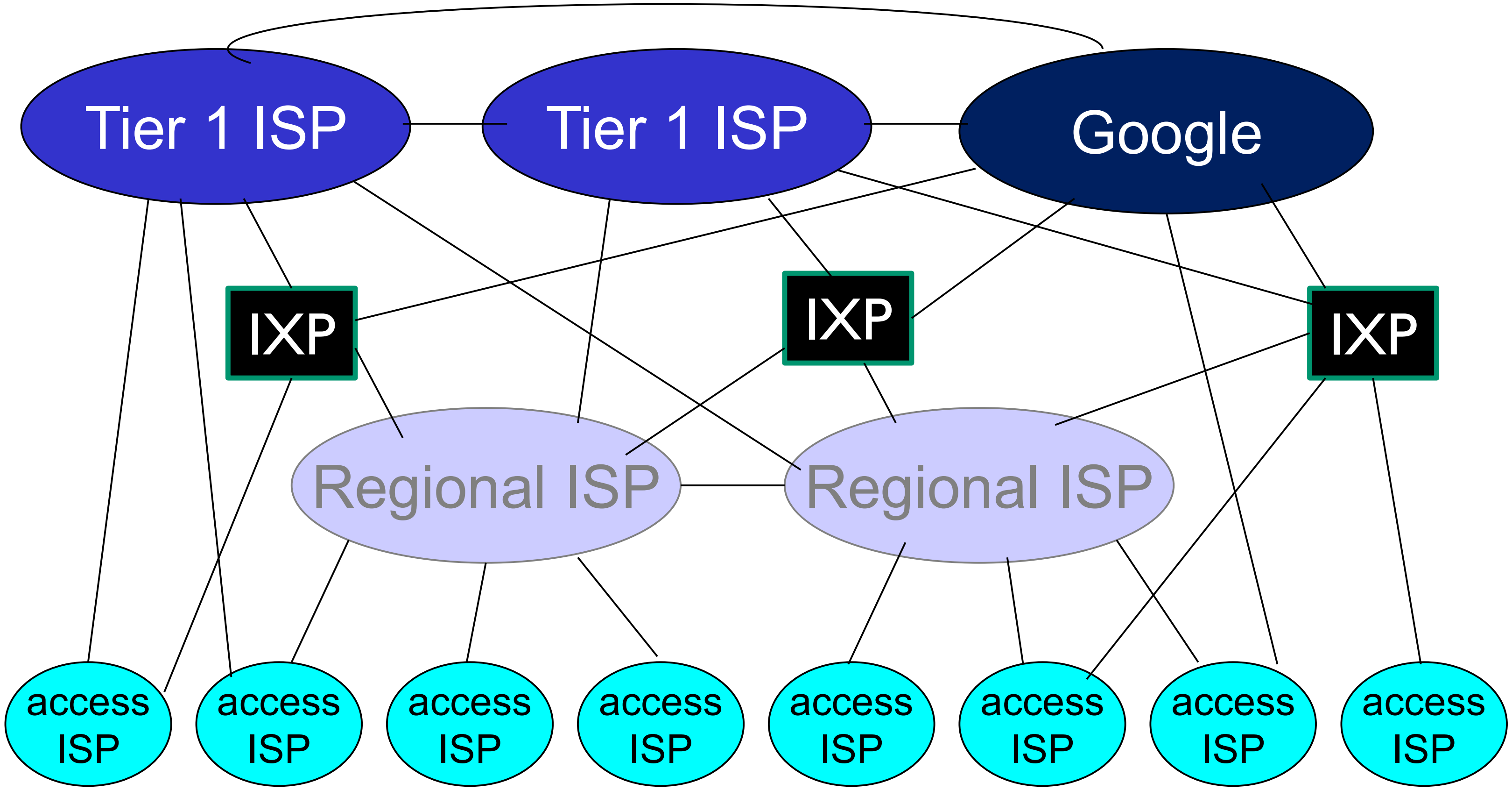


Internet structure: network of networks

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

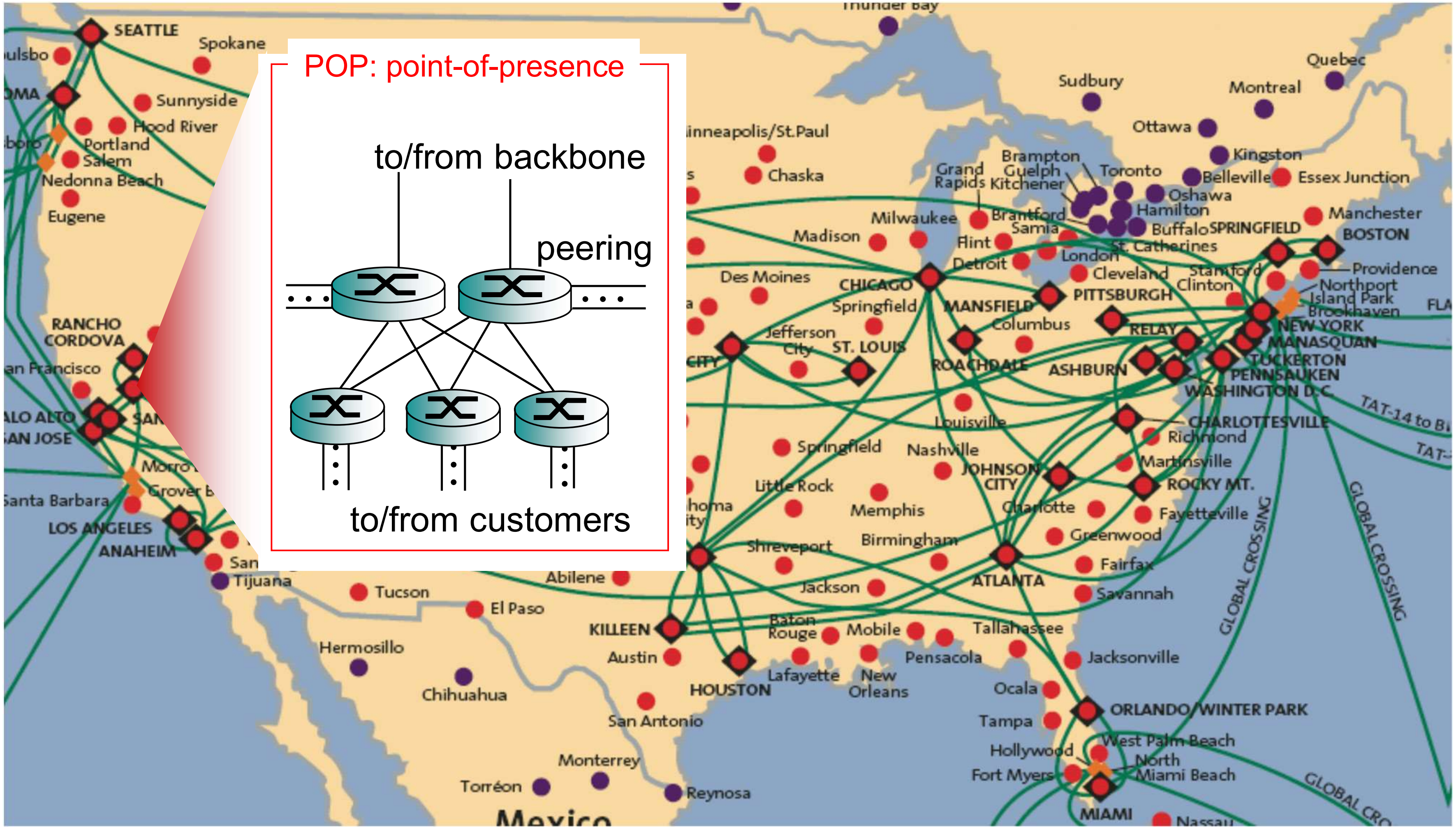


Internet structure: network of networks

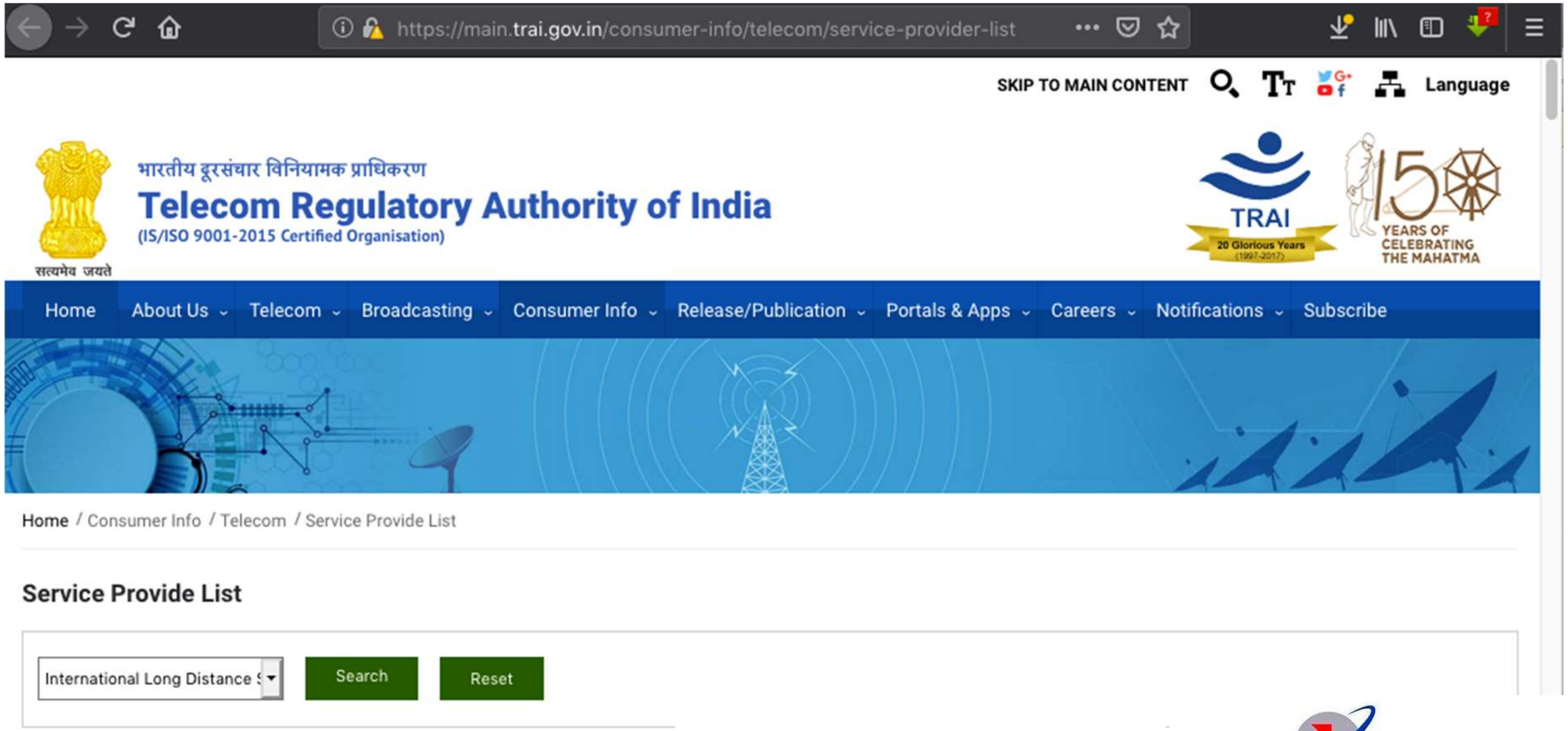


- at center: small # of well-connected large networks
  - "tier-1" commercial ISPs (e.g., Level 3, Sprint, AT&T, NTT), national & international coverage
  - content provider network (e.g, Google): private network that connects it data centers to Internet, often bypassing tier-1, regional ISPs

Tier-1 ISP: e.g., Sprint



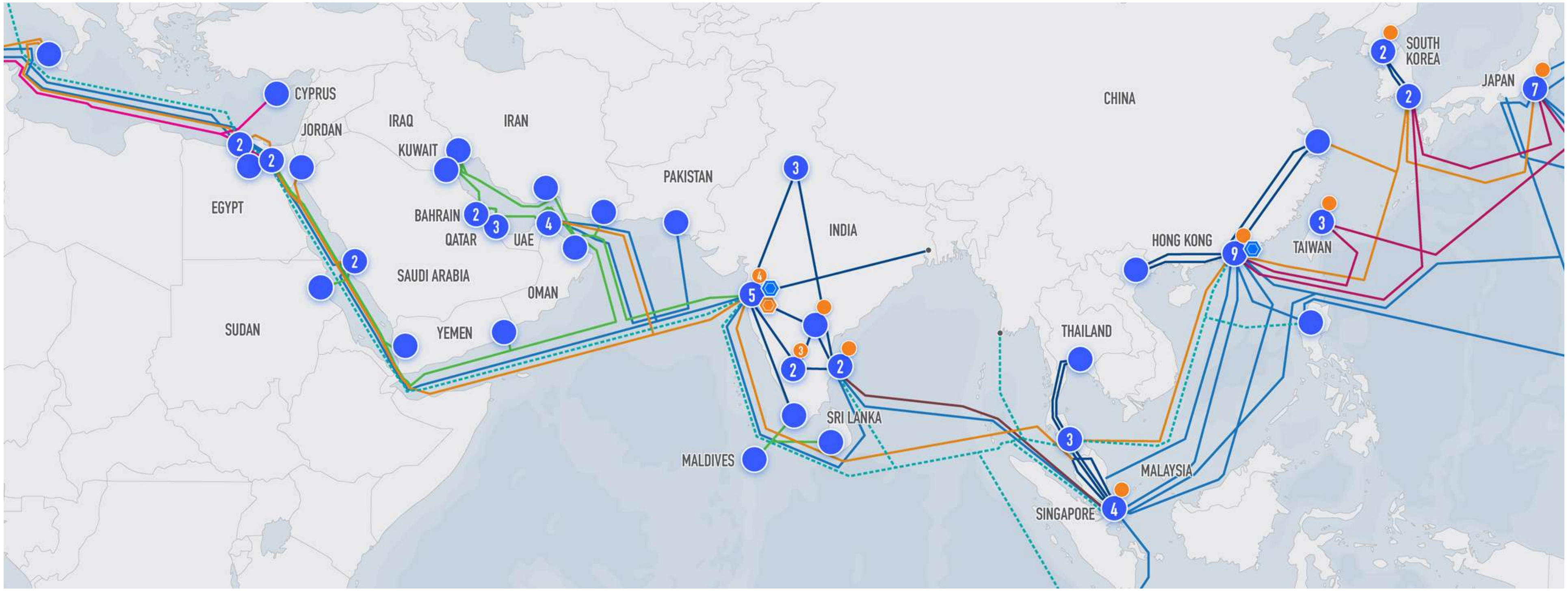
The Indian Scenario



jio airtel vodafone BSNL 4G Connecting India

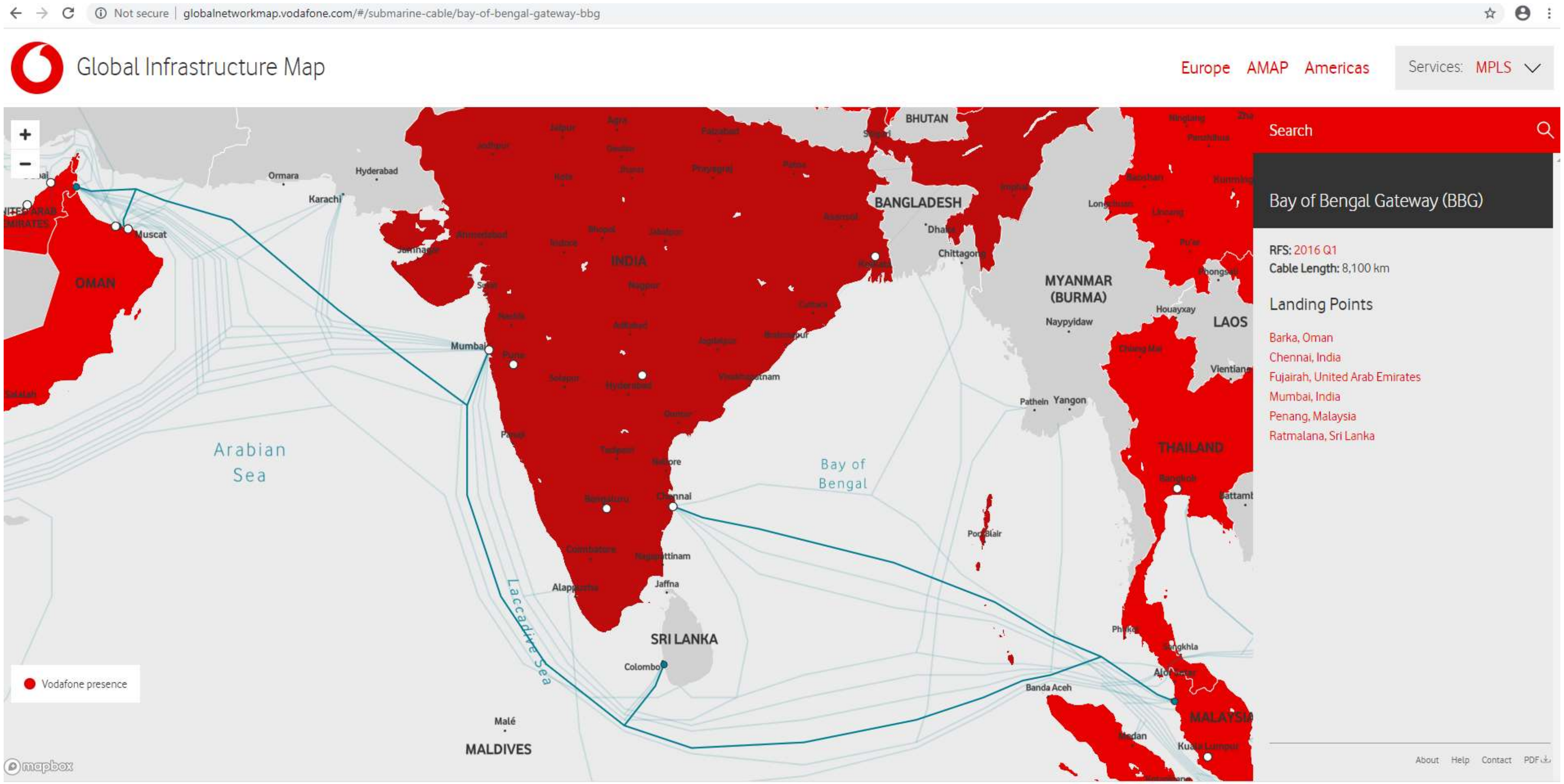
https://main.trai.gov.in/consumer-info/telecom/service-provider-list
http://www.ispai.in/UI/organizationlist.php?cmd=resetall

Some Large Interconnections - Reliance



https://www.rcom.co.in/infrastructure/our-global-network/network-maps/

Some Large Interconnections - Vodafone



http://globalnetworkmap.vodafone.com/#/submarine-cable/bay-of-bengal-gateway-bbg
http://globalnetworkmap.vodafone.com/

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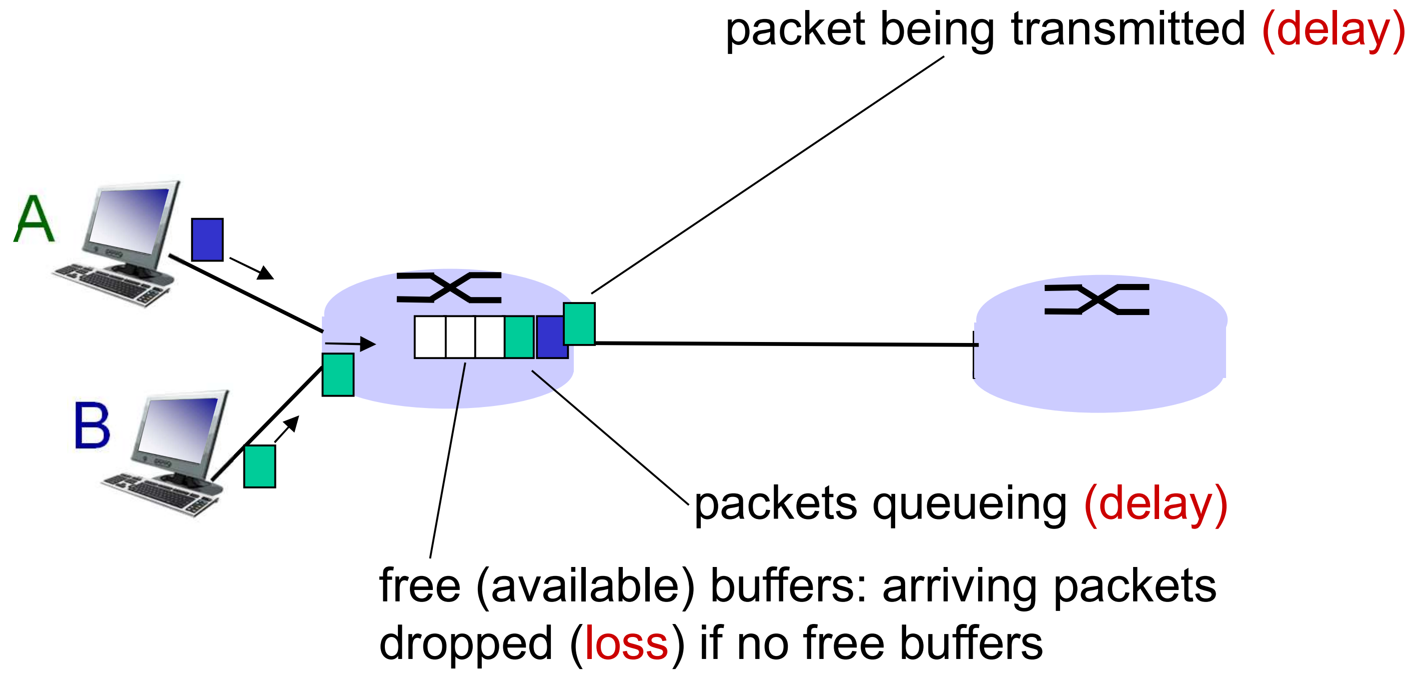
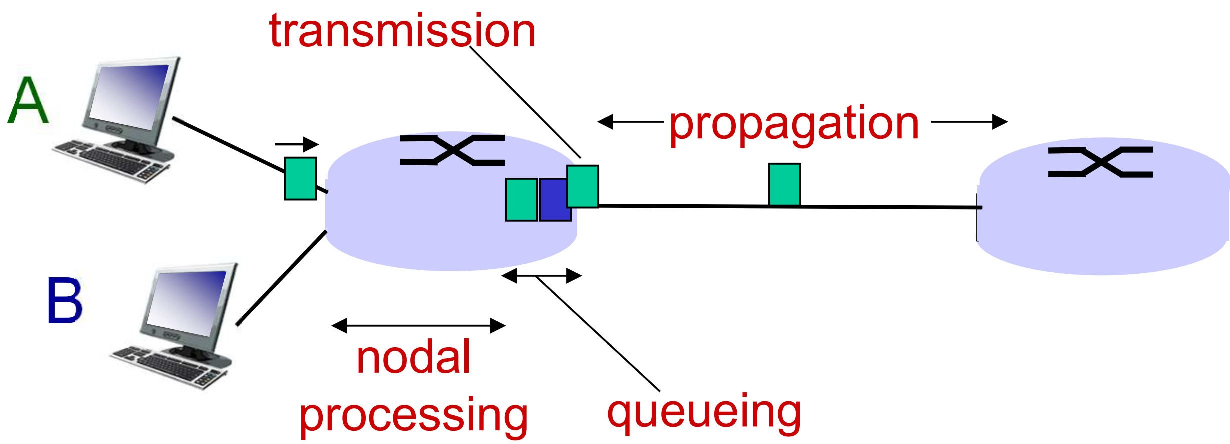
How do loss and delay occur?

packets *queue* in router buffers

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



Four sources of packet delay



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

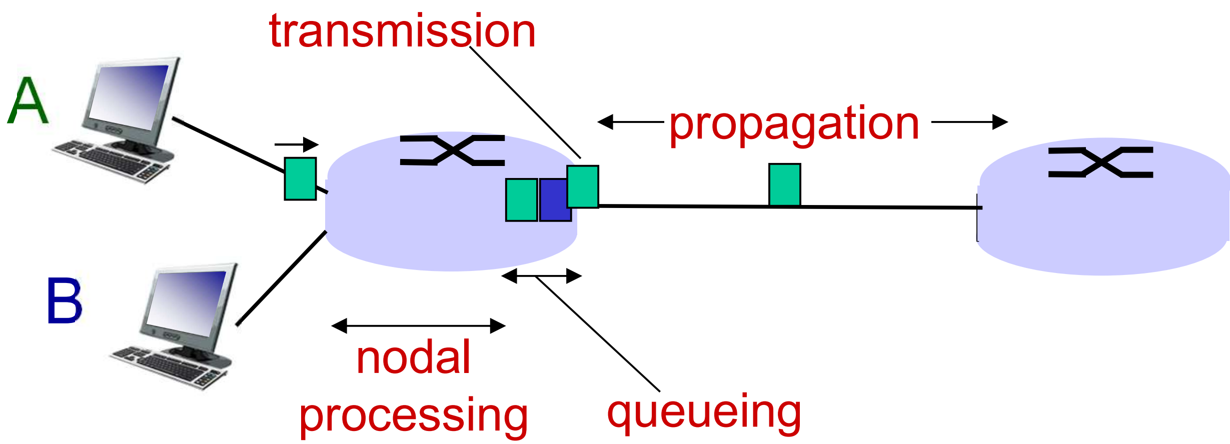
d_{proc}: nodal processing

- check bit errors
- determine output link
- typically < msec

d_{queue}: queueing delay

- time waiting at output link for transmission
- depends on congestion level of router

Four sources of packet delay



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

d_{trans}: transmission delay:

- L: packet length (bits)
- R: link *bandwidth (bps)*
- $d_{trans} = L/R$

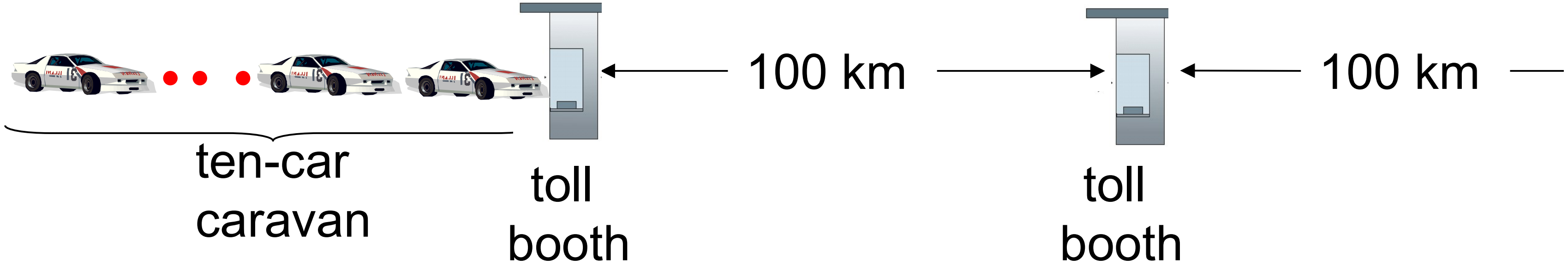
d_{prop}: propagation delay:

- d: length of physical link
- s: propagation speed in medium (~2x10^8 m/sec)
- $d_{prop} = d/s$

d_{trans} and d_{prop} *very* different

* Check out the Java applet for an interactive animation on trans vs. prop delay

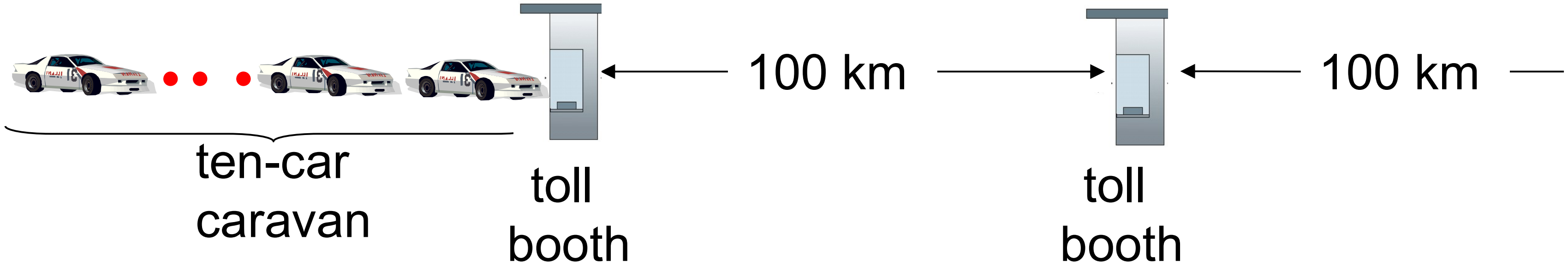
Caravan analogy



- cars "propagate" at 100 km/hr
- toll booth takes 12 sec to service car (bit transmission time)
- car~bit; caravan ~ packet
- *Q*: How long until caravan is lined up before 2nd toll booth?

- time to "push" entire caravan through toll booth onto highway = 12*10 = 120 sec
- time for last car to propagate from 1st to 2nd toll both: 100km/(100km/hr)= 1 hr
- *A*: 62 minutes

Caravan analogy (more)



- suppose cars now "propagate" at 1000 km/hr
- and suppose toll booth now takes one min to service a car
- *Q:* Will cars arrive to 2nd booth before all cars serviced at first booth?
  - *A: Yes!* after 7 min, 1st car arrives at second booth; three cars still at 1st booth.

Four sources of packet delay

A Numerical example -1

This elementary problem begins to explore propagation delay and transmission delay, two central concepts in data networking. Consider two hosts, A and B, connected by a single link of rate R bps. Suppose that the two hosts are separated by m meters, and suppose the propagation speed along the link is s meters/sec. Host A is to send a packet of size L bits to Host B.

a. Express the propagation delay, d_{prop}, in terms of m and s.

b. Determine the transmission time of the packet, d_{trans}, in terms of L and R.

c. Ignoring processing and queuing delays, obtain an expression for the end-to-end delay.

d. Suppose Host A begins to transmit the packet at time $t = 0$. At time $t = d_{trans}$, where is the last bit of the packet?

e. Suppose d_{prop} is greater than d_{trans}. At time $t = d_{trans}$, where is the first bit of the packet?

f. Suppose d_{prop} is less than d_{trans}. At time $t = d_{trans}$, where is the first bit of the packet?

g. Suppose $s = 2.5 \cdot 10^8$, $L = 120$ bits, and $R = 56$ kbps. Find the distance m so that d_{prop} equals d_{trans}.

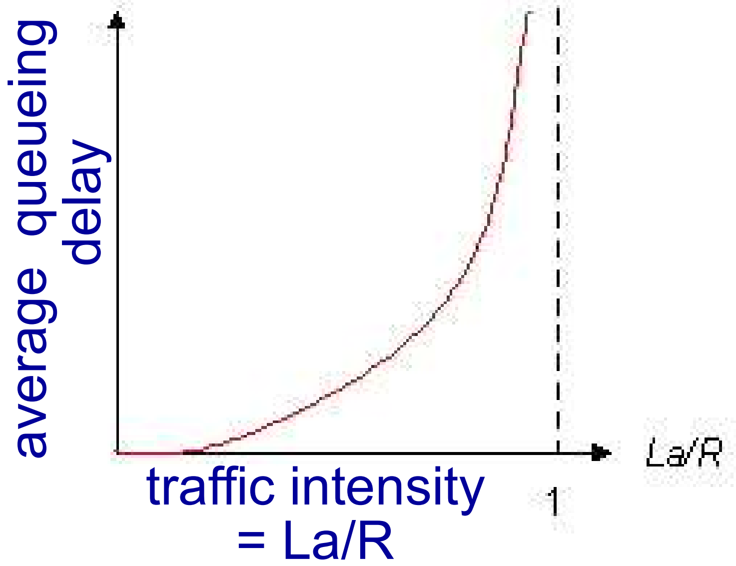
Four sources of packet delay

A Numerical example -2

Consider a packet of length L which begins at end system A and travels over three links to a destination end system. These three links are connected by two packet switches. Let d_i, s_i, and R_i denote the length, propagation speed, and the transmission rate of link i, for $i = 1, 2, 3$. The packet switch delays each packet by d_{proc}. Assuming no queuing delays, in terms of d_i, s_i, R_i, ($i = 1,2,3$), and L, what is the total end-to-end delay for the packet? Suppose now the packet is 1,500 bytes, the propagation speed on all three links is $2.5 \cdot 10^8$ m/s, the transmission rates of all three links are 2 Mbps, the packet switch processing delay is 3 msec, the length of the first link is 5,000 km, the length of the second link is 4,000 km, and the length of the last link is 1,000 km. For these values, what is the end-to-end delay?

Queueing delay (revisited)

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



- *La/R* ~ 0: avg. queueing delay small
- *La/R* -> 1: avg. queueing delay large
- *La/R* > 1: more "work" arriving than can be serviced, average delay infinite!

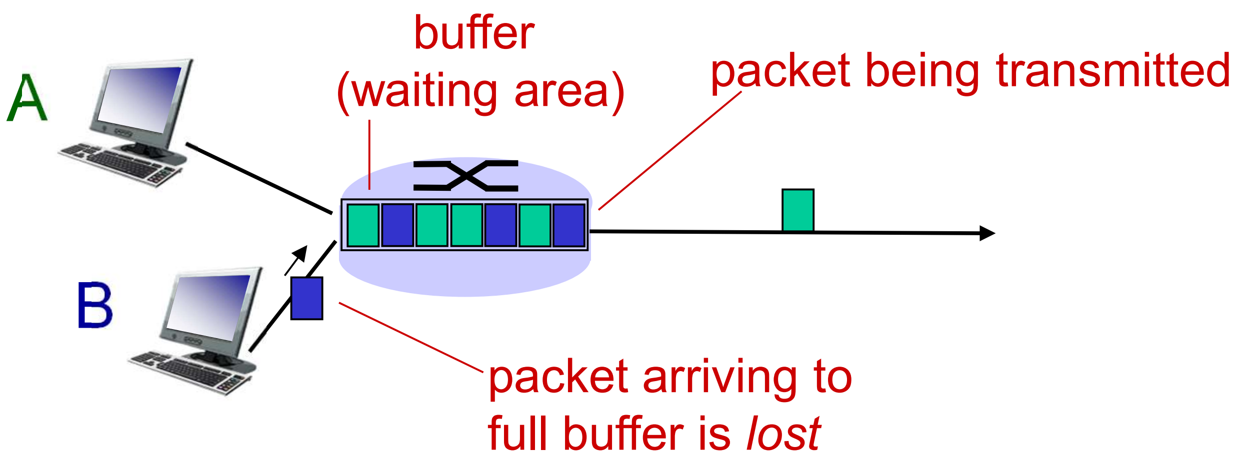
La/R ~ 0

La/R -> 1

* Check out the Java applet for an interactive animation on queuing and loss

Packet loss

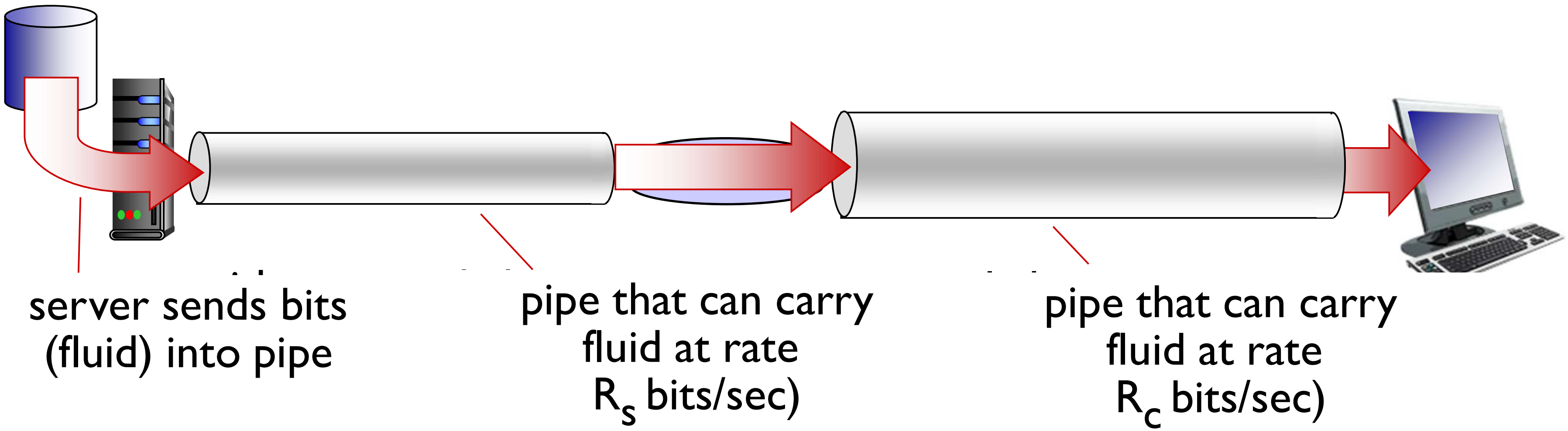
- queue (aka buffer) preceding link in buffer has finite capacity
- packet arriving to full queue dropped (aka lost)
- lost packet may be retransmitted by previous node, by source end system, or not at all



* Check out the Java applet for an interactive animation on queuing and loss

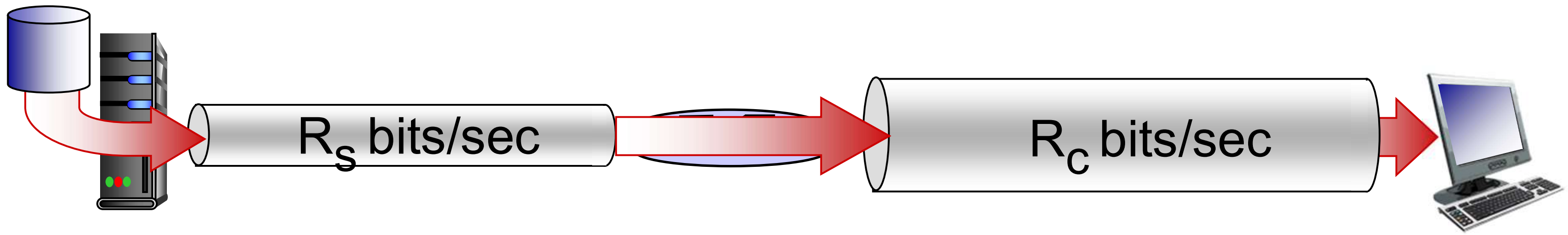
Throughput

- *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

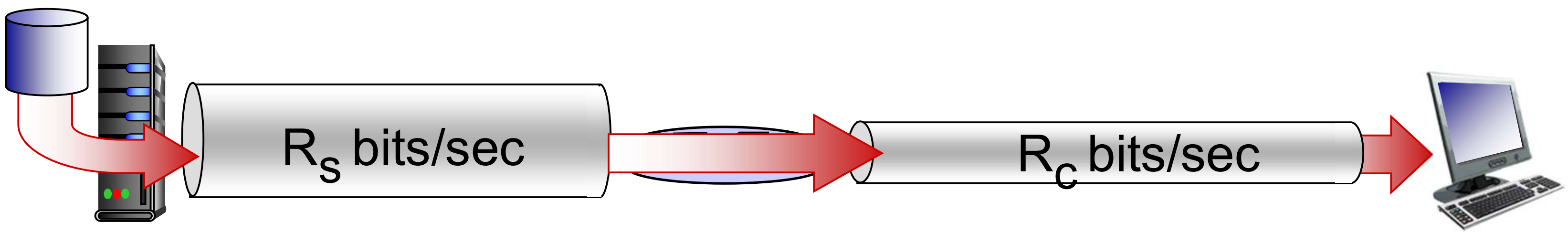


Throughput (more)

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



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

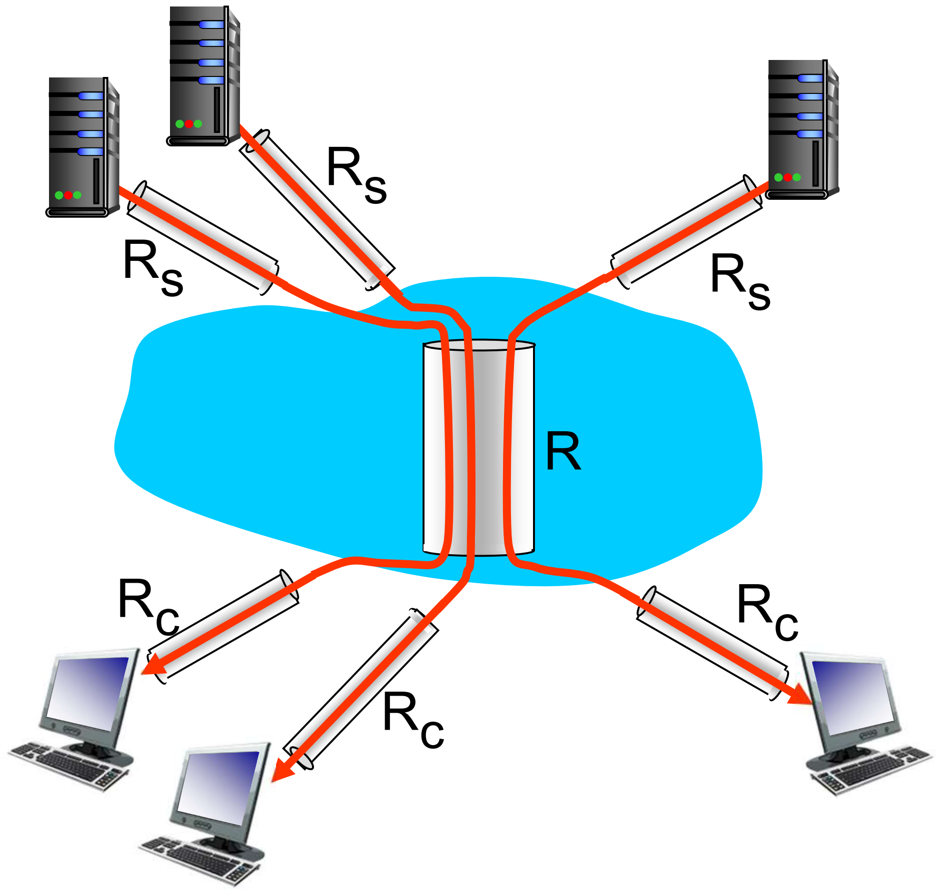


bottleneck link

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

Throughput: Internet scenario

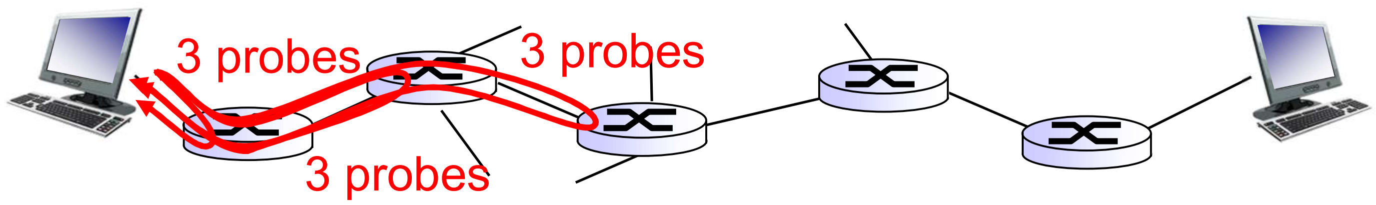
- per-connection end-end throughput: $\min(R_c, R_s, R/10)$
- in practice: R_c or R_s is often bottleneck



10 connections (fairly) share backbone bottleneck link R bits/sec

"Real" Internet delays and routes

- Round trip time (RTT) : end to end two way delay
- ping program : checks reachability
- 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.



RTT: IIT-M to some destinations…

```
[Manikantan:~ Admin$ ping stanford.edu -c 2
PING stanford.edu (171.67.215.200): 56 data bytes
64 bytes from 171.67.215.200: icmp_seq=0 ttl=234 time=313.174 ms
64 bytes from 171.67.215.200: icmp_seq=1 ttl=234 time=520.792 ms

--- stanford.edu ping statistics ---
2 packets transmitted, 2 packets received, 0.0% packet loss
round-trip min/avg/max/stddev = 313.174/416.983/520.792/103.809 ms
[Manikantan:~ Admin$ ping tum.de -c 2
PING tum.de (129.187.255.228): 56 data bytes
64 bytes from 129.187.255.228: icmp_seq=0 ttl=239 time=164.255 ms
64 bytes from 129.187.255.228: icmp_seq=1 ttl=239 time=184.936 ms

--- tum.de ping statistics ---
2 packets transmitted, 2 packets received, 0.0% packet loss
round-trip min/avg/max/stddev = 164.255/174.596/184.936/10.340 ms
[Manikantan:~ Admin$ ping nus.edu.sg
PING nus.edu.sg (137.132.21.27): 56 data bytes
64 bytes from 137.132.21.27: icmp_seq=0 ttl=46 time=36.831 ms
64 bytes from 137.132.21.27: icmp_seq=1 ttl=46 time=39.193 ms
64 bytes from 137.132.21.27: icmp_seq=2 ttl=46 time=40.792 ms
64 bytes from 137.132.21.27: icmp_seq=3 ttl=46 time=39.280 ms
^C
```

The network path : IIT-M to Stanford

```
Manikantan:~ Admin$ traceroute stanford.edu
traceroute to stanford.edu (171.67.215.200), 64 hops max, 52 byte packets
 1  192.168.1.1 (192.168.1.1)  1.399 ms  0.760 ms  0.738 ms
 2  10.21.239.254 (10.21.239.254)  4.420 ms  3.115 ms  2.935 ms
 3  10.25.0.14 (10.25.0.14)  3.002 ms  2.710 ms  3.398 ms
 4  10.119.232.138 (10.119.232.138)  3.304 ms  3.283 ms  4.888 ms
 5  10.119.232.137 (10.119.232.137)  17.057 ms  5.226 ms  3.193 ms
 6  10.163.255.201 (10.163.255.201)  28.199 ms  31.276 ms  58.391 ms
 7  10.255.232.217 (10.255.232.217)  28.544 ms  27.130 ms  27.288 ms
 8  180.149.48.18 (180.149.48.18)  27.870 ms  28.814 ms  29.317 ms
 9  180.149.48.6 (180.149.48.6)  147.090 ms
    180.149.48.2 (180.149.48.2)  145.395 ms  158.003 ms
10  180.149.48.20 (180.149.48.20)  145.675 ms
    180.149.48.13 (180.149.48.13)  408.987 ms  375.460 ms
11  ae-3.4079.rtsw.wash.net.internet2.edu (162.252.70.138)  409.599 ms
    180.149.48.13 (180.149.48.13)  409.300 ms
    ae-3.4079.rtsw.wash.net.internet2.edu (162.252.70.138)  409.510 ms
12  ae-3.4079.rtsw.wash.net.internet2.edu (162.252.70.138)  407.840 ms  408.944 ms
    162.252.70.159 (162.252.70.159)  435.166 ms
13  162.252.70.159 (162.252.70.159)  424.791 ms  367.475 ms
    hpr-lax-hpr2--i2-r&e.cenic.net (137.164.26.200)  409.660 ms
14  hpr-lax-hpr2--i2-r&e.cenic.net (137.164.26.200)  412.136 ms
    hpr-svl-hpr3--lax-hpr3-100ge.cenic.net (137.164.25.74)  404.798 ms  409.072 ms
15  hpr-svl-hpr3--lax-hpr3-100ge.cenic.net (137.164.25.74)  412.183 ms
    hpr-stan-ge--svl-hpr2.cenic.net (137.164.27.162)  406.297 ms
    hpr-svl-hpr3--lax-hpr3-100ge.cenic.net (137.164.25.74)  408.774 ms
16  woa-west-rtr-vl2.sunet (171.64.255.132)  614.091 ms
    hpr-stan-ge--svl-hpr2.cenic.net (137.164.27.162)  409.451 ms
    woa-west-rtr-vl2.sunet (171.64.255.132)  408.020 ms
17  woa-west-rtr-vl2.sunet (171.64.255.132)  444.375 ms  373.352 ms *
18  * web.stanford.edu (171.67.215.200)  440.017 ms  408.558 ms
Manikantan:~ Admin$
```

The network path : IIT-M to TU-Munchen

```
Manikantan:~ Admin$ traceroute tum.de
traceroute to tum.de (129.187.255.228), 64 hops max, 52 byte packets
 1  192.168.1.1 (192.168.1.1)  4.048 ms  2.383 ms  1.666 ms
 2  10.21.239.254 (10.21.239.254)  3.352 ms  2.893 ms  4.201 ms
 3  10.25.0.14 (10.25.0.14)  26.537 ms  3.261 ms  2.596 ms
 4  10.119.232.138 (10.119.232.138)  40.140 ms  33.266 ms  13.273 ms
 5  10.119.232.137 (10.119.232.137)  3.200 ms  3.657 ms  3.092 ms
 6  10.163.255.201 (10.163.255.201)  28.323 ms  27.197 ms  27.290 ms
 7  10.255.232.217 (10.255.232.217)  54.111 ms  29.028 ms  27.403 ms
 8  180.149.48.18 (180.149.48.18)  40.365 ms  32.004 ms  27.454 ms
 9  180.149.48.6 (180.149.48.6)  148.942 ms  145.983 ms  146.799 ms
10  180.149.48.20 (180.149.48.20)  145.605 ms
    180.149.48.10 (180.149.48.10)  145.897 ms
    180.149.48.20 (180.149.48.20)  146.015 ms
11  180.149.48.10 (180.149.48.10)  159.651 ms  145.489 ms
    ae0.mx1.fra.de.geant.net (62.40.98.128)  152.569 ms
12  cr-fra1.x-win.dfn.de (62.40.124.218)  152.913 ms  158.075 ms  153.647 ms
13  cr-fra1.x-win.dfn.de (62.40.124.218)  162.973 ms  152.899 ms
    cr-gar1-be6.x-win.dfn.de (188.1.145.230)  161.327 ms
14  cr-gar1-be6.x-win.dfn.de (188.1.145.230)  161.265 ms
    kr-gar188-0.x-win.dfn.de (188.1.37.90)  161.235 ms  162.454 ms
15  kr-gar188-0.x-win.dfn.de (188.1.37.90)  170.167 ms
    vl-3001.cvr2-2wr.lrz.de (129.187.0.168)  161.194 ms
    kr-gar188-0.x-win.dfn.de (188.1.37.90)  161.376 ms
16  vl-3001.cvr2-2wr.lrz.de (129.187.0.168)  162.334 ms  165.202 ms
    wwwv1.tum.de (129.187.255.228)  161.353 ms
17  wwwv1.tum.de (129.187.255.228)  161.154 ms
    f5slb4.lrz.de (129.187.255.244)  2375.643 ms !H *
18  f5slb4.lrz.de (129.187.255.244)  1139.495 ms !H *  1354.359 ms !H
Manikantan:~ Admin$
```

"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