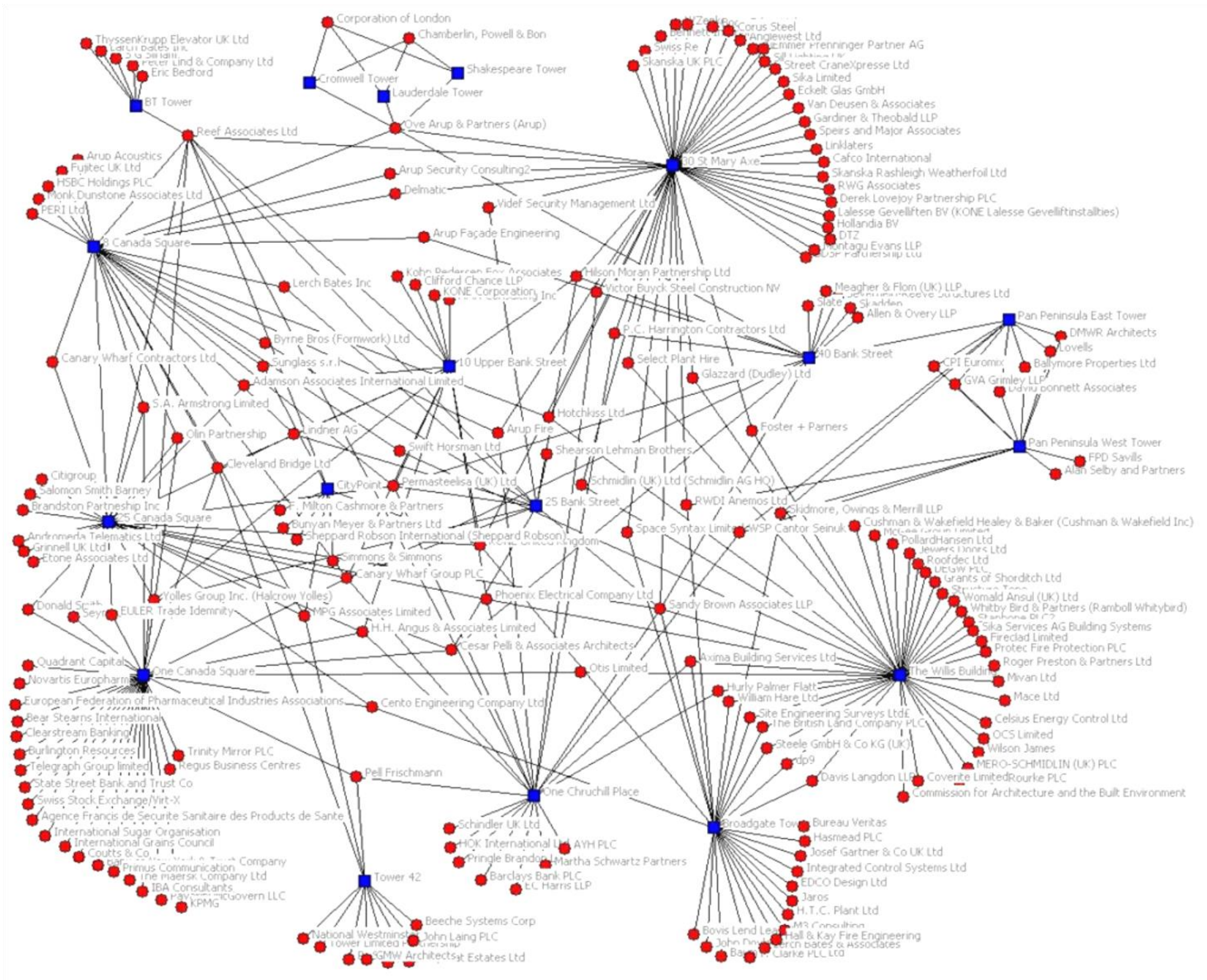


CS542

Chapter 1 Introduction

Chapter 1: introduction

our goal:

- get "feel" and terminology
- more depth, detail *later* in course
- approach:
  - use Internet as example

overview:

- what's the Internet?
- what's a protocol?
- network edge; hosts, access net, physical media
- network core: packet/circuit switching, Internet structure
- performance: loss, delay, throughput
- security
- protocol layers, service models
- history

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

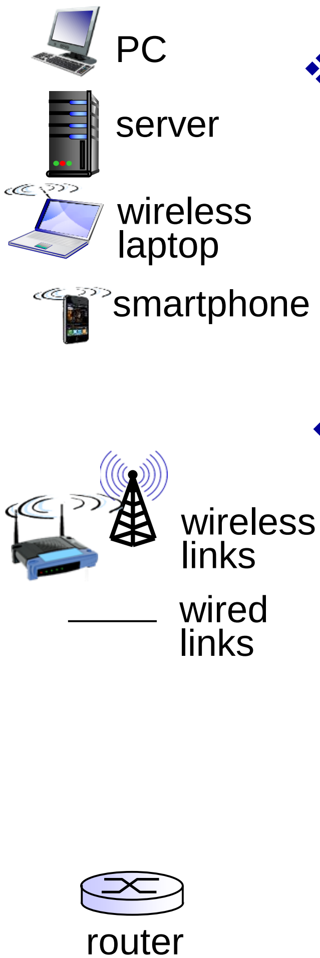
1.4 delay, loss, throughput in networks

1.5 protocol layers, service models

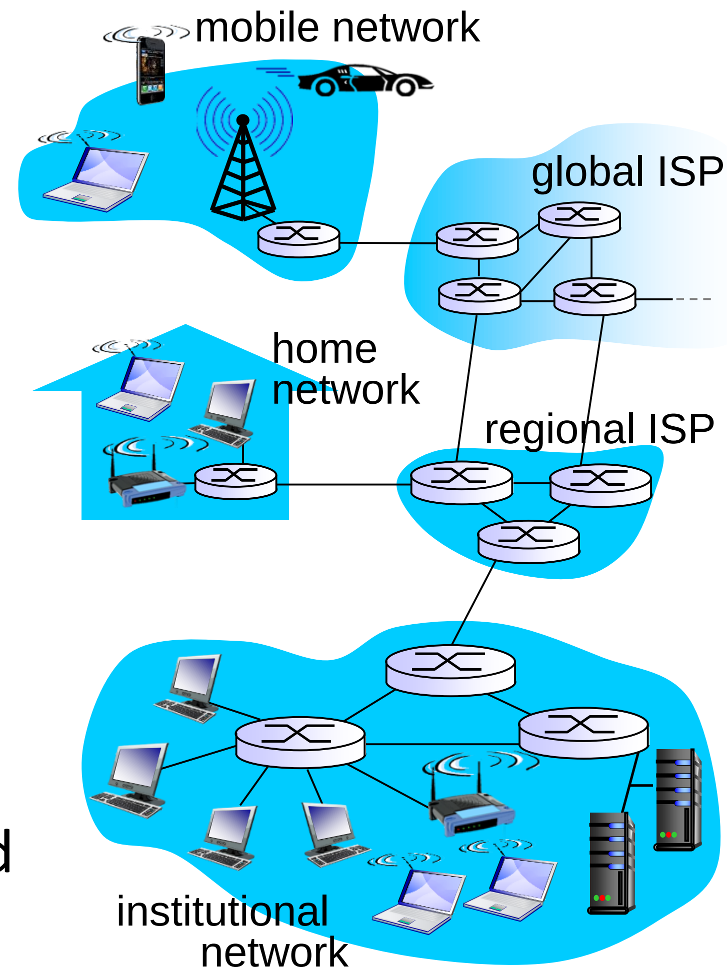
1.6 networks under attack: security

1.7 history

What's the Internet: "nuts and bolts" view



- millions of connected computing devices:
  - *hosts* = *end systems*
  - running *network apps*
- *communication links*
  - fiber, copper, radio, satellite
  - transmission rate: *bandwidth*
- *Packet switches:* forward packets (chunks of data)
  - *routers* and *switches*



"Fun" Internet-connected devices

IP picture frame
http://www.ceiva.com/

Web-enabled toaster +
weather forecaster

Tweet-a-watt:
monitor energy use

Slingbox: watch,
control cable TV remotely

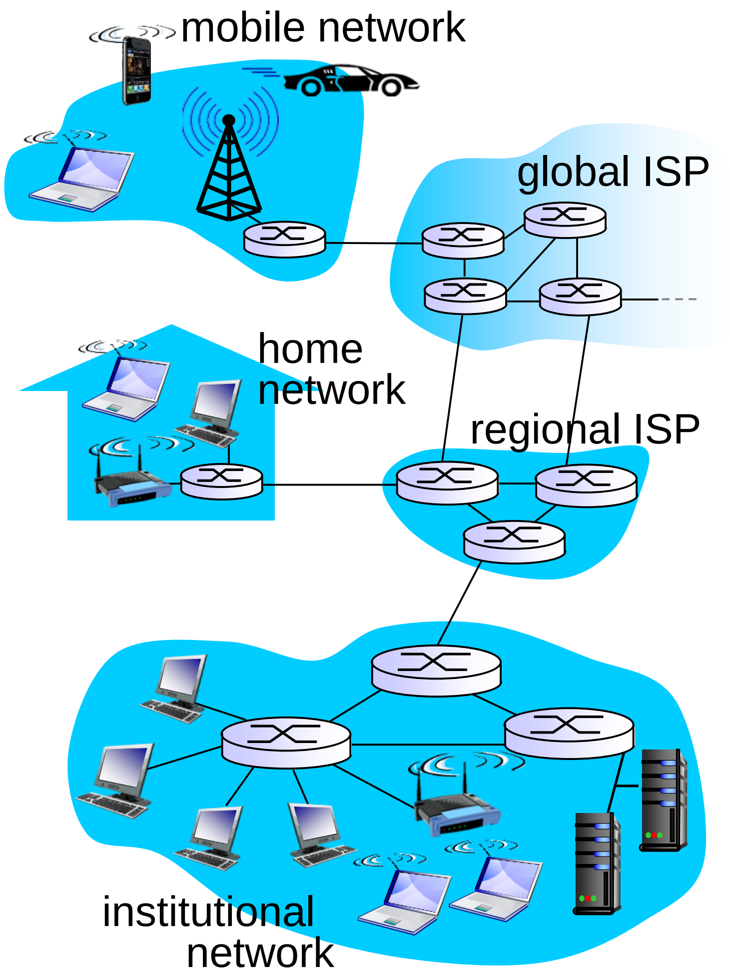
Internet
refrigerator

sensorized,
bed
mattress

Internet phones

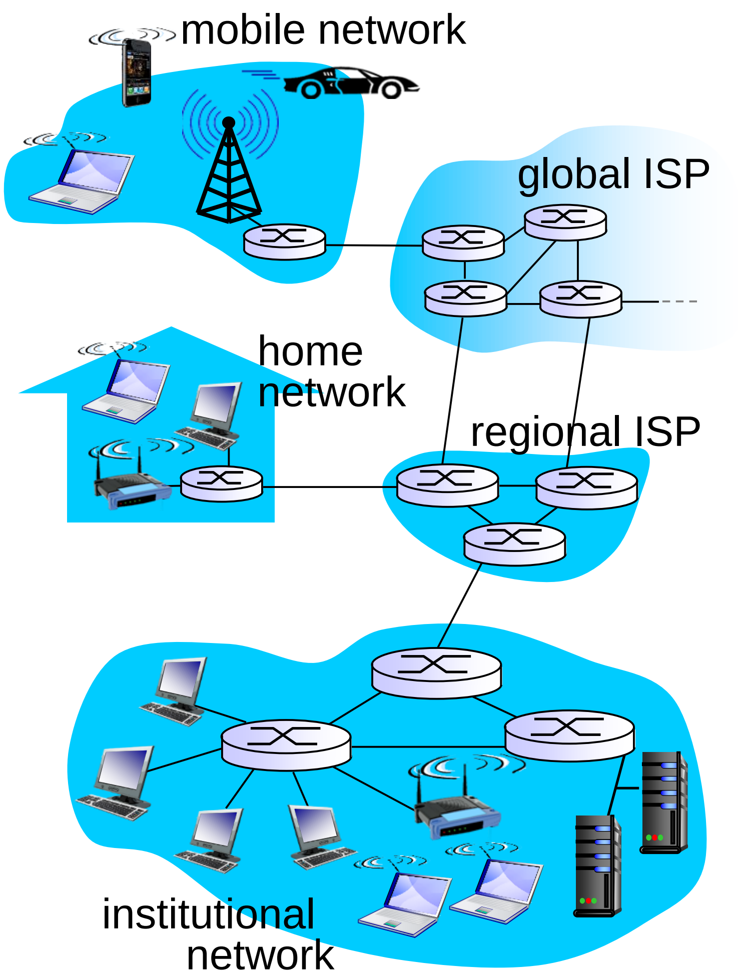
What's the Internet: "nuts and bolts" view

- *Internet:* "network of networks"
  - Interconnected ISPs
- *protocols* control sending, receiving of msgs
  - e.g., TCP, IP, HTTP, Skype, 802.11
- *Internet standards*
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force



What's the Internet: a service view

- *Infrastructure that provides services to applications:*
  - Web, VoIP, email, games, e-commerce, social nets, …
- *provides programming interface to apps*
  - hooks that allow sending and receiving app programs to "connect" to Internet
  - provides service options, analogous to postal service



What’s a protocol?

human protocols:

- “what’s the time?”
- “I have a question”
- introductions

... specific msgs sent

... specific actions taken when msgs received, or other events

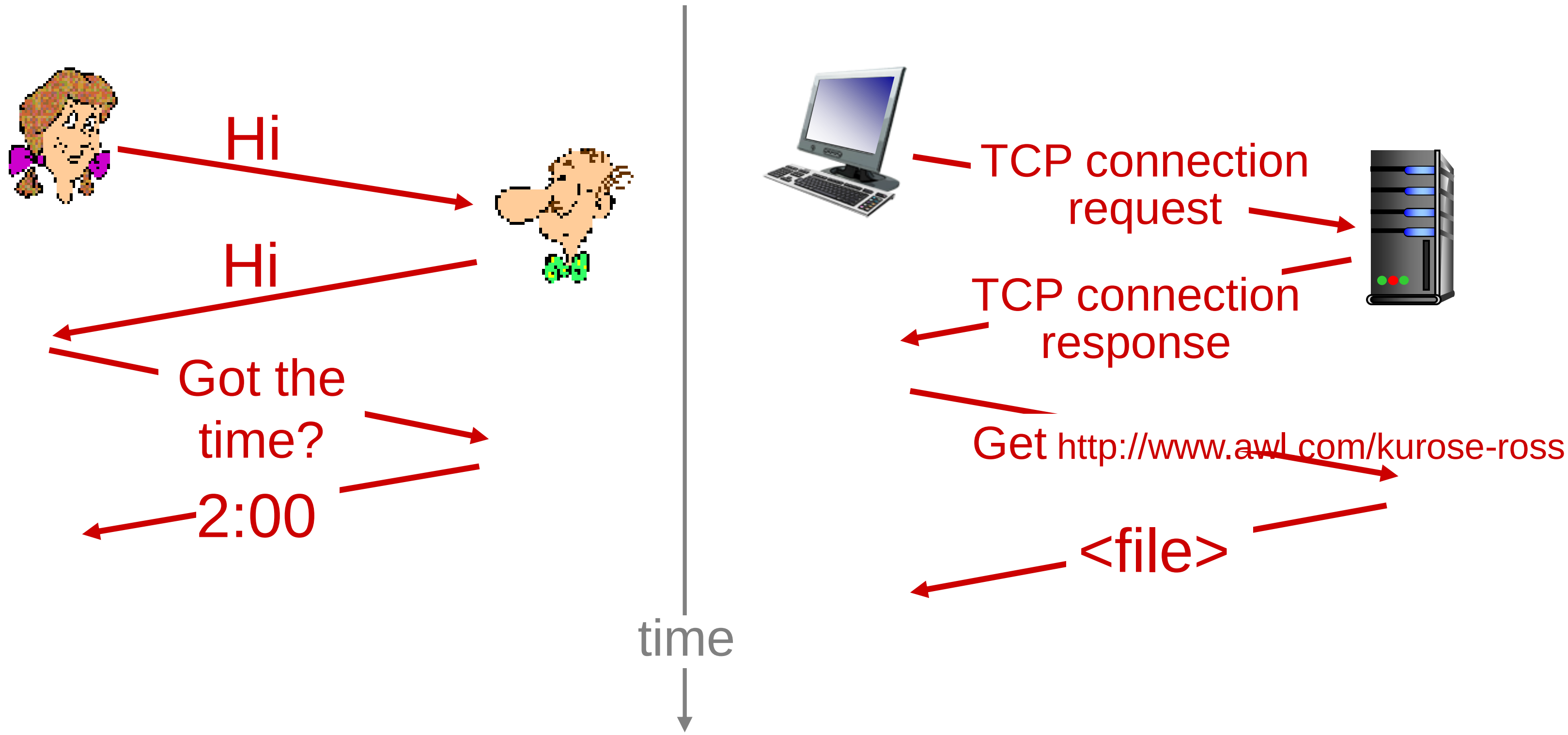
network protocols:

- machines rather than humans
- all communication activity in Internet governed by protocols

protocols define format, order of msgs sent and received among network entities, and actions taken on msg transmission, receipt

What's a protocol?

a human protocol and a computer network protocol:



Q: other human protocols?

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

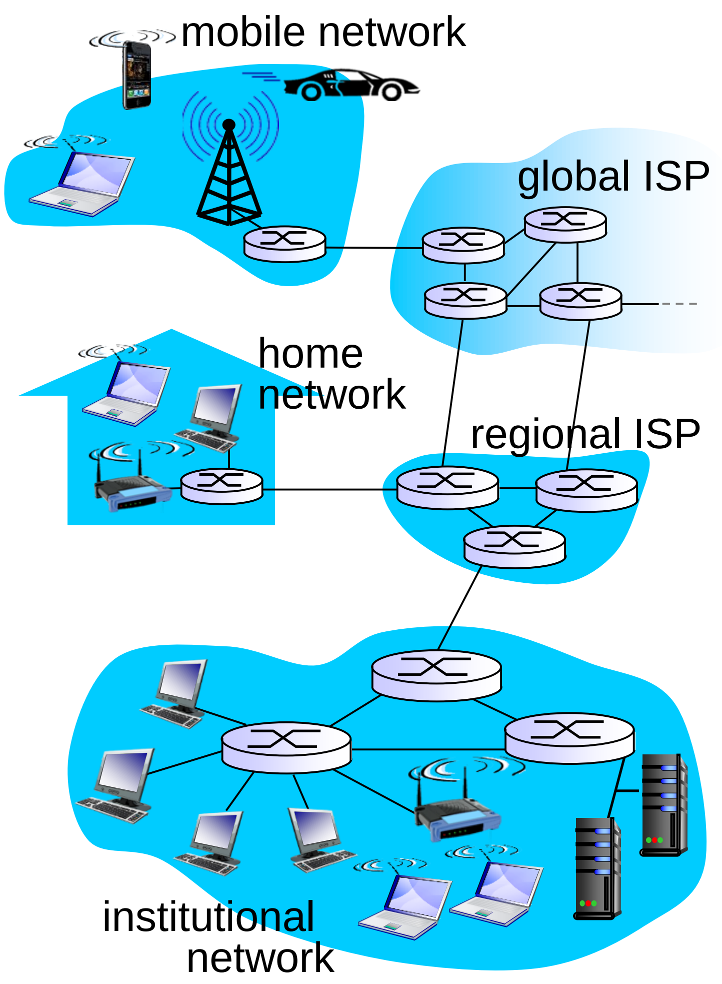
1.5 protocol layers, service models

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



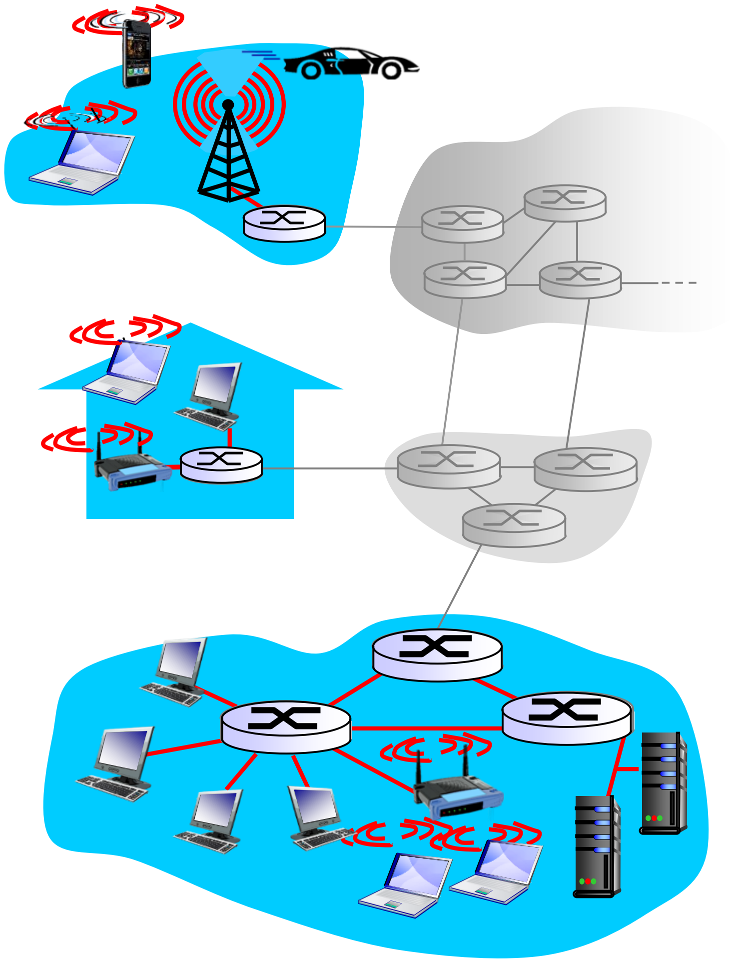
Access networks and physical media

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 networks

Residential Area

- Dial up
- DSL
- Cable modem
- FTTH
- WiMax
- Power line

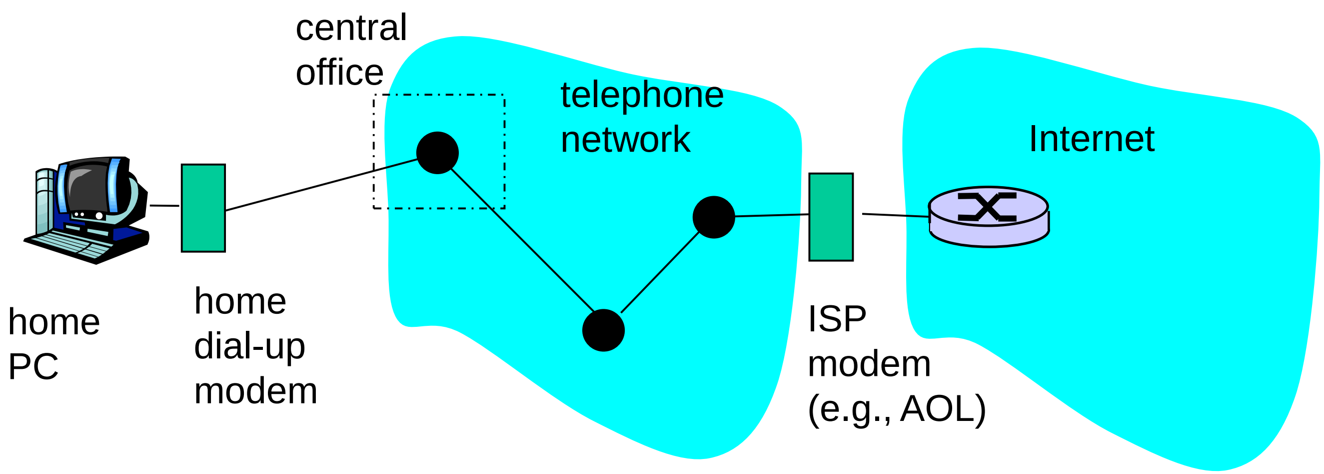
Corporate/Campus

- Ethernet LAN

Anywhere

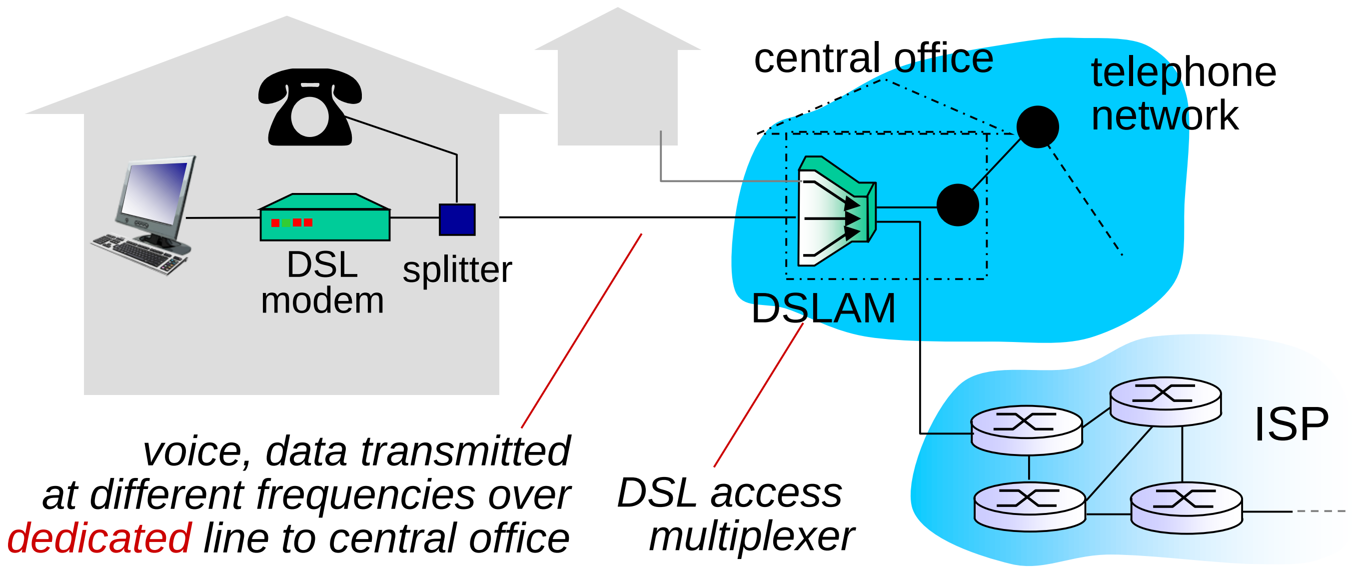
- Hotspots
- Municipals wireless, WiFi City
- Mobile Data
  - CDMA EV/DO
  - HSDPA
  - Mobile WiMax
  - LTE
  - Etc.

Dial-up Modem



- Uses existing telephony infrastructure
  - Home is connected to central office
- up to 56Kbps direct access to router (often less)
- Can't surf and phone at same time: not "always on"

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)

Example: Chicago DSL Plans (2007)

Packages	Downstream	Upstream
Basic	384 ~ 768 Kbps	128 Kbps
Express	384 Kbps ~ 1.5 Mbps	128 ~ 384 Kbps
Pro	1.5 ~ 3 Mbps	384 ~ 512 Kbps
Elite	3.0 ~ 6.0 Mbps	512 ~ 768 Kbps

As of January 2007 by www.att.com

Example: Chicago DSL Plans (2009)

Packages	Downstream	Upstream
Basic	up to 768 Kbps	up to 384 Kbps
Express	up to 1.5 Mbps	up to 384 Kbps
Pro	up to 3 Mbps	up to 512 Kbps
Elite	up to 6.0 Mbps	up to 768 Kbps

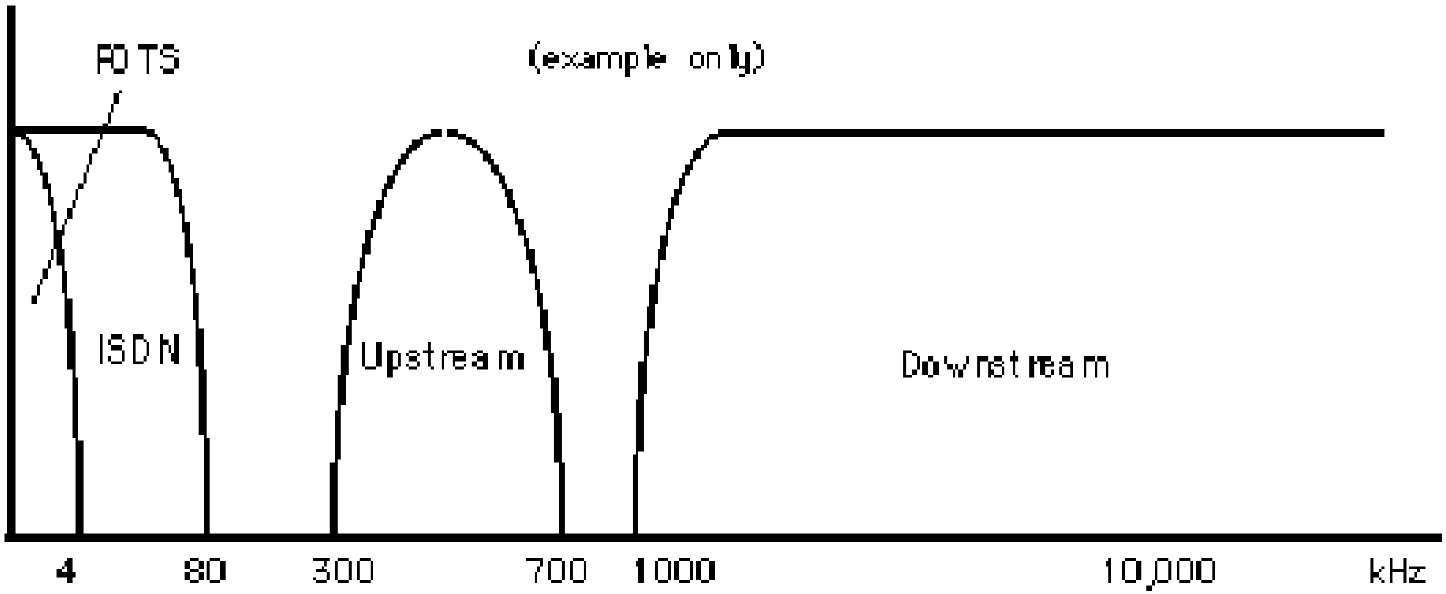
As of August 2009 by www.att.com

Example: Chicago DSL Plans (2017)

Beyond 6 Mbps but this is not a true DSL

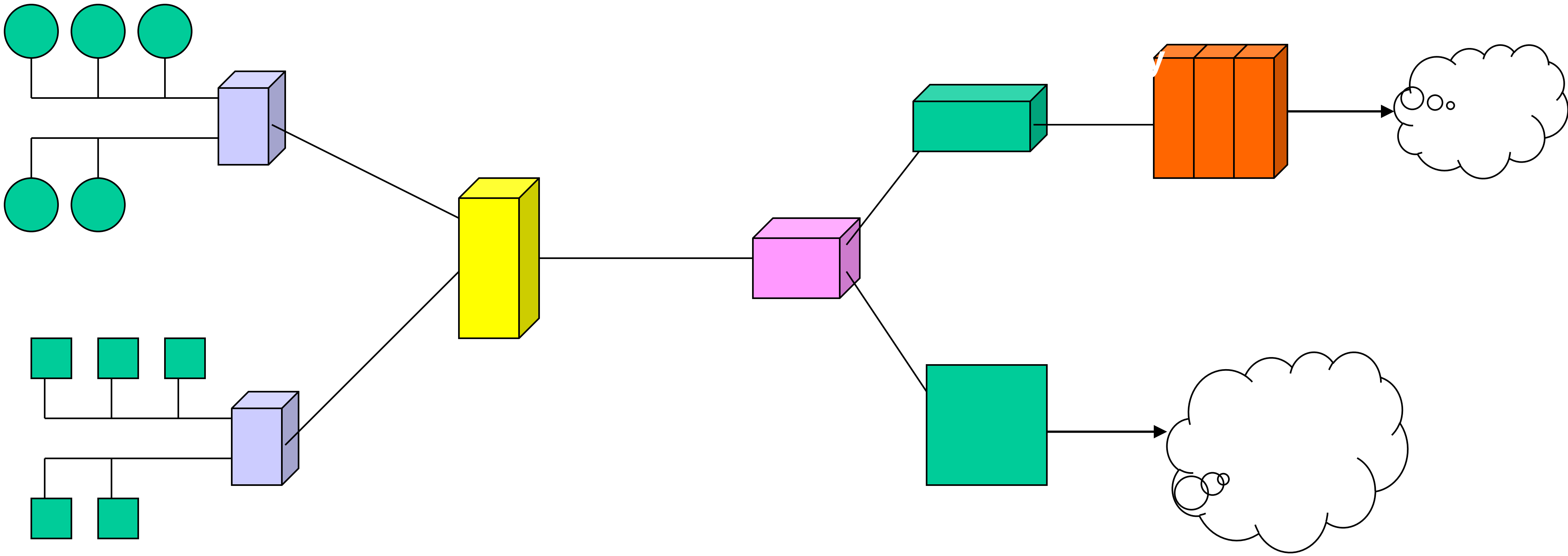
ATT changes DSL Internet package to U-verse Internet which includes FTTN and VDSL technologies and provides up to 100 Mbps package in 2017.

Frequency Division Multiplexing in xDSL

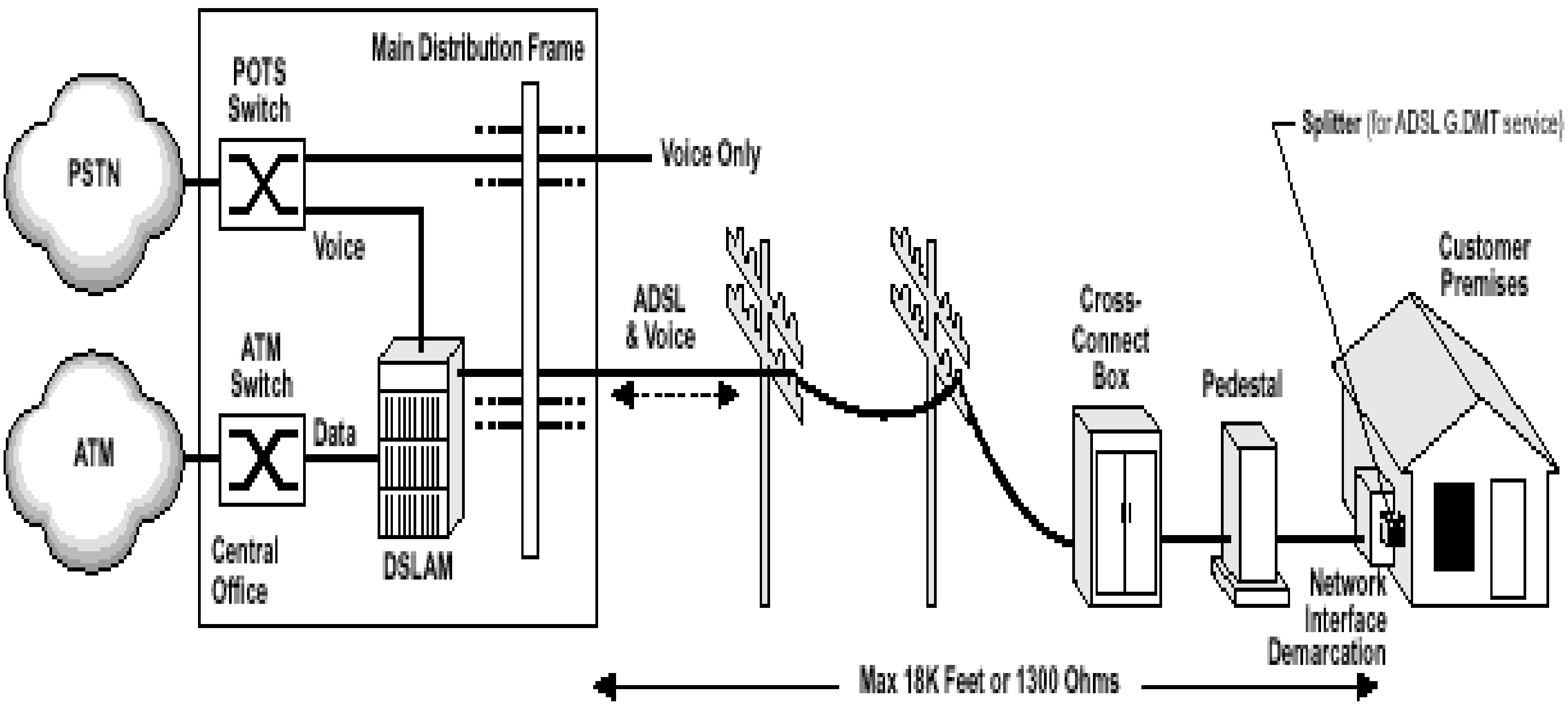


- This frequency division also means service providers can keep voice and data on separate networks; thereby eliminating the congestion on the PSTN that is created by transferring data over circuit-switched rather than packet or cell-switched connections.

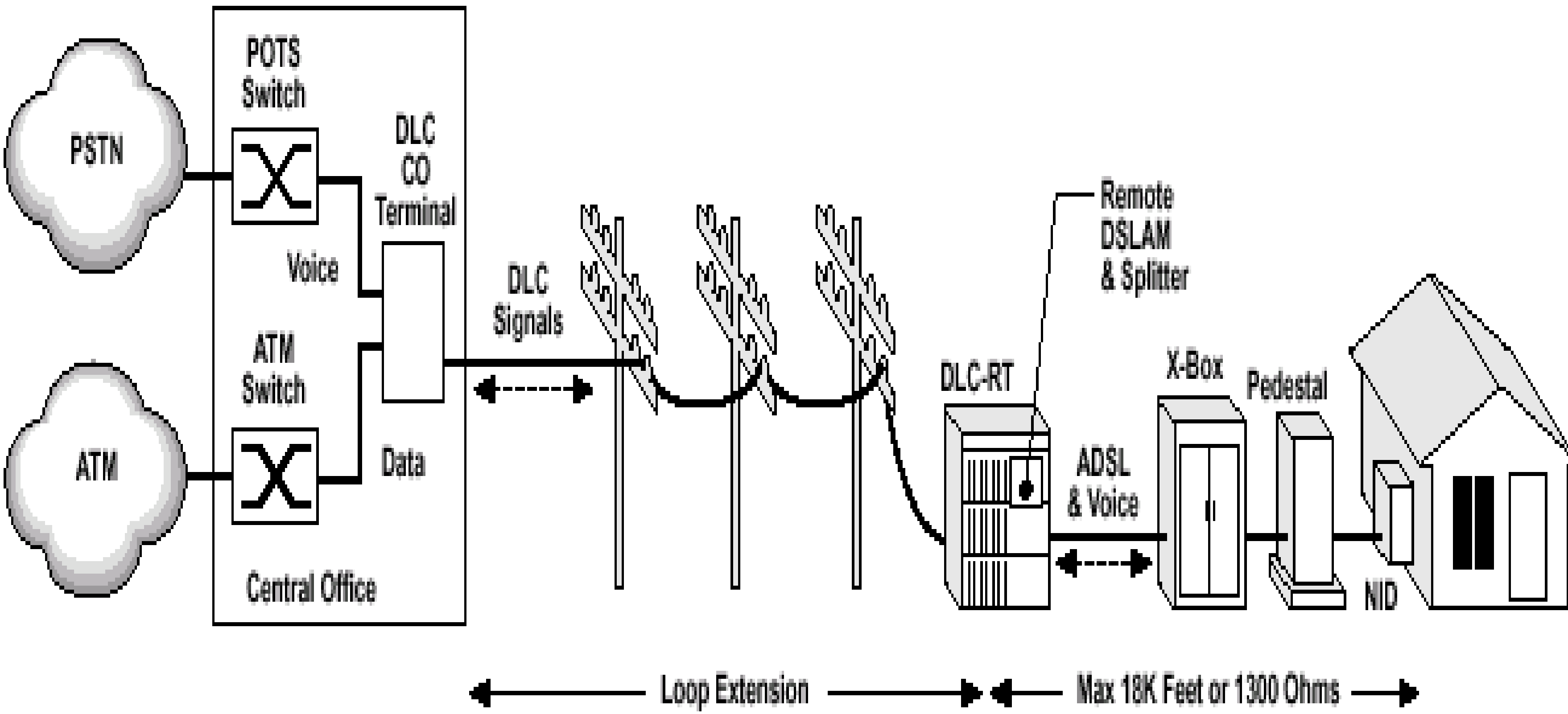
Integrate Services over DSL/ATM Architecture (one example)



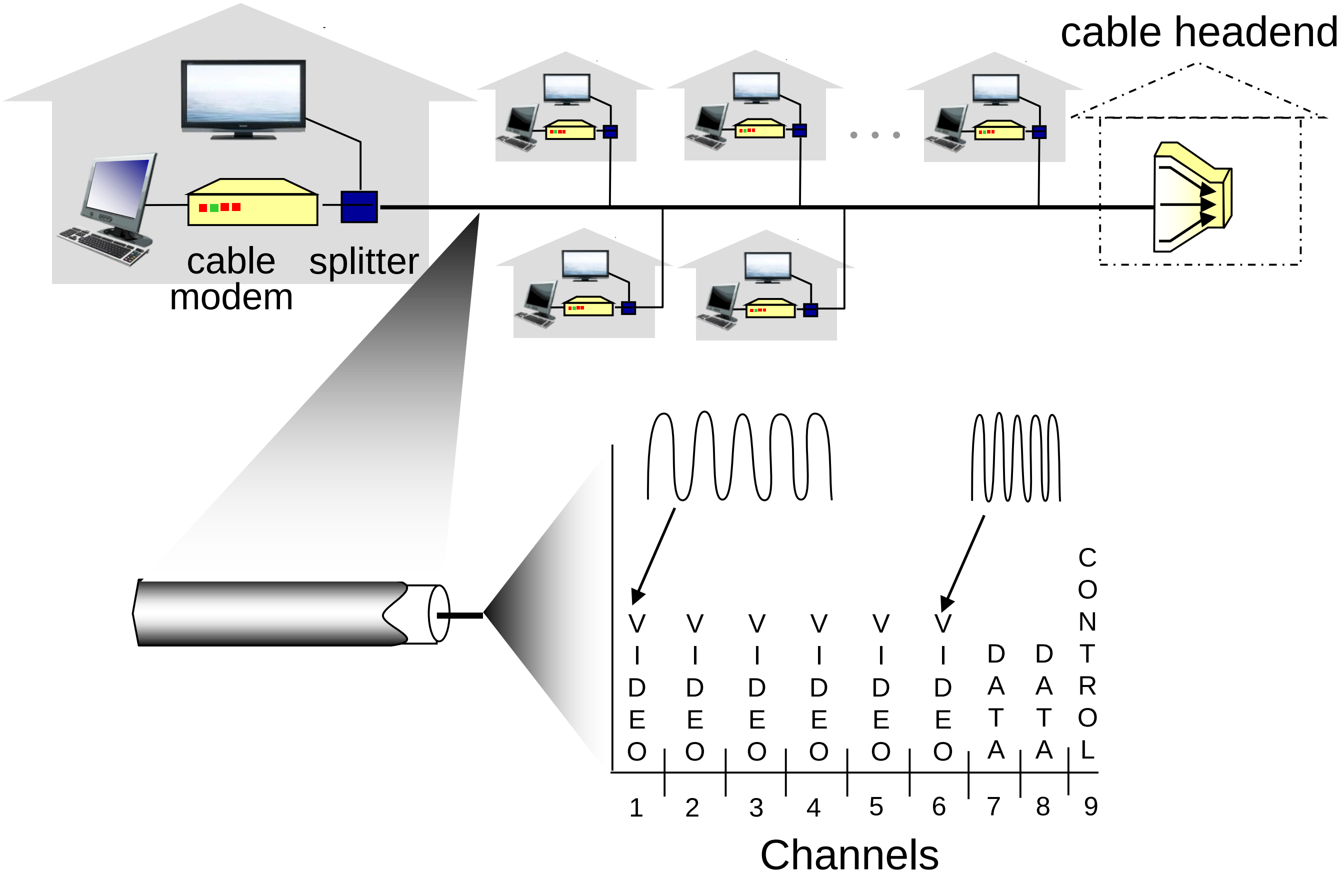
DSL Architecture (I)



DSL Architecture (II)

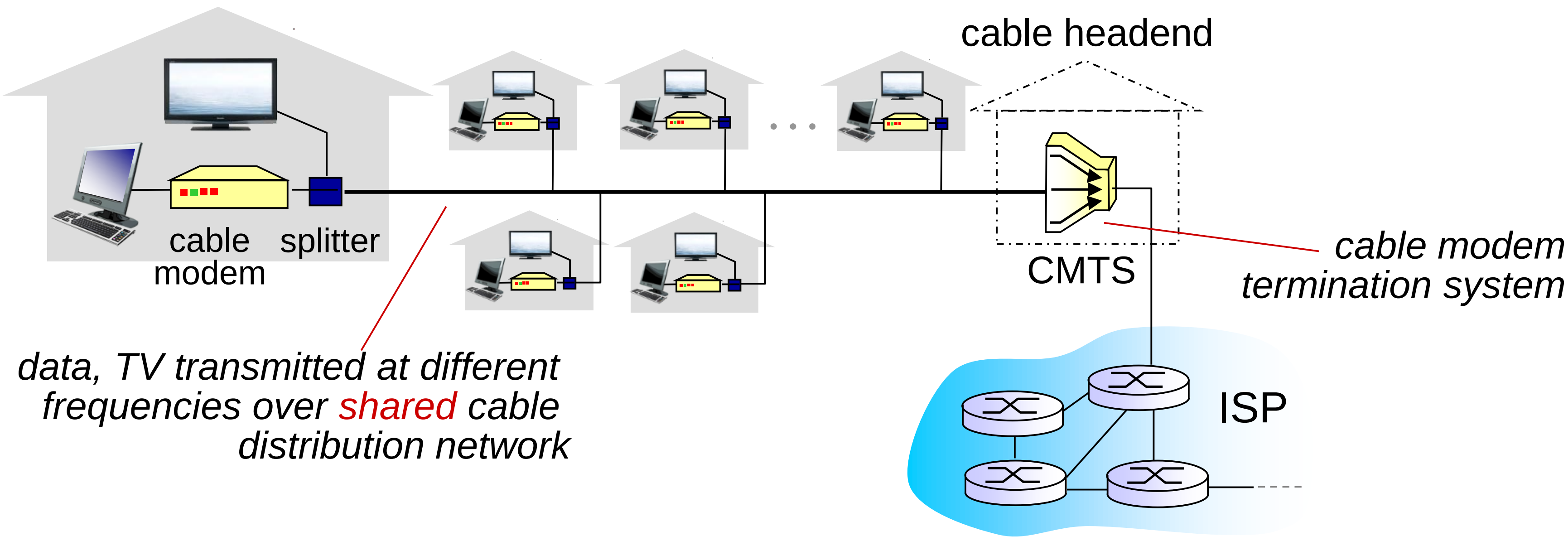


Access net: cable network



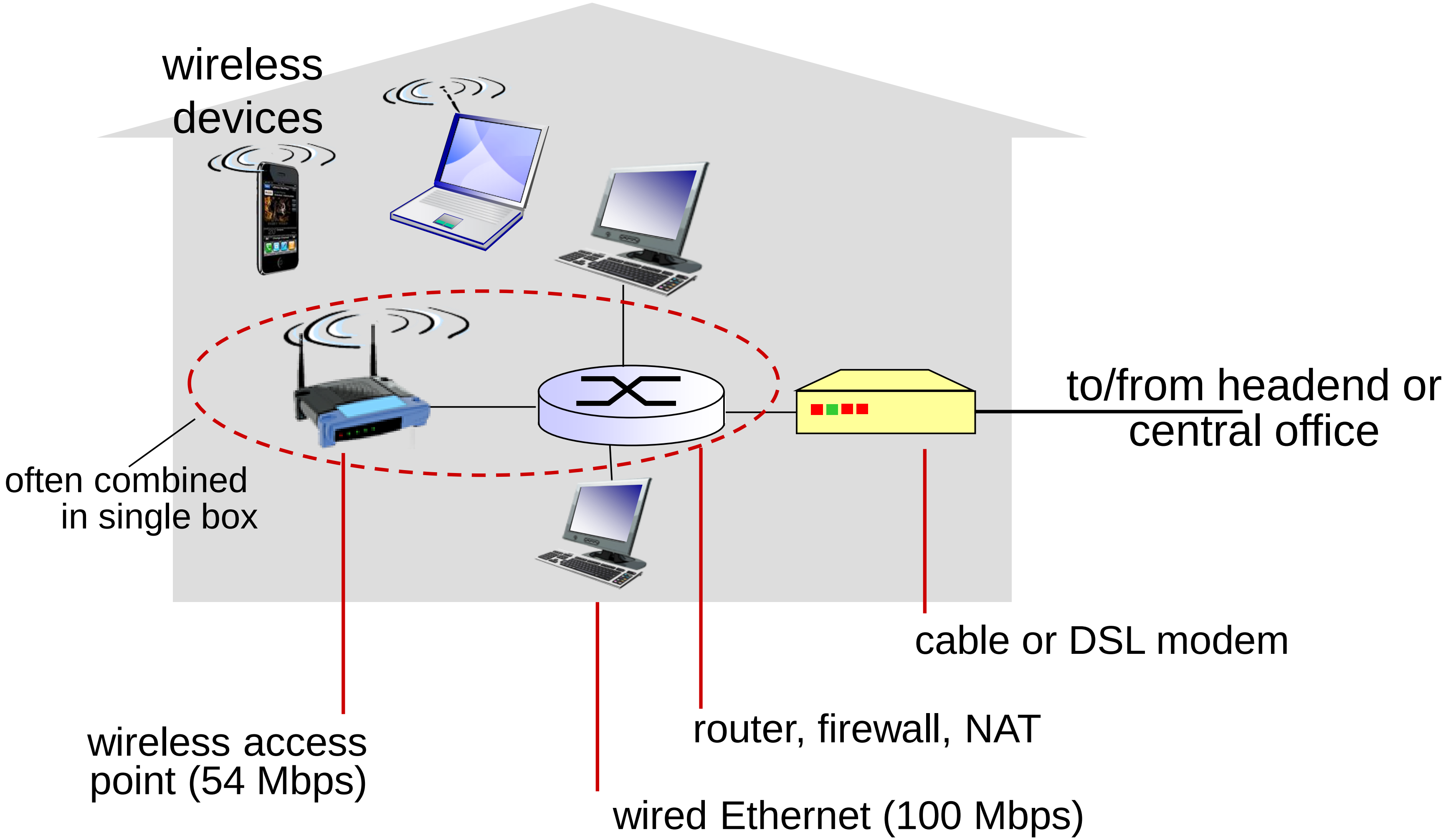
frequency division multiplexing: different channels transmitted in different frequency bands

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

Access net: home network



Example: Cable modem Plans

Packages	Speed of connection
Standard	6 Mbps (12 Mbps with powerboost)
Beyond Standard	8 Mbps (16 Mbps with powerboost)

As of 2007 by www.comcast.com

Example: Cable modem Plans

Packages	Speed of connection
Economy	1 Mbps down, up to 384 Kbps up
Performance	15 Mbps down, up to 1 Mbps up
Blast	20 Mbps down, up to 4 Mbps up
Extreme	50 Mbps down, up to 10 Mbps up
	(all above with PowerBoost)

As of 2009 by www.comcast.com

Example: Cable modem Plans

Up to 300 Mbps downstream

As of September 2017 by www.comcast.com

Example: Other cable modem Plans

Packages	Speed of connection
Xcite	2 Mbps down
Xpress	8 Mbps down
Xtreme	15 Mbps down, up to 1 Mbps up
Xtreme Turbo	15 Mbps down, up to 2 Mbps up

As of 2009 by www.wowway.com

Example: Another cable modem Plans

Up to 1 Gbps Download Speed
Up to 50 Mbps Upload speed

As of 2017 by www.wowway.com

Population of broadband Access

By 2003,

Broadband lines per 100 population:

23 South Korea (~50 Mbps VDSL)

13 China

7 USA

Less 10 Europe

** Research up to date population of high speed Internet Acces

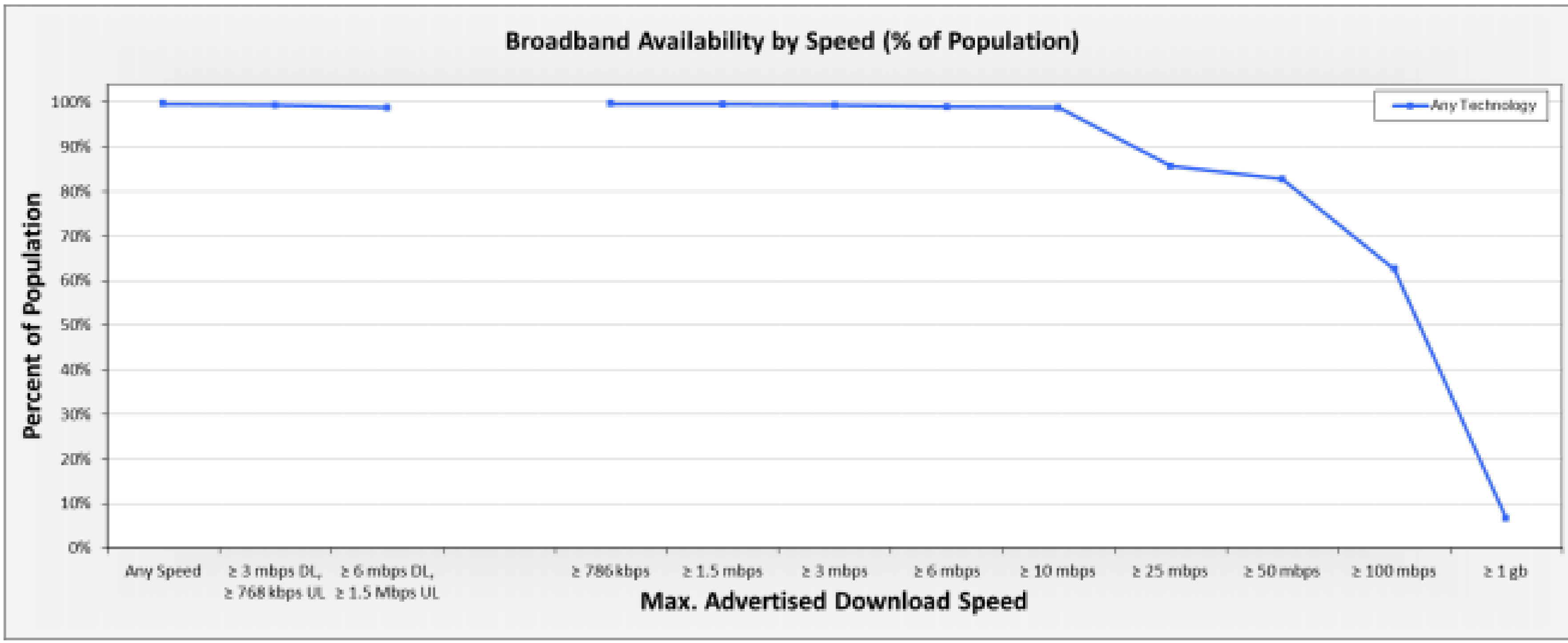
Population of broadband Access

Rank	Countries	Amount
# 1	Korea, South:	2.466 per 10 people
# 2	Hong Kong:	2.335 per 10 people
# 3	Netherlands:	2.334 per 10 people
# 4	Denmark:	2.255 per 10 people
# 5	Switzerland:	2.07 per 10 people
# 6	Canada:	1.93 per 10 people
# 7	Norway:	1.925 per 10 people
# 8	Finland:	1.92 per 10 people
# 9	Sweden:	1.868 per 10 people
# 10	Taiwan:	1.841 per 10 people
# 11	Israel:	1.824 per 10 people
# 12	Belgium:	1.792 per 10 people
# 13	Japan:	1.641 per 10 people
# 14	France:	1.472 per 10 people
# 15	United Kingdom:	1.466 per 10 people
# 16	United States:	1.382 per 10 people
# 17	Austria:	1.305 per 10 people
# 18	Australia:	1.177 per 10 people
= 19	Portugal:	1.087 per 10 people
= 19	Spain:	1.087 per 10 people
# 21	Germany:	1.02 per 10 people
# 22	Italy:	1.016 per 10 people
# 23	Chile:	0.41 per 10 people
# 24	Poland:	0.352 per 10 people
# 25	China:	0.268 per 10 people
# 26	Argentina:	0.175 per 10 people
# 27	Turkey:	0.162 per 10 people
# 28	Brazil:	0.156 per 10 people
# 29	Russia:	0.099 per 10 people
# 30	Mexico:	0.088 per 10 people
# 31	India:	0.006 per 10 people

http://www.nationmaster.com/graph/int_bro_acc_percap-interne

Percent of Broadband Population

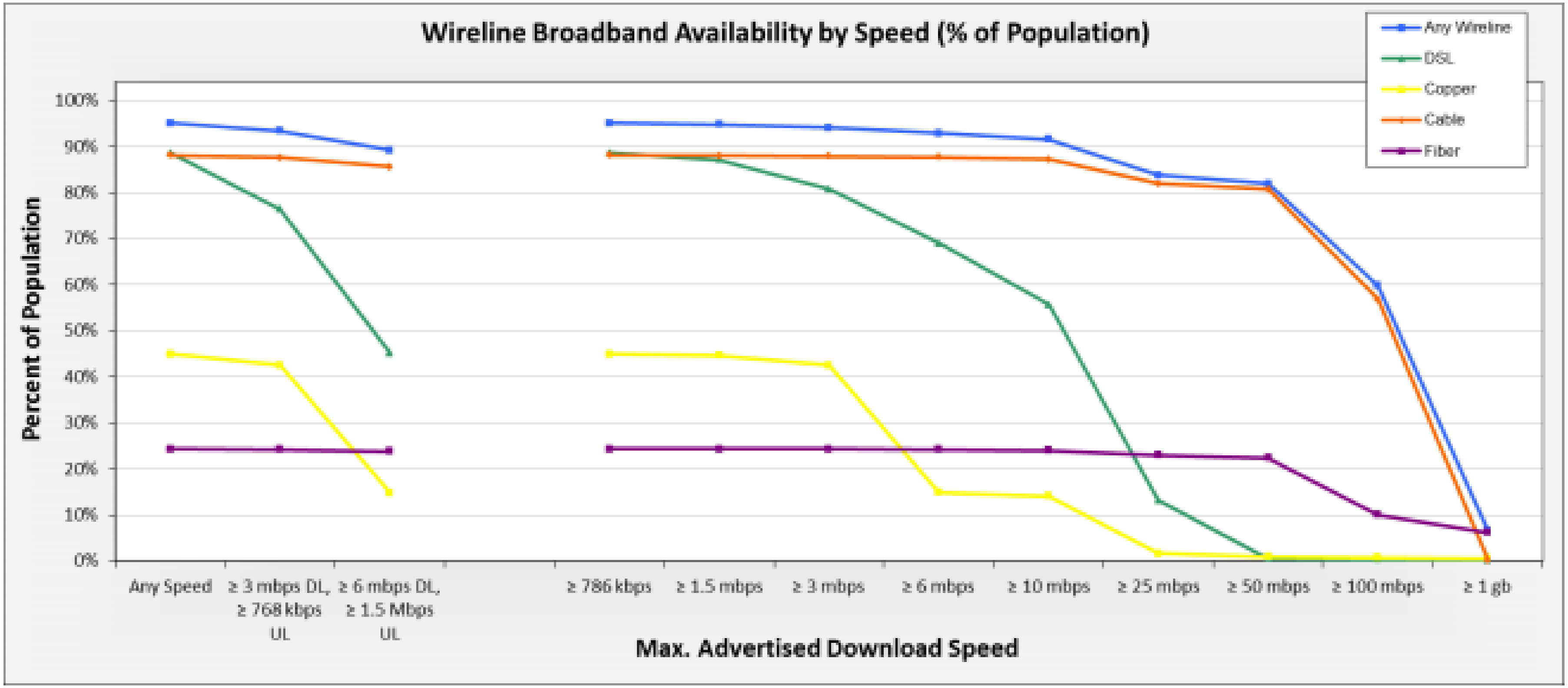
Graph: Any Technology
This graph illustrates the percent of population nationwide with access to any technology, by speed tier.



http://www.broadbandmap.gov/download/Technology%20by%20Speed.pdf

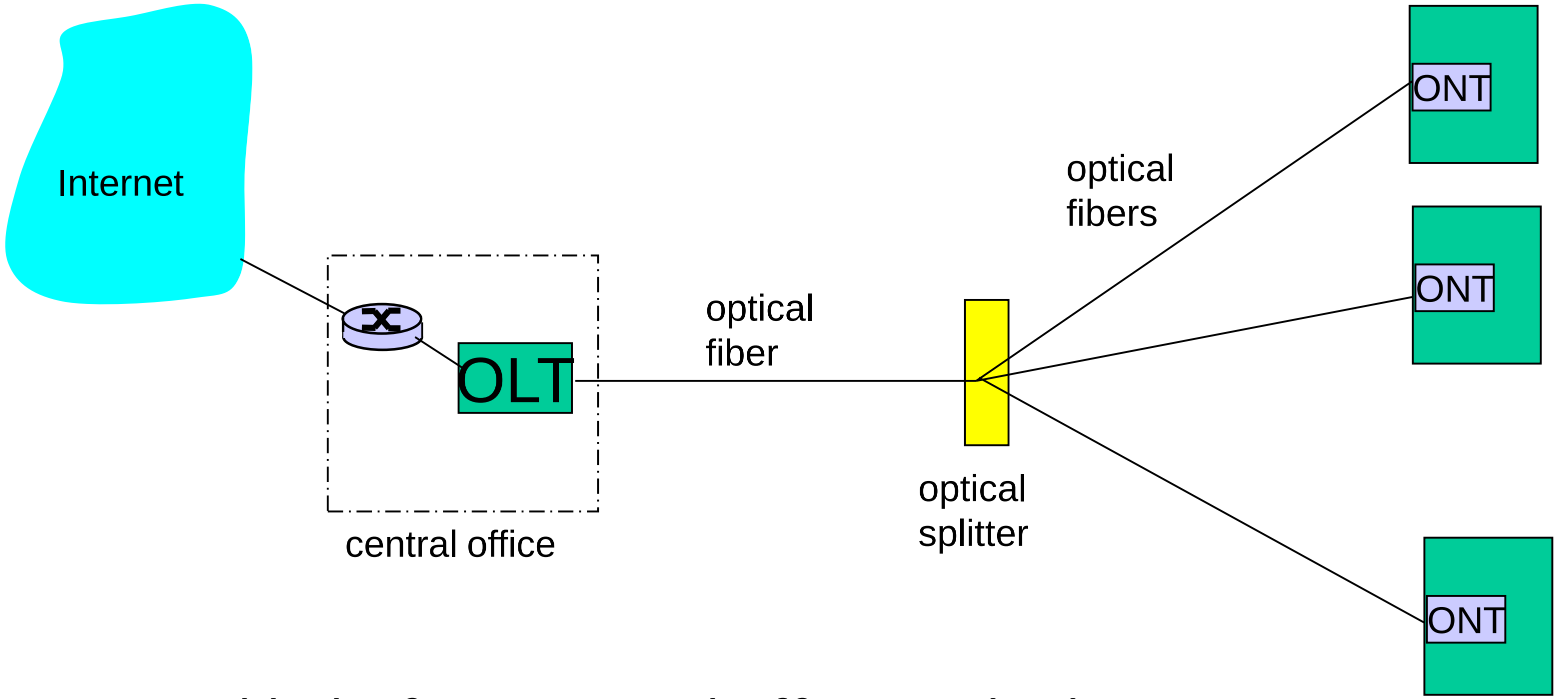
Percent of Broadband Population

Graph: Wireline Technology
This graph illustrates the percent of population nationwide with access to wireline technologies, by speed tier.



http://www.broadbandmap.gov/download/Technology%20by%20Speed.pdf

Fiber to the Home

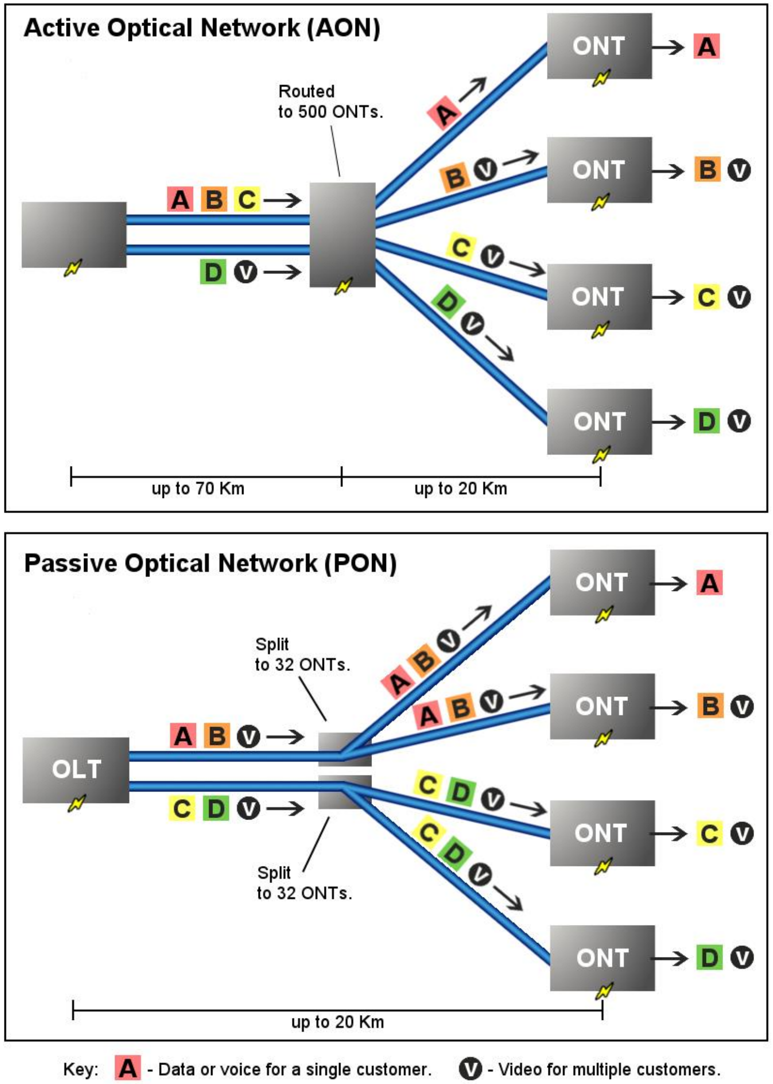


- Optical links from central office to the home
- Two competing optical technologies:
  - Passive Optical network (PON)
  - Active Optical Network (AON)
- Much higher Internet rates; fiber also carries television and phone services

Fiber to the Home

Shared fiber

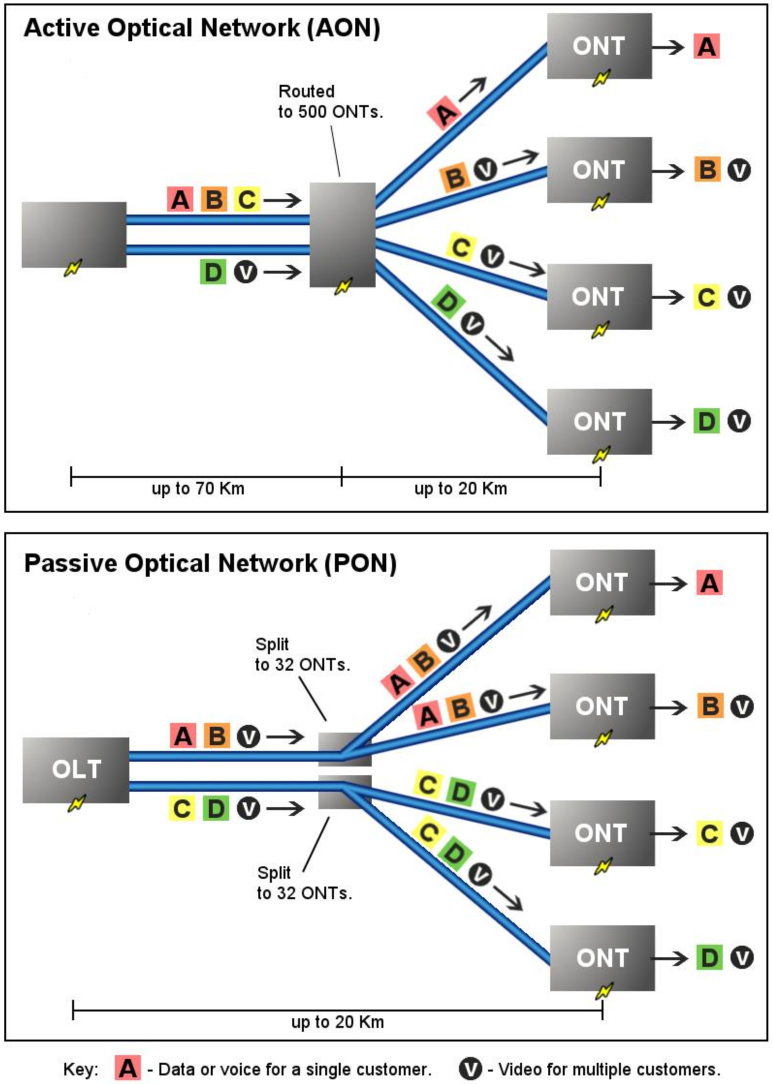
More commonly each fiber leaving the central office is actually shared by many customers. It is not until such a fiber gets relatively close to the customers that it is split into individual customer-specific fibers. There are two competing optical distribution network architectures which achieve this split: active optical networks (AONs) and PONs.



Fiber to the Home

AON

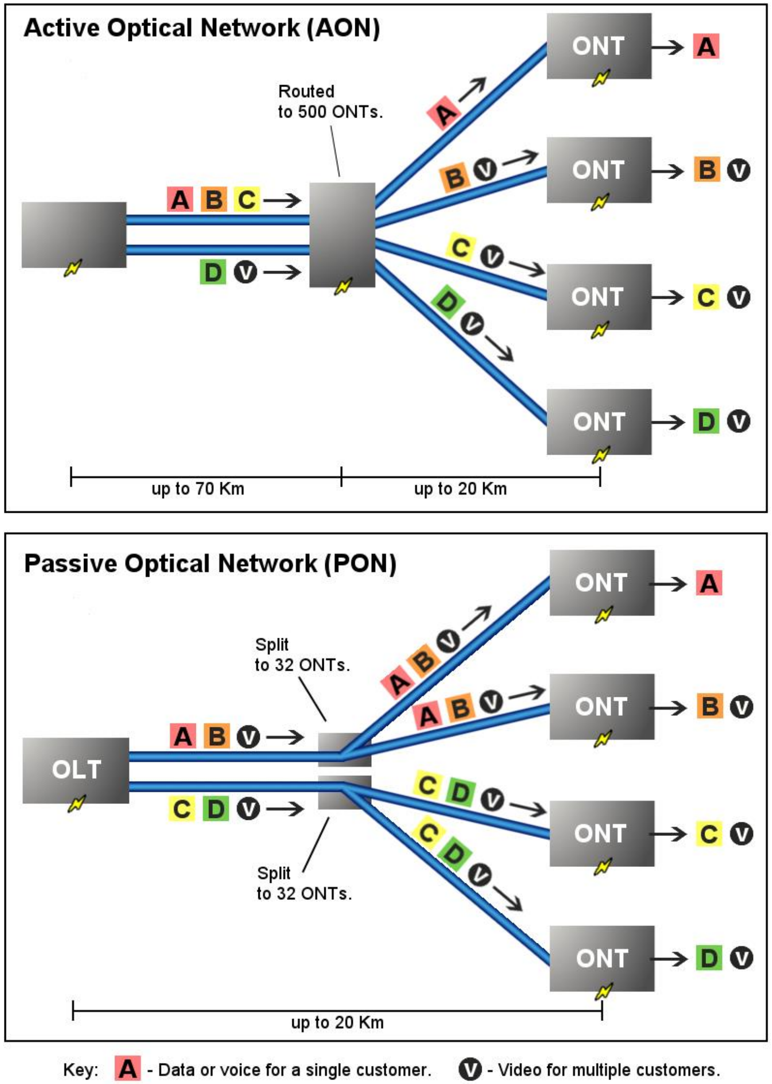
Active optical networks rely on some sort of electrically powered equipment to distribute the signal, such as a switch, router, or multiplexer. Each signal leaving the central office is directed only to the customer for which it is intended. Incoming signals from the customers avoid colliding at the intersection because the powered equipment there provides buffering.



Fiber to the Home

PON

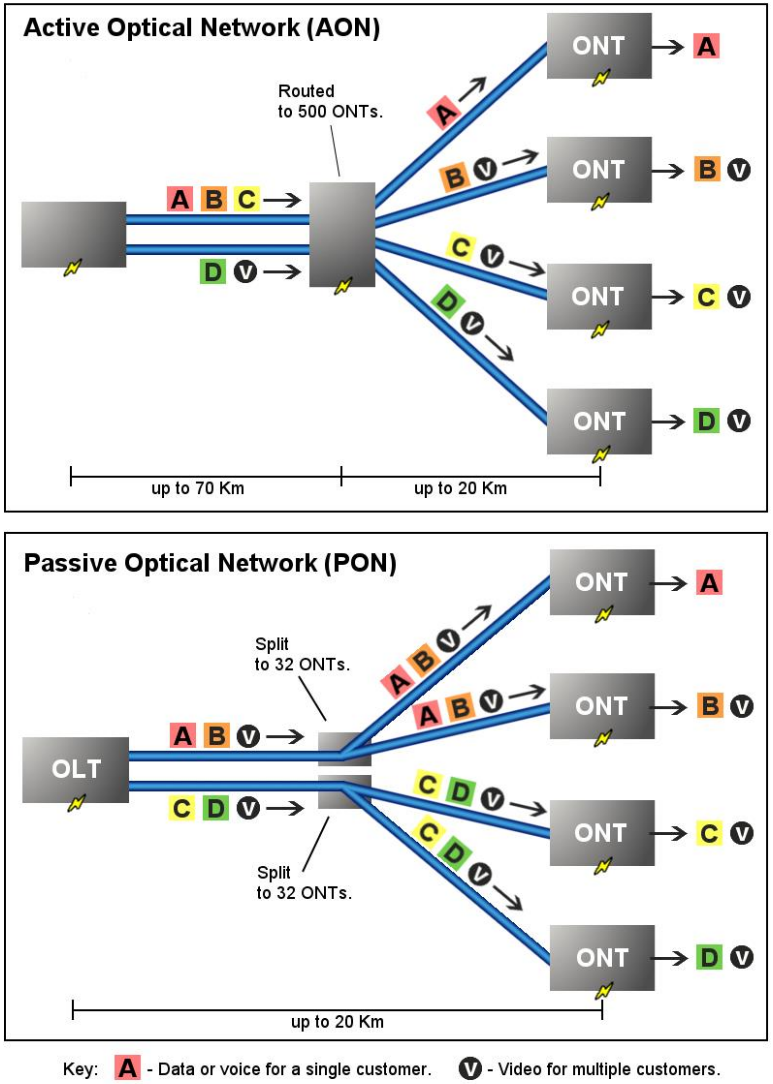
Passive optical network is a point-to-multipoint, fiber to the premises network architecture in which unpowered optical splitters are used to enable a single optical fiber to serve multiple premises, typically 32-128. A PON configuration reduces the amount of fiber and central office equipment required compared with point to point architectures.



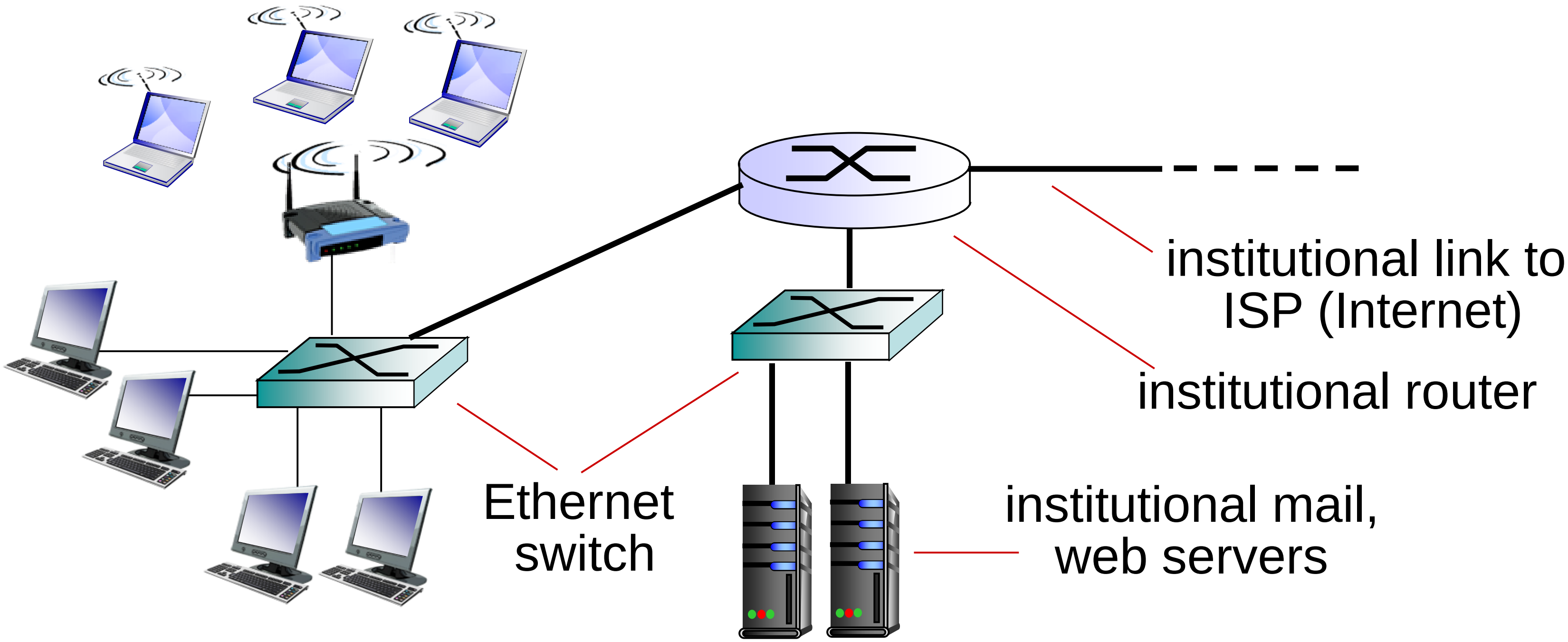
Fiber to the Home

PON

Downstream signal coming from the central office is broadcast to each customer premises sharing a fiber. Encryption is used to prevent eavesdropping.
Upstream signals are combined using a multiple access protocol, invariably time division multiple access (TDMA). The OLTs "range" the ONUs in order to provide time slot assignments for upstream communication.



Enterprise access networks (Ethernet)



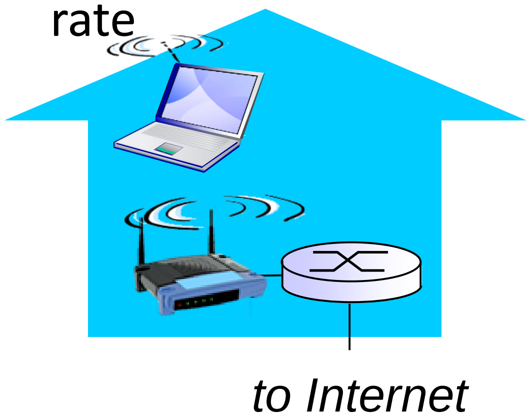
- typically used in companies, universities, etc
- 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates
- today, end systems typically connect into Ethernet switch

Wireless access networks

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

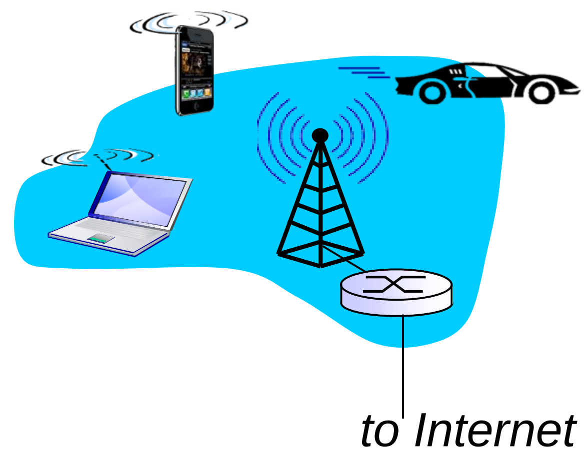
wireless LANs:

- within building (100 ft)
- 802.11b/g/n/ac (WiFi): 11, 54, 300, 1300 Mbps transmission rate



wide-area wireless access

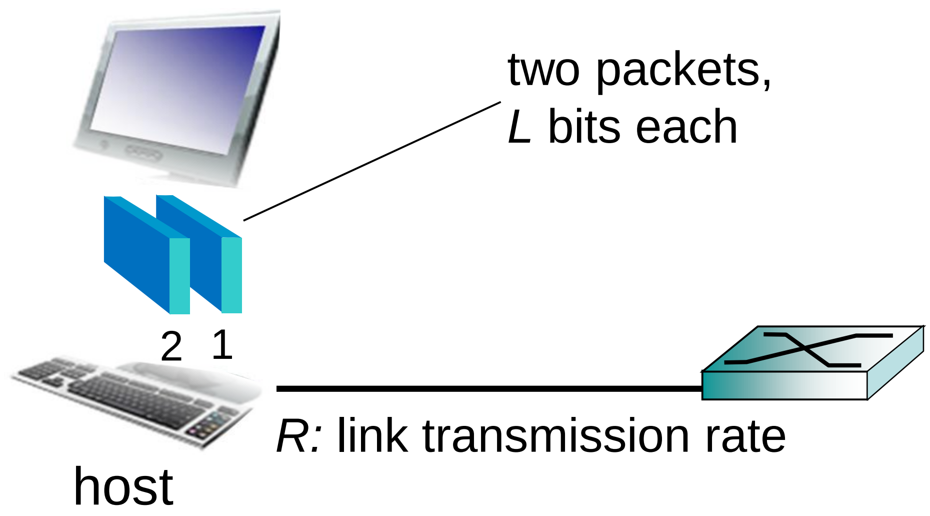
- provided by telco (cellular) operator, 10's km
- between 1 and 10 Mbps
- 3G, 4G: LTE



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

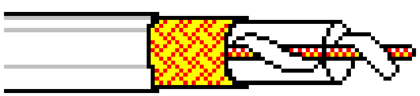
twisted pair (TP)

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

Physical media: coax, fiber

coaxial cable:

- two concentric copper conductors
- bidirectional
- broadband:
  - multiple channels on cable
  - HFC



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

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, 1 Gbps
- wide-area (e.g., cellular)
  - 3G / 4G cellular: ~ few Mbps
  - 5G is coming
- satellite
  - Kbps to 45Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus low altitude

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

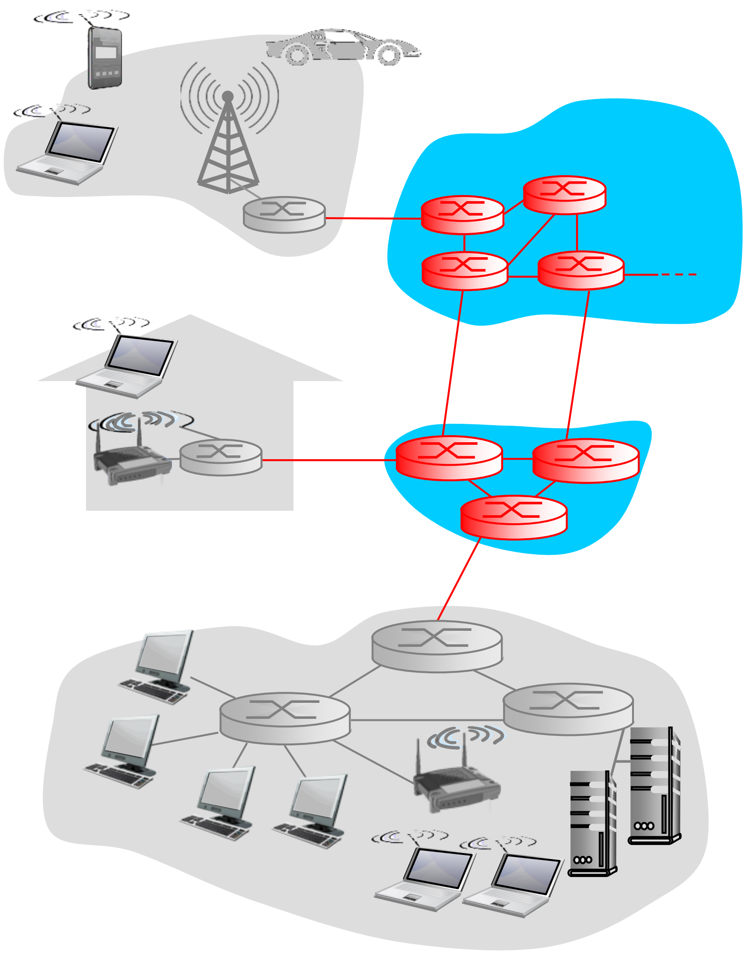
1.5 protocol layers, service models

1.6 networks under attack: security

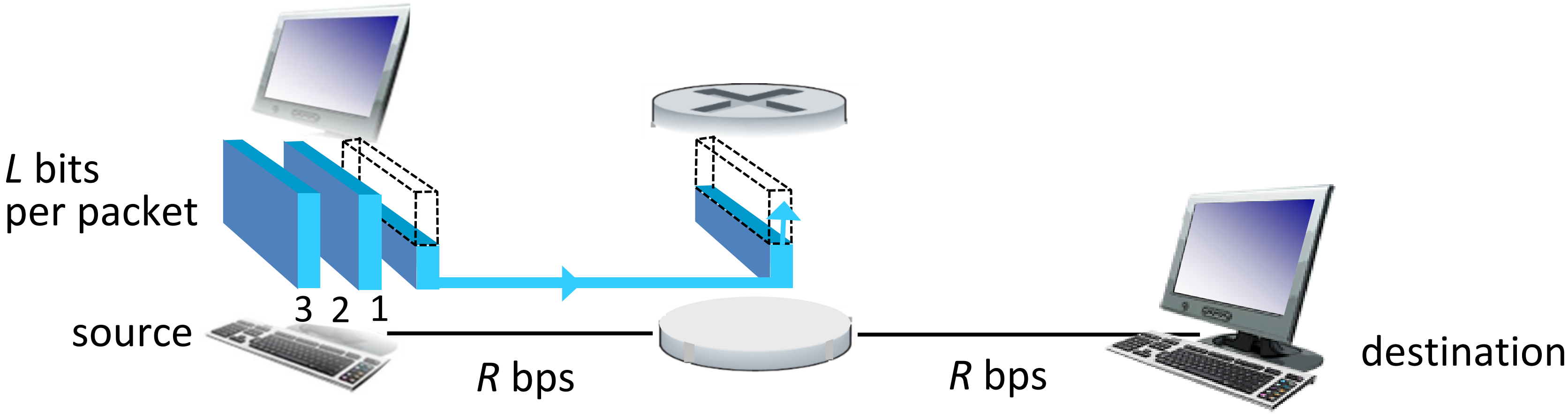
1.7 history

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



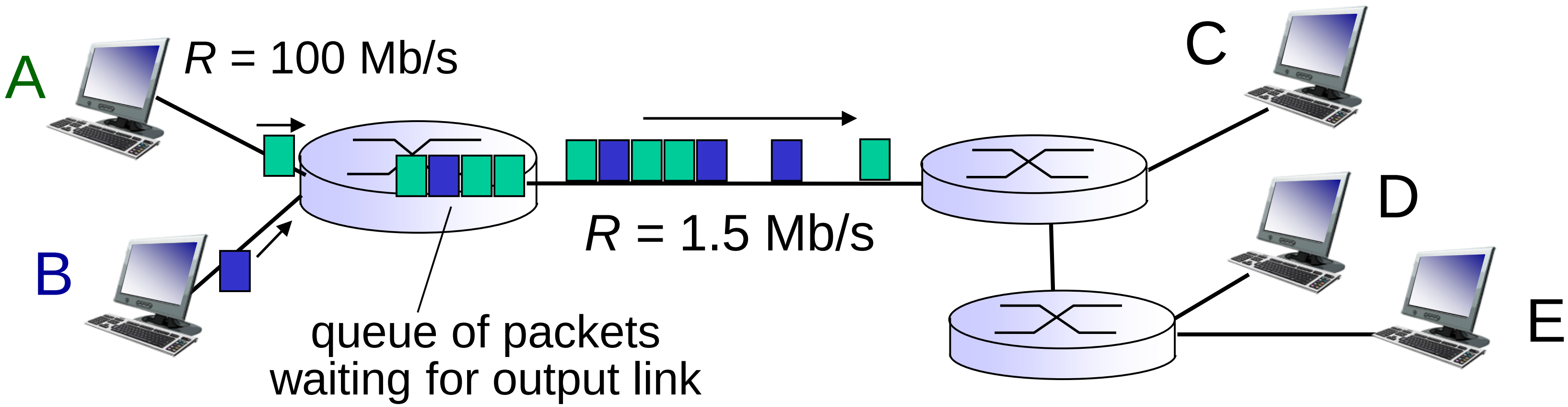
- takes L/R seconds to transmit (push out) L-bit packet into link at R bps
- *store and forward:* entire packet must arrive at router before it can be transmitted on next link
- end-end delay = $2L/R$ (assuming zero propagation delay)

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:

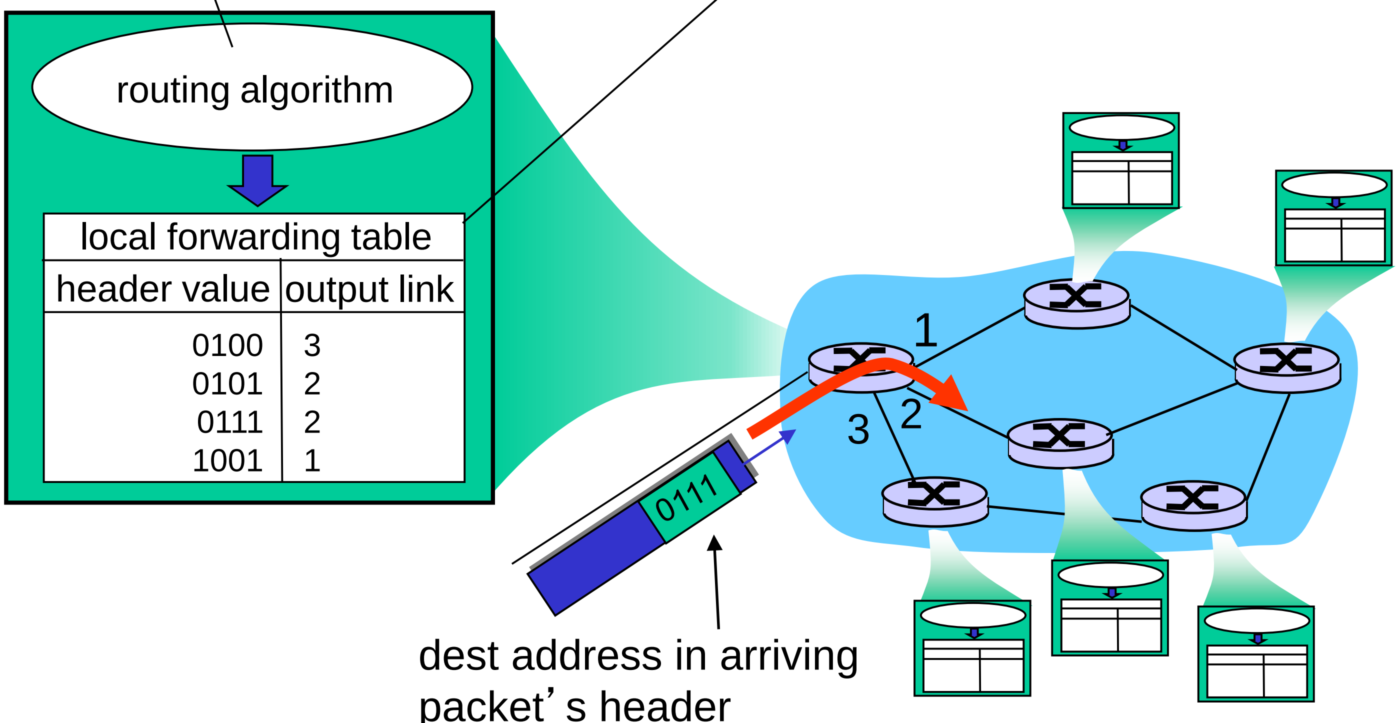
- If arrival rate (in bits) to link exceeds transmission rate of link for a period of time:
  - packets will queue, wait to be transmitted on link
  - packets can be dropped (lost) if memory (buffer) fills up

Two key network-core functions

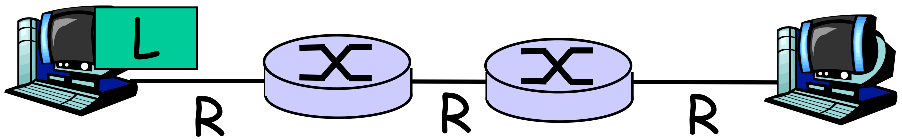
routing: determines source-destination route taken by packets

- *routing algorithms*

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



Packet-switching: store-and-forward



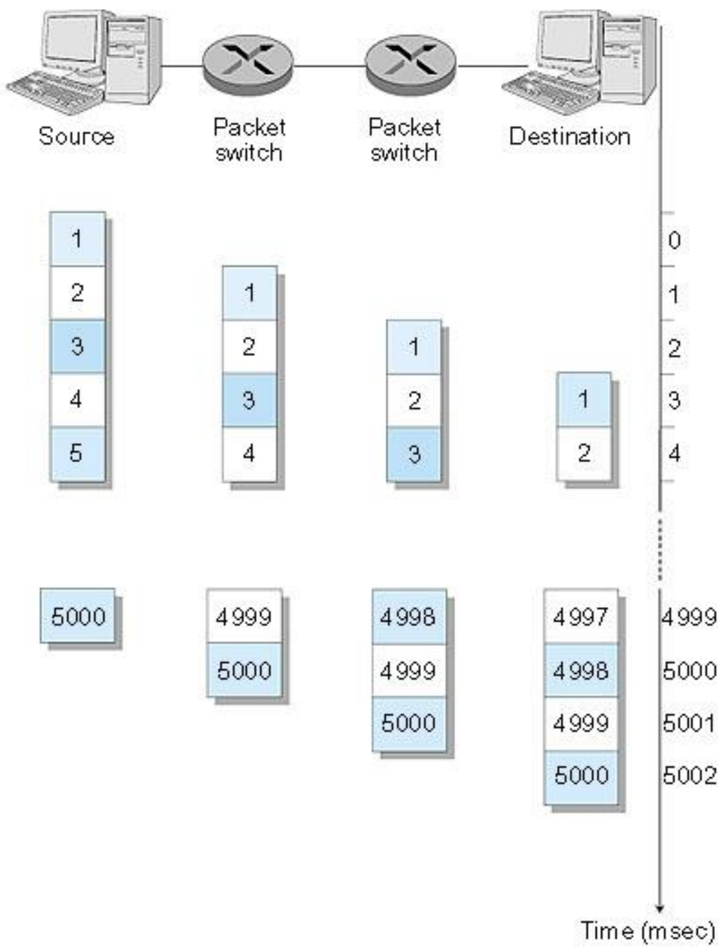
- takes L/R seconds to transmit (push out) packet of L bits on to link at R bps
- *store and forward:* entire packet must arrive at router before it can be transmitted on next link
- delay = 3L/R (assuming zero propagation delay)

Example:

- L = 7.5 Mbits
- R = 1.5 Mbps
- transmission delay = 15 sec

more on delay shortly …

Packet Switching: Message Segmenting

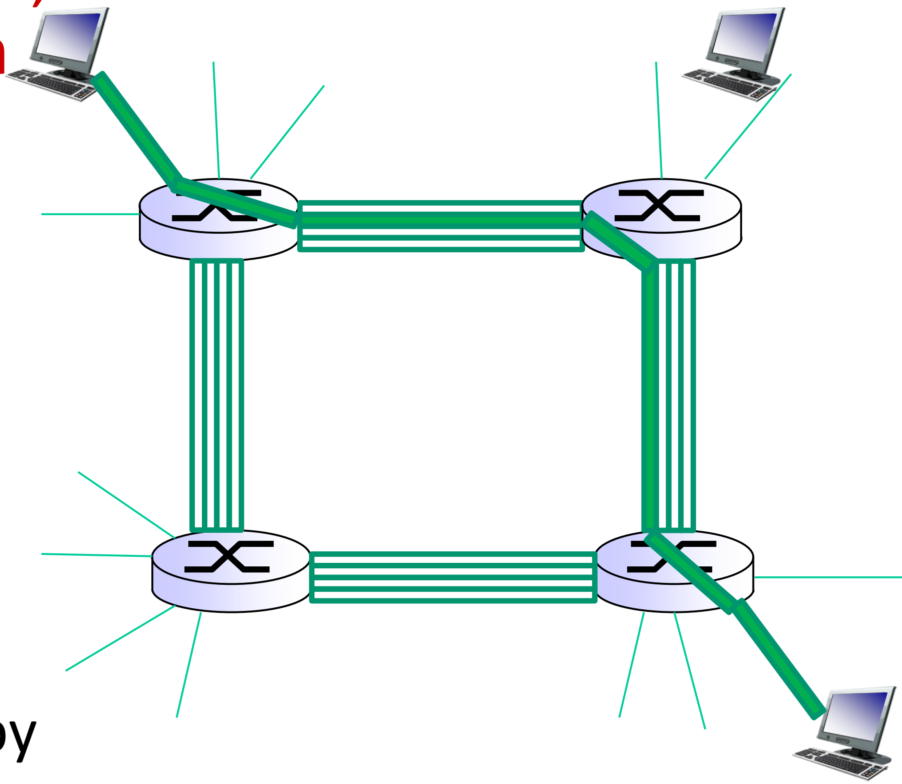


Now break up the message into 5000 packets

- Each packet 1,500 bits
- 1 msec to transmit packet on one link
- *pipelining:* each link works in parallel
- Delay reduced from 15 sec to 5.002 sec

Alternative core: circuit switching

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



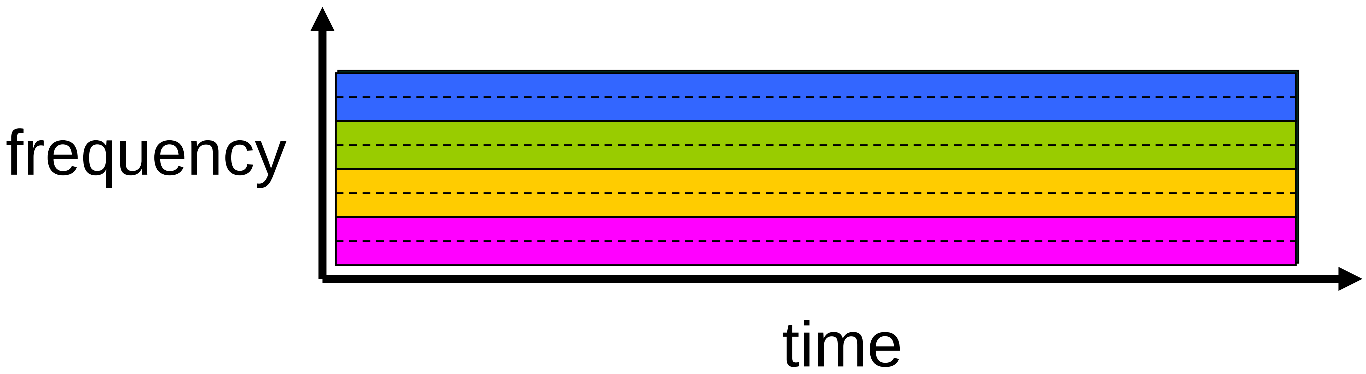
- In diagram, each link has four circuits.
  - call gets 2^{nd} circuit in top link and 1^{st} circuit in right link.
- dedicated resources: no sharing
  - circuit-like (guaranteed) performance
- circuit segment idle if not used by call *(no sharing)*
- Commonly used in traditional telephone networks

Circuit switching: FDM versus TDM

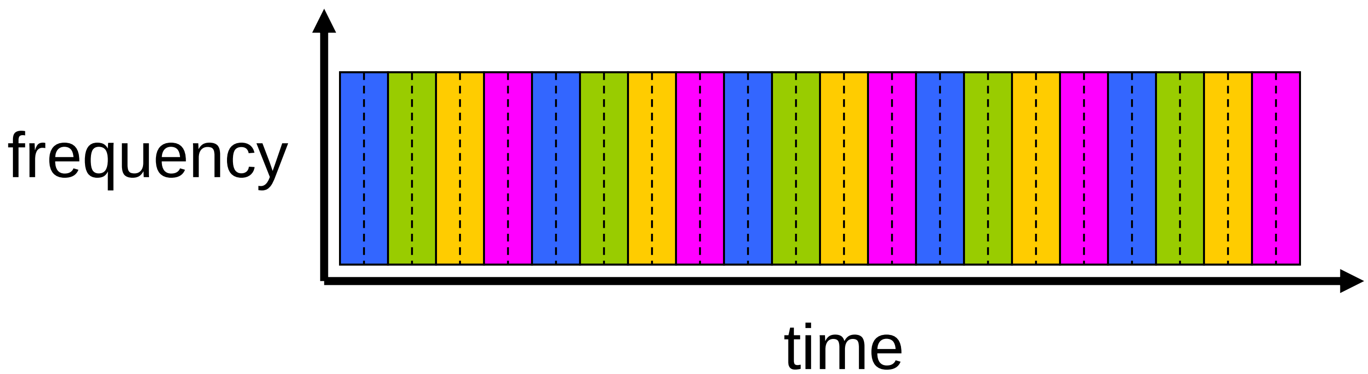
Example:

4 users

FDM



TDM



Numerical example

- How long does it take to send a file of 640,000 bits from host A to host B over a circuit-switched network?
  - All links are 1.536 Mbps
  - Each link uses TDM with 24 slots/sec
  - 500 msec to establish end-to-end circuit

Let’s work it out!

Numerical example II

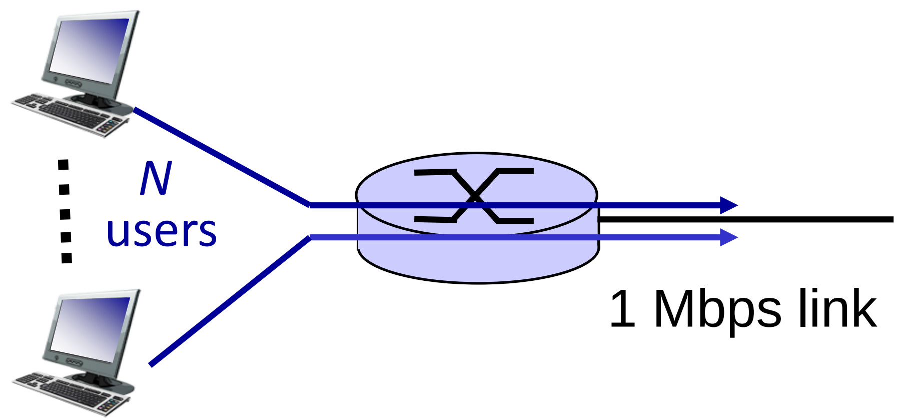
- How long does it take to send a file of 100 MB from host A to host B over a core PSTN?
  - 1000 Km distance between host A and host B

Solve it NOW!!!!!

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 *

* Check out the online interactive exercises for more examples

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 under study

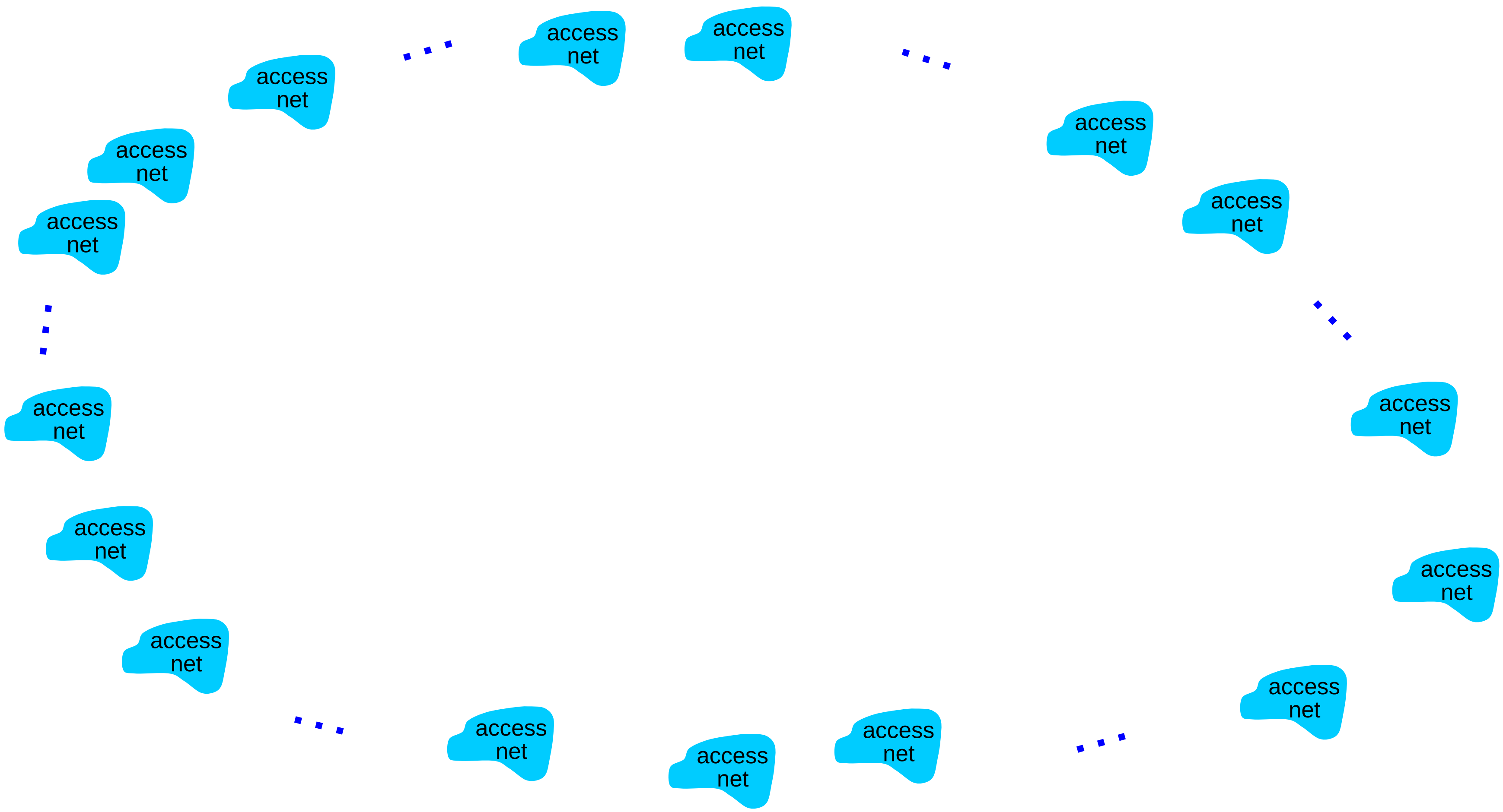
Q: human analogies of reserved resources (circuit switching) versus on-demand allocation (packet-switching)?

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

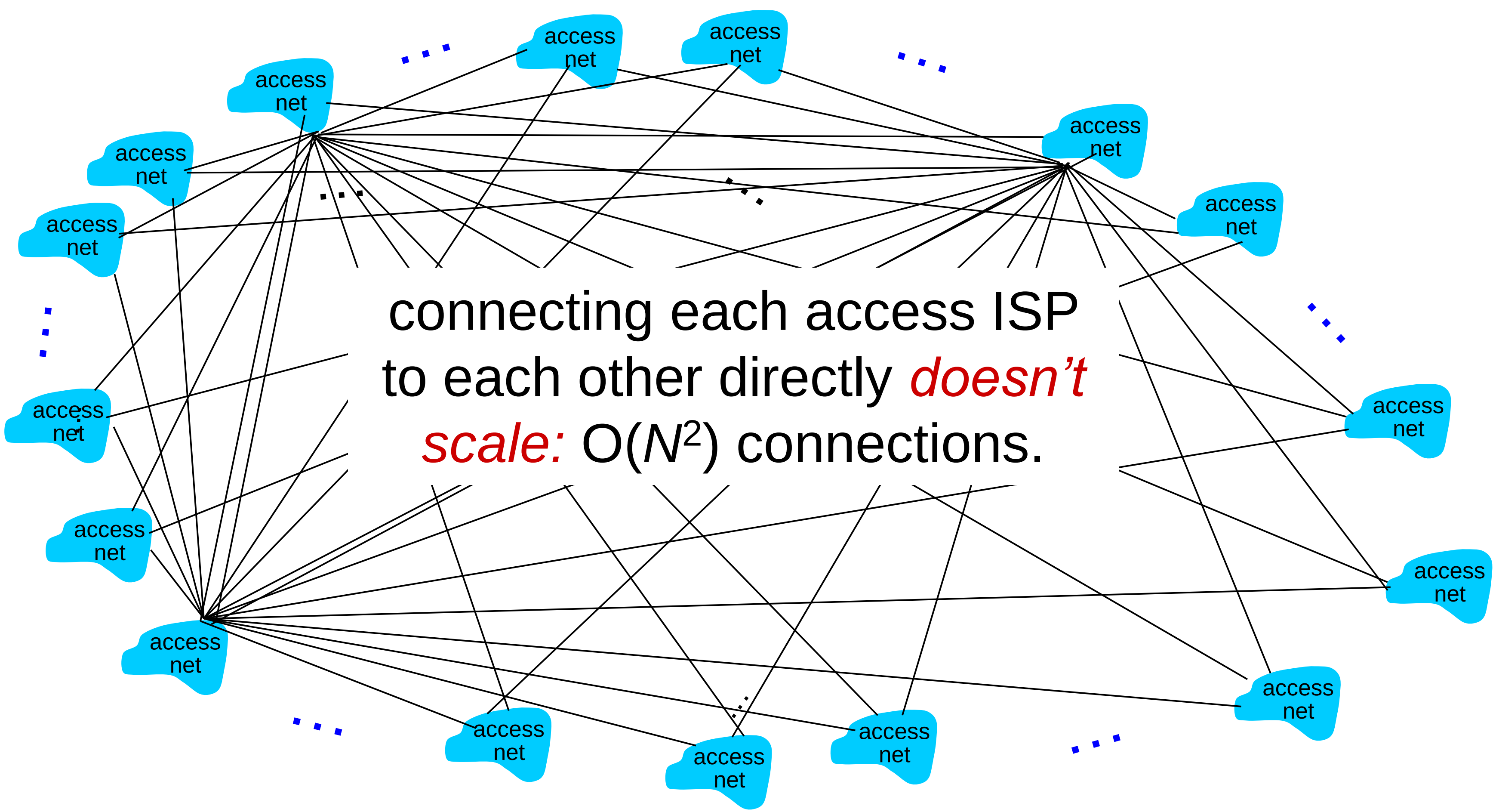
Internet structure: network of networks

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



Internet structure: network of networks

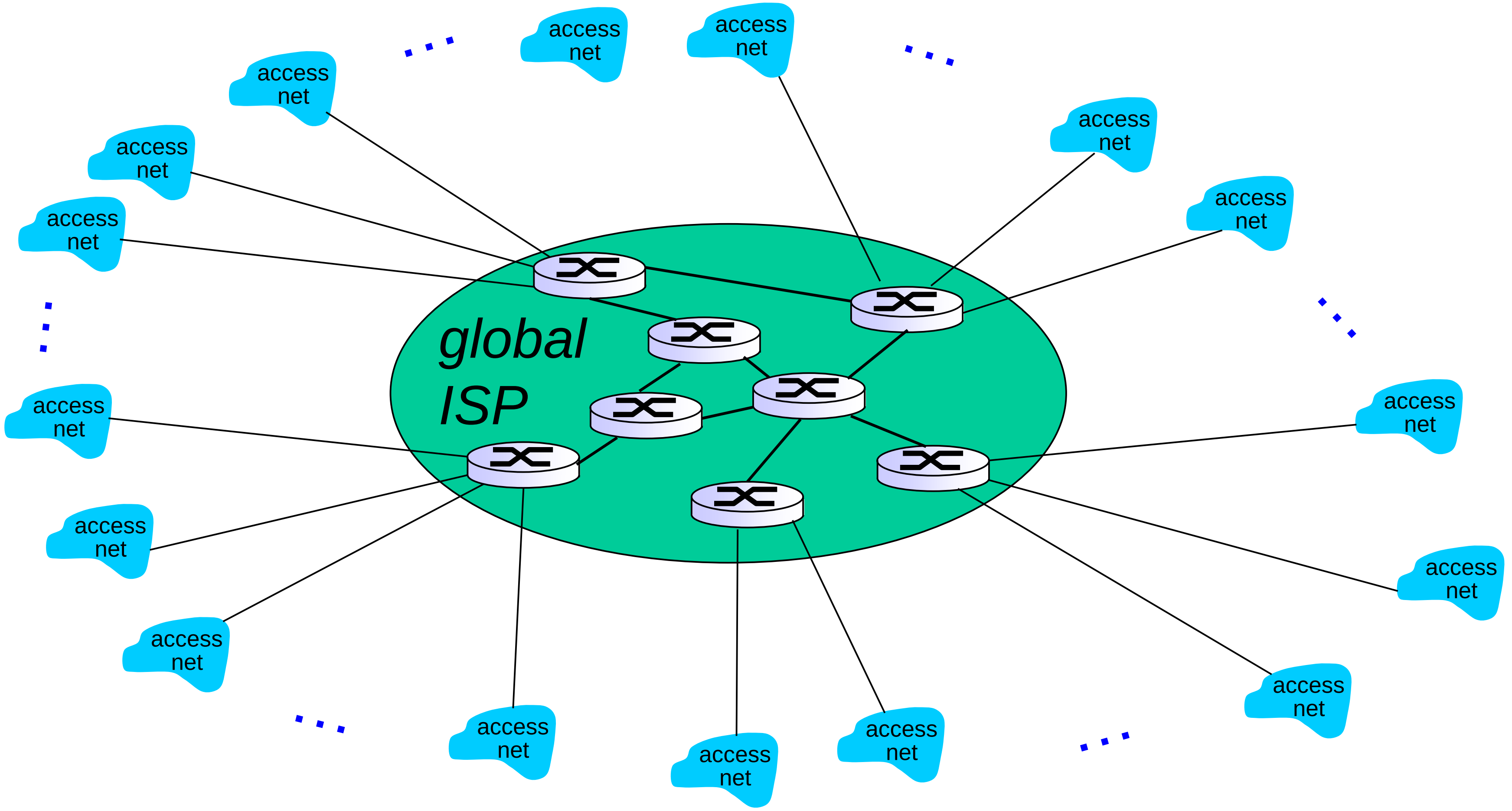
Option: connect each access ISP to every other access ISP?



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

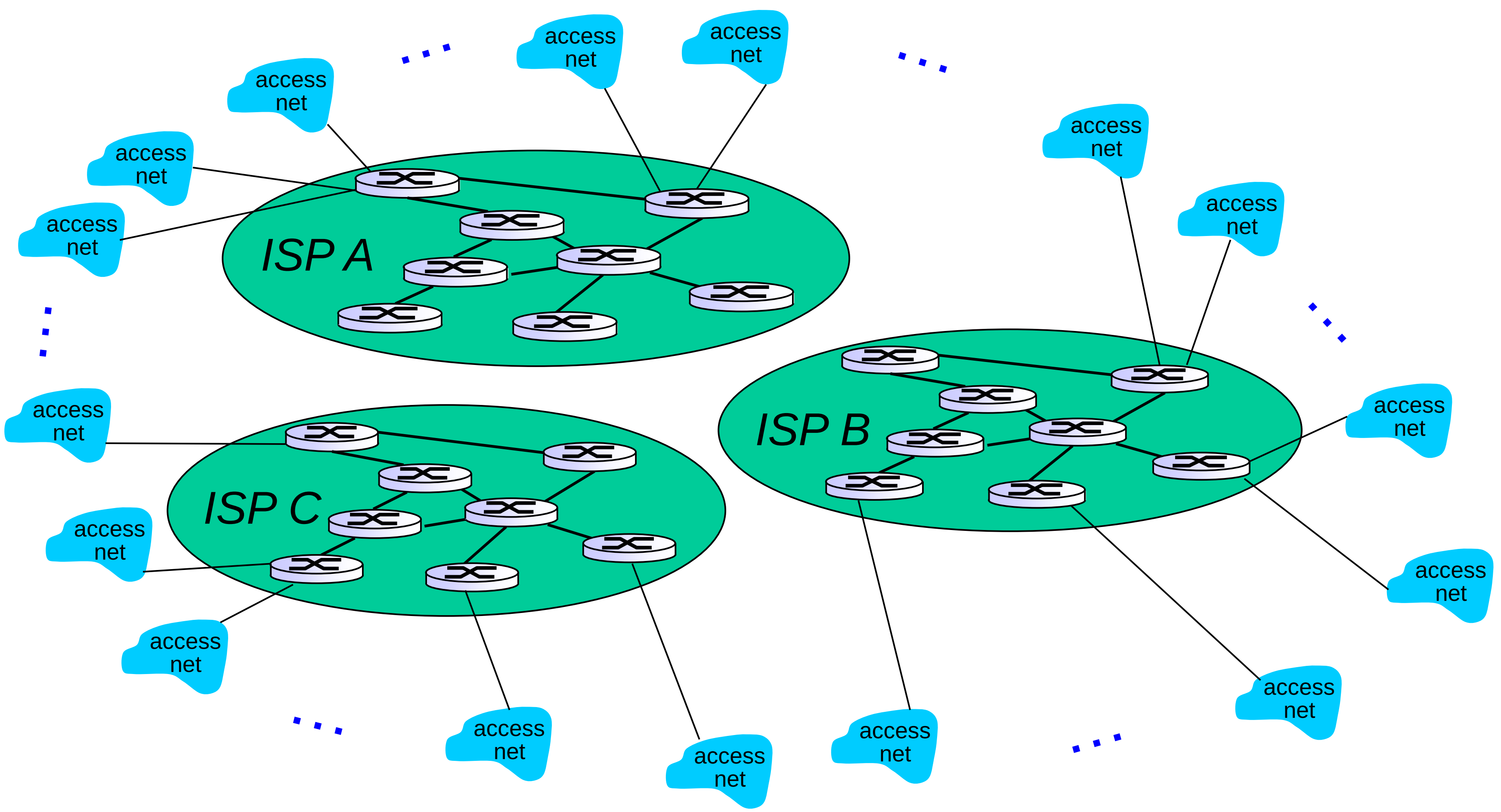
Internet structure: network of networks

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



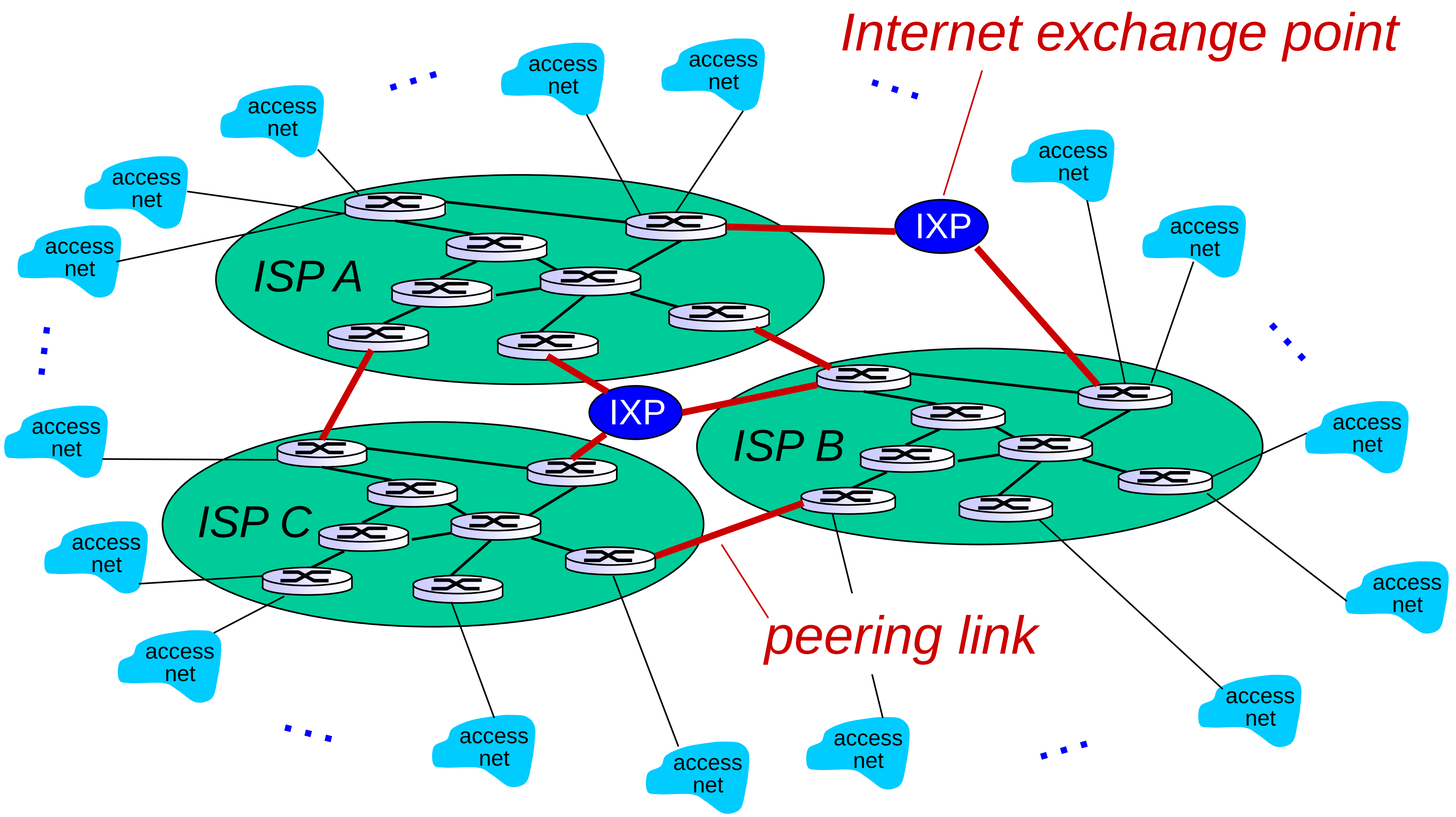
Internet structure: network of networks

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



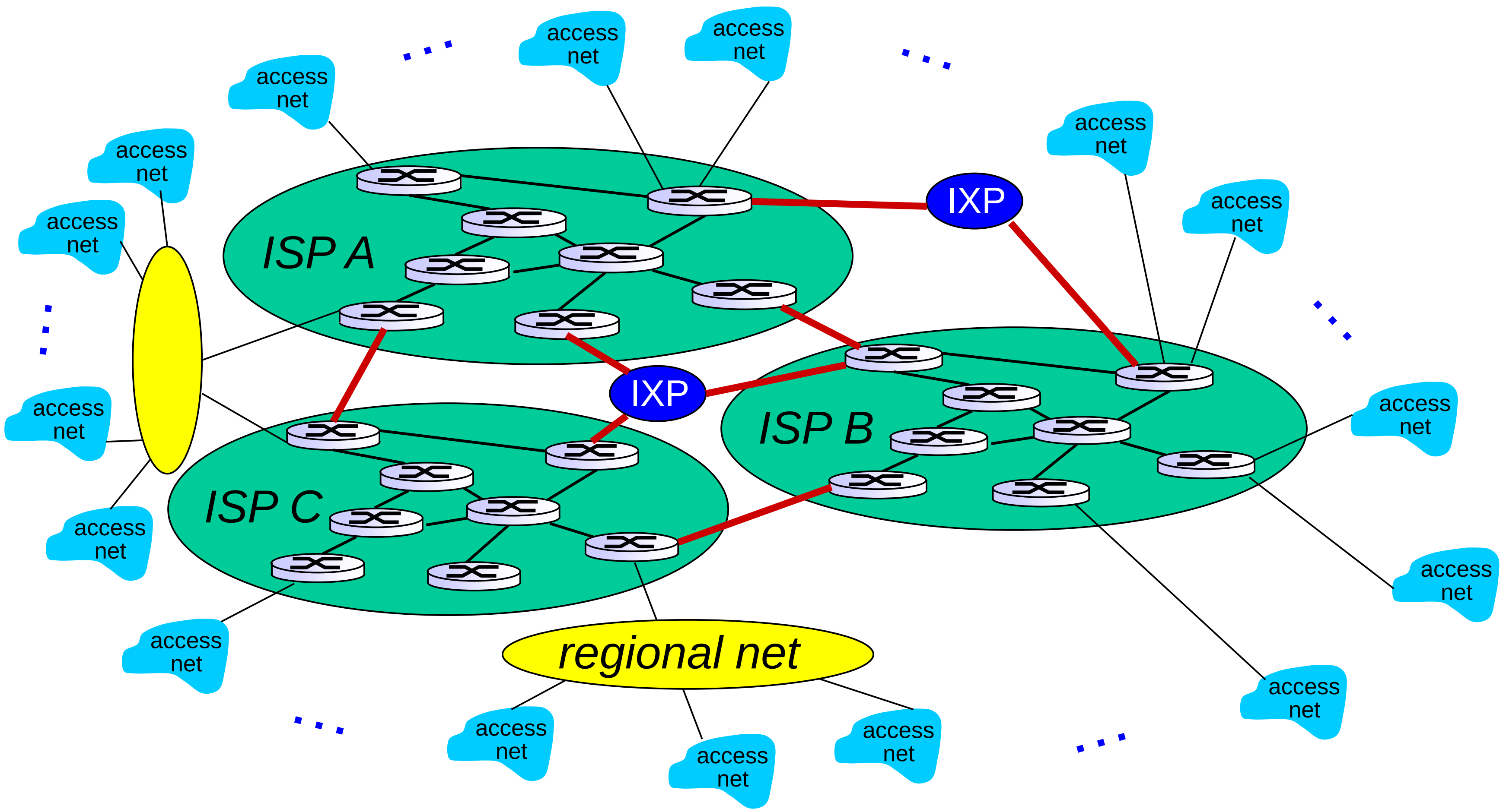
Internet structure: network of networks

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



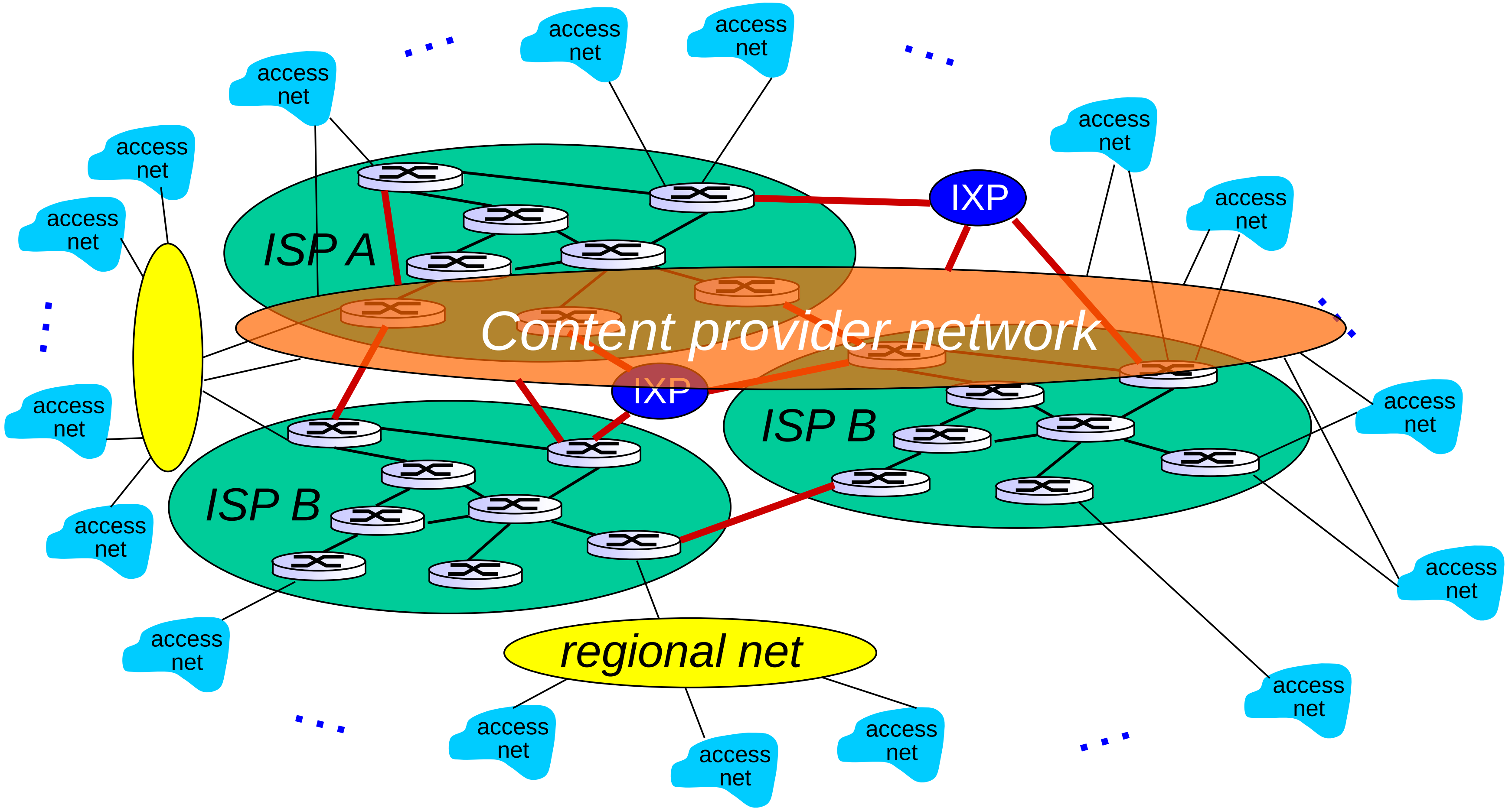
Internet structure: network of networks

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

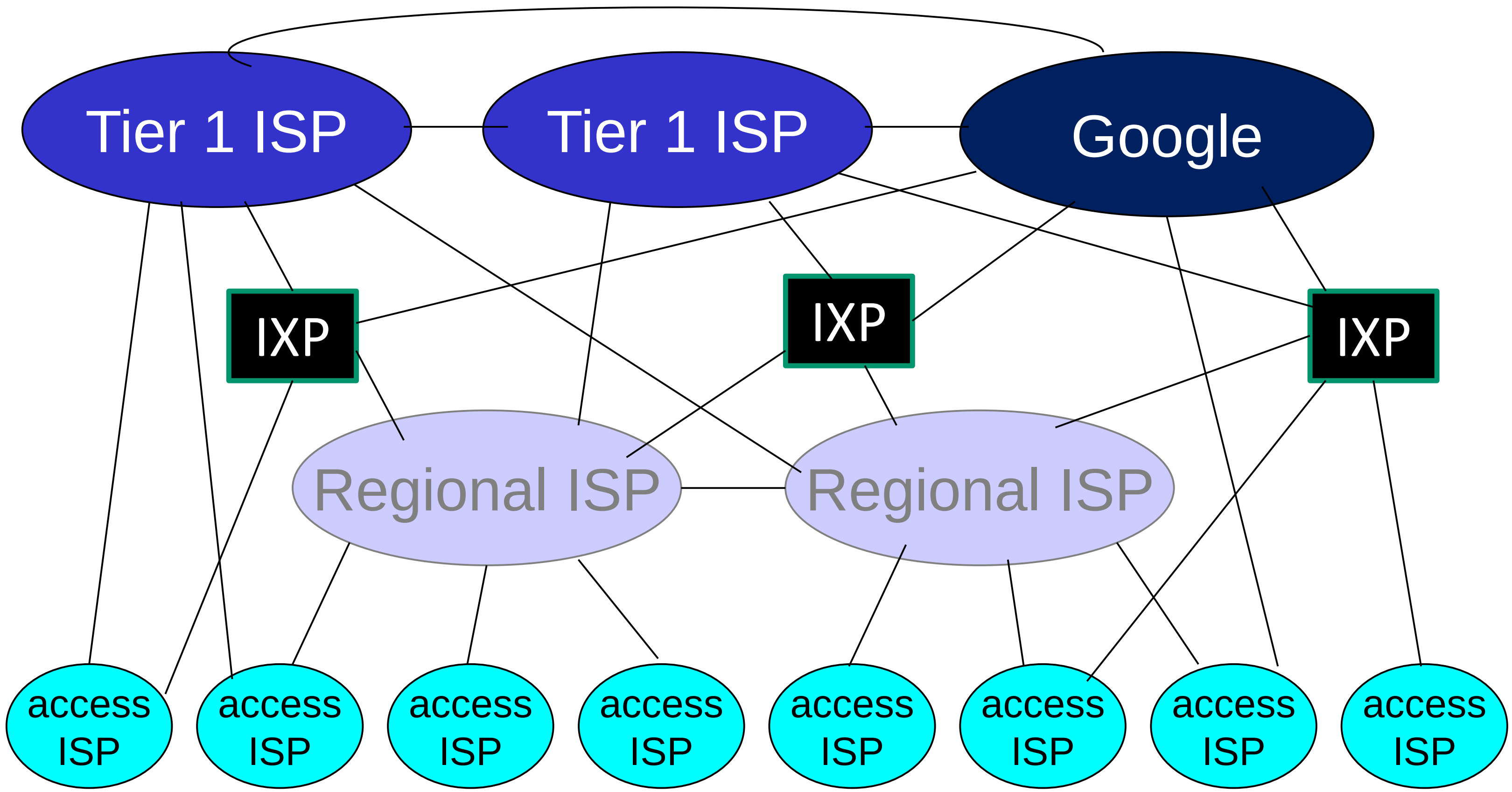


Internet structure: network of networks

… 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

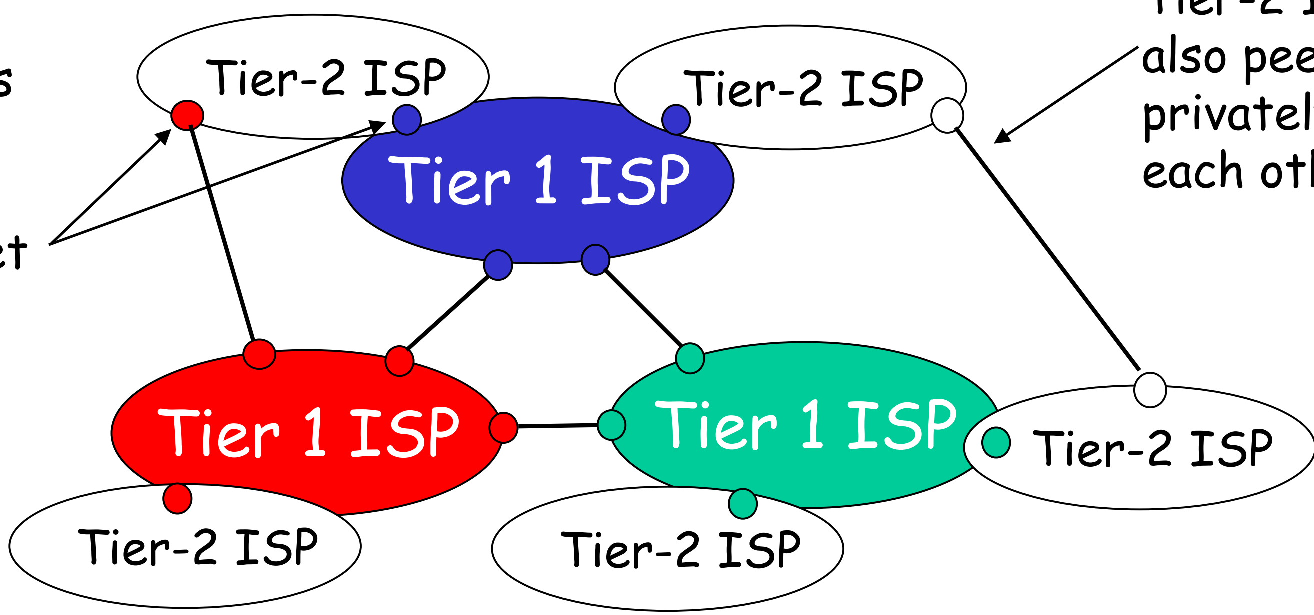


- at center: small # of well-connected large networks
  - "tier-1" commercial ISPs (e.g., Level 3, Sprint, AT&T, NTT), national & international coverage
  - content provider network (e.g, Google): private network that connects it data centers to Internet, often bypassing tier-1, regional ISPs

Internet structure: network of networks

- “Tier-2” ISPs: smaller (often regional) ISPs
  - Connect to one or more tier-1 ISPs, possibly other tier-2 ISPs

Tier-2 ISP pays tier-1 ISP for connectivity to rest of Internet
- tier-2 ISP is *customer* of tier-1 provider

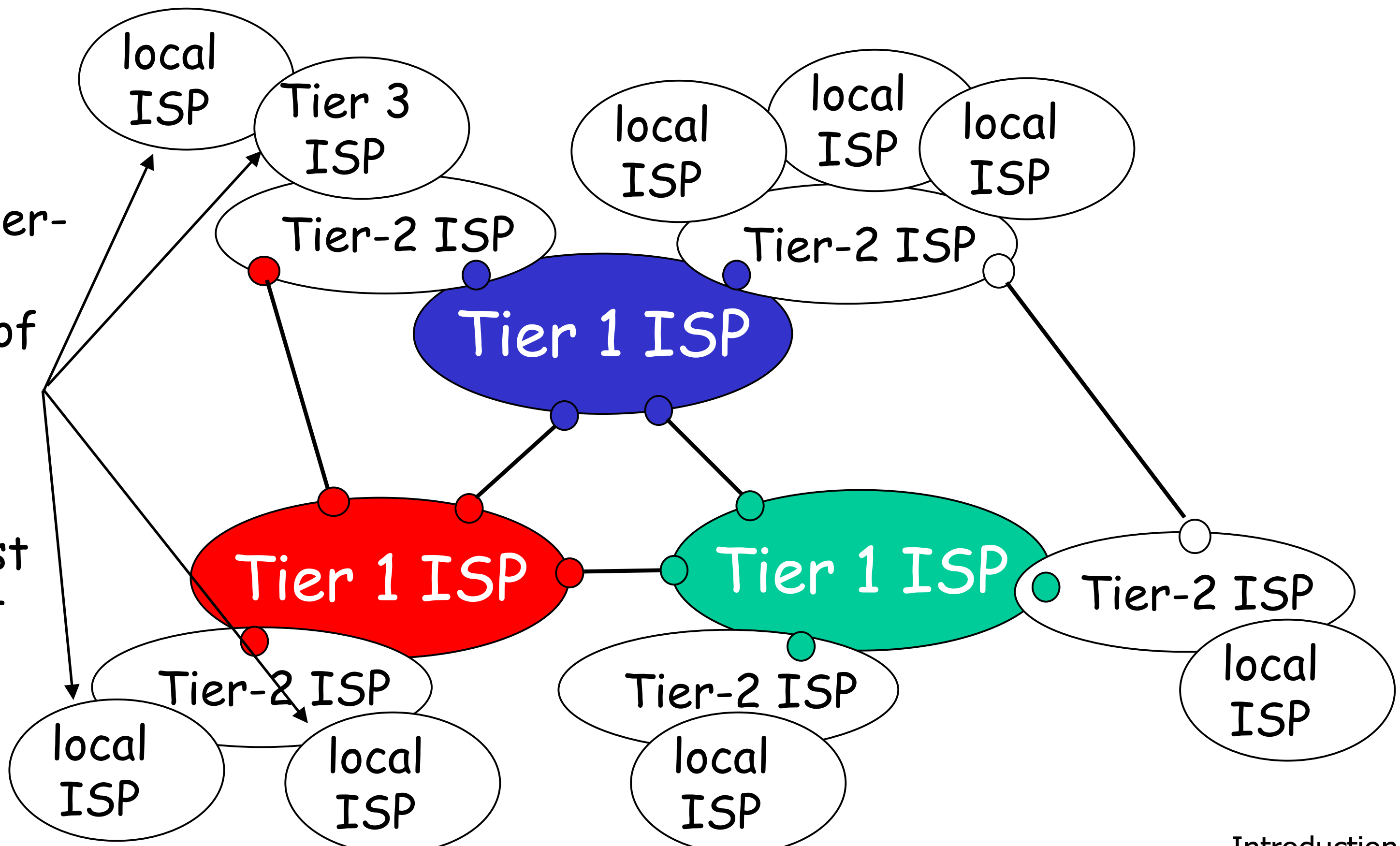


Tier-2 ISPs also peer privately with each other.

Internet structure: network of networks

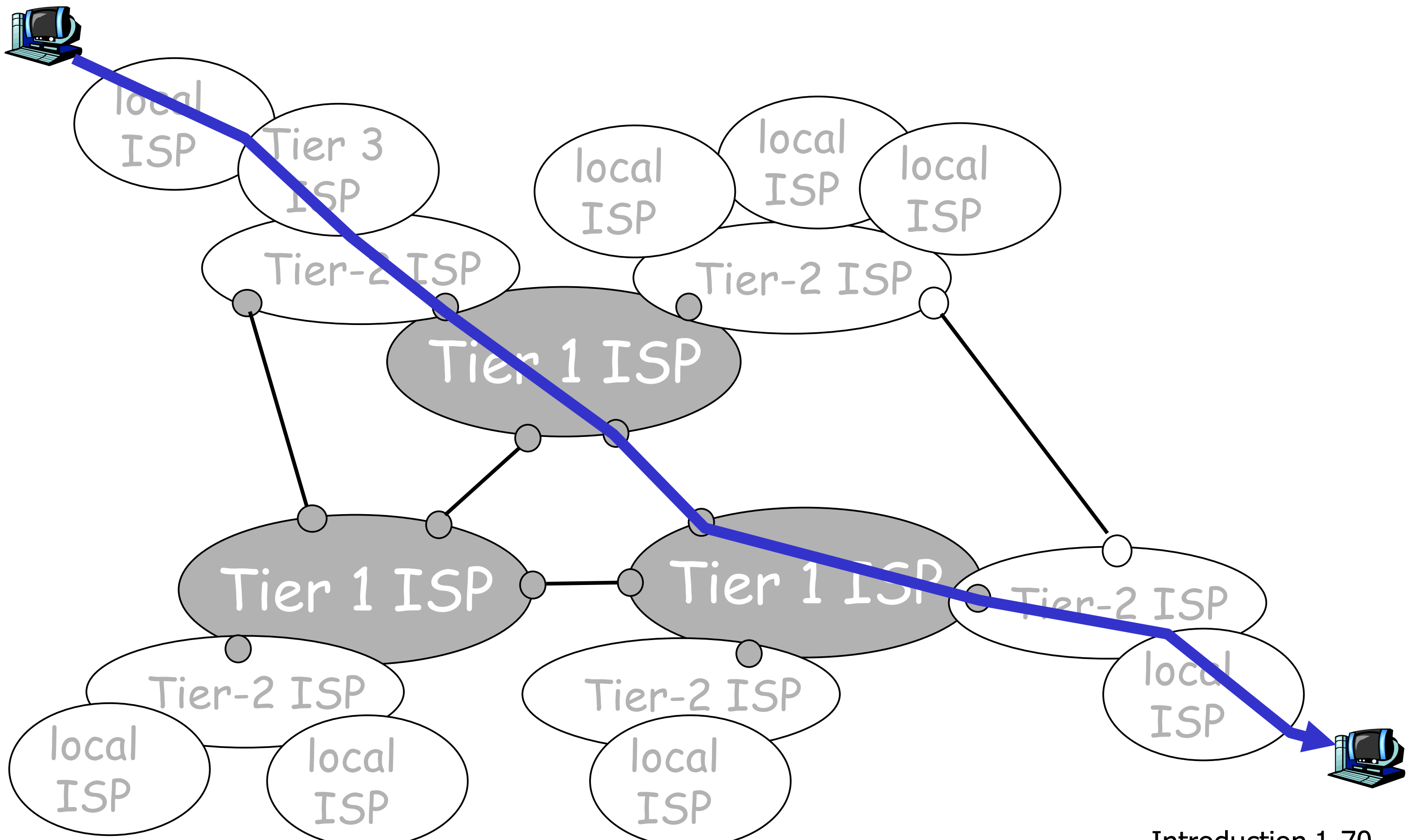
- "Tier-3" ISPs and local ISPs
  - last hop ("access") network (closest to end systems)

Local and tier-3 ISPs are *customers* of higher tier ISPs connecting them to rest of Internet

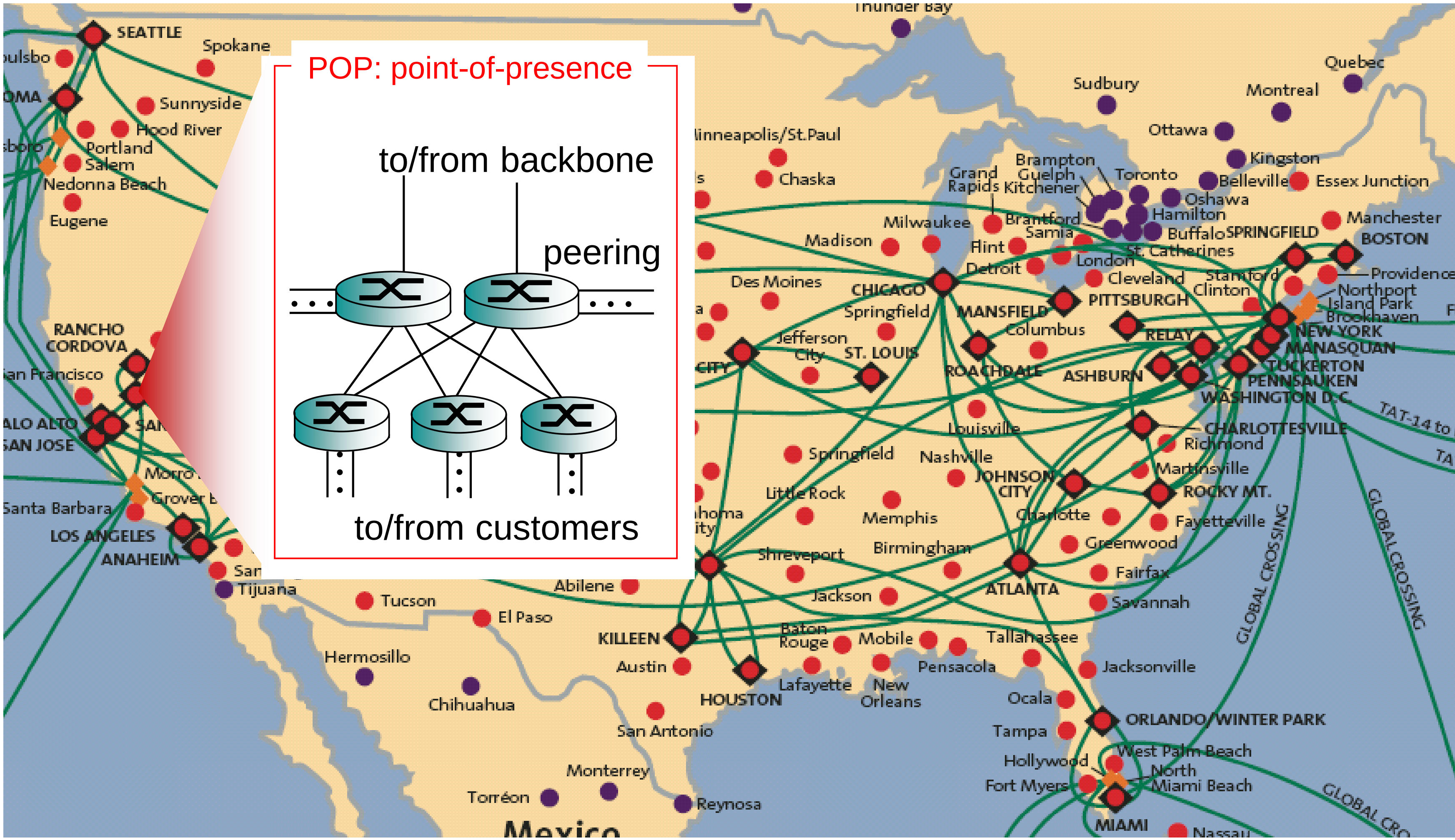


Internet structure: network of networks

- a packet passes through many networks!



Tier-1 ISP: e.g., Sprint



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

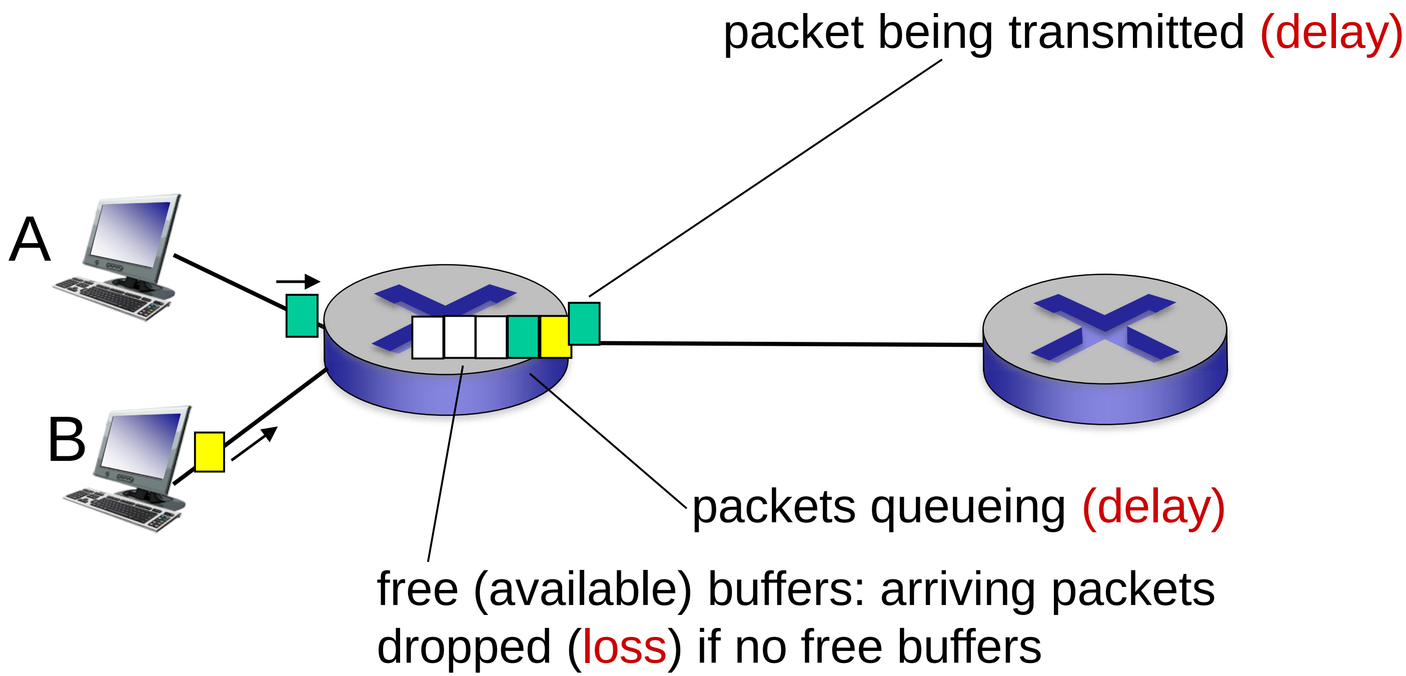
1.6 networks under attack: security

1.7 history

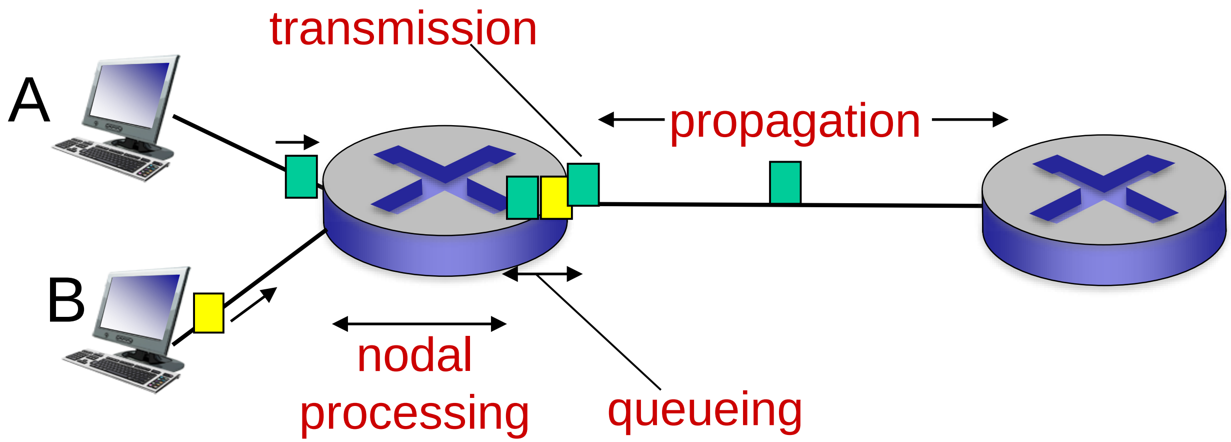
How do loss and delay occur?

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



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

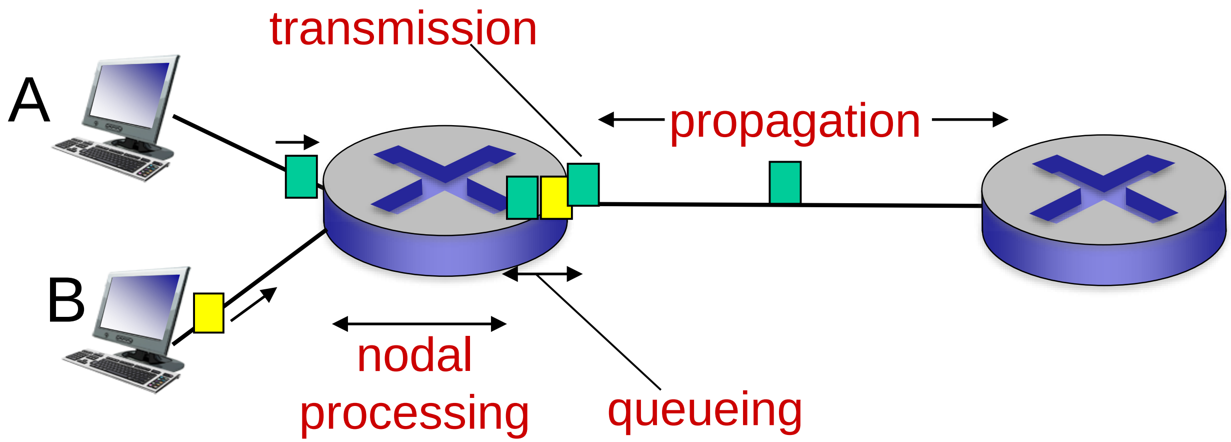
d_{proc}: nodal processing

- 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_{trans} and d_{prop} very different

d_{prop}: propagation delay:

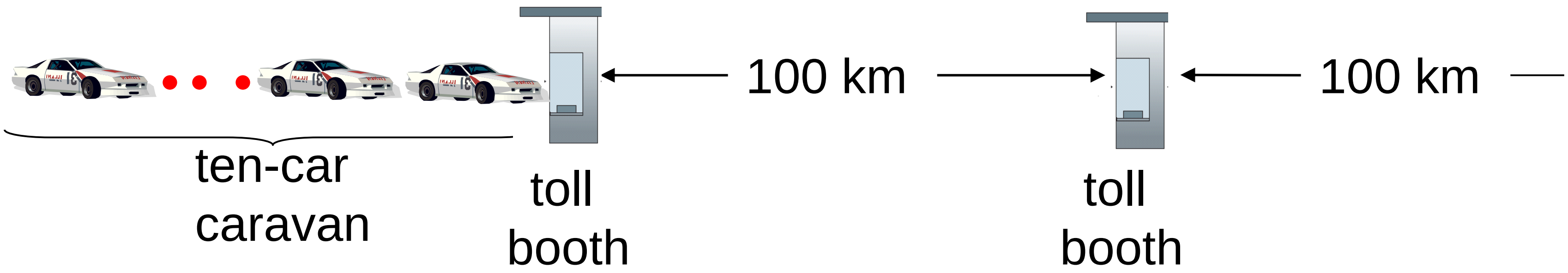
- d: length of physical link
- s: propagation speed (~2×10^8 m/sec)
- $d_{prop} = d/s$

* Check out the online interactive exercises for more examples: http://gaia.cs.umass.edu/kurose_ross/interactive/

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

Caravan analogy

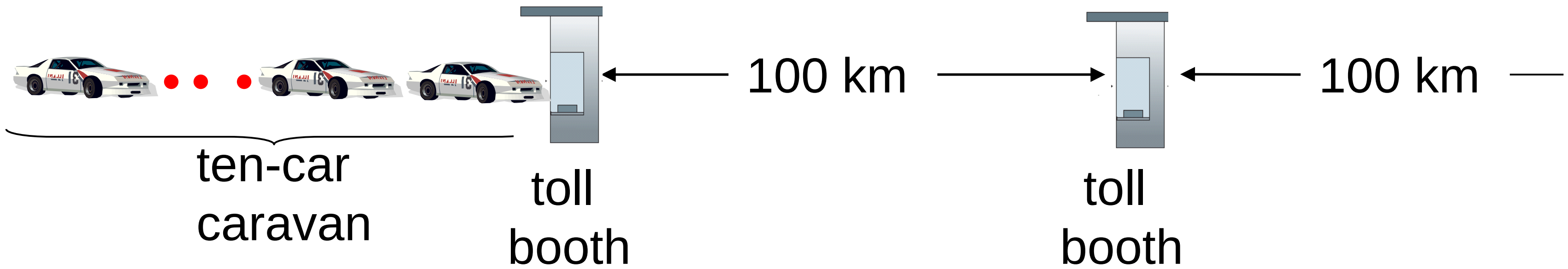
A car = bit, caravan = packet



- 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: ?*

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.

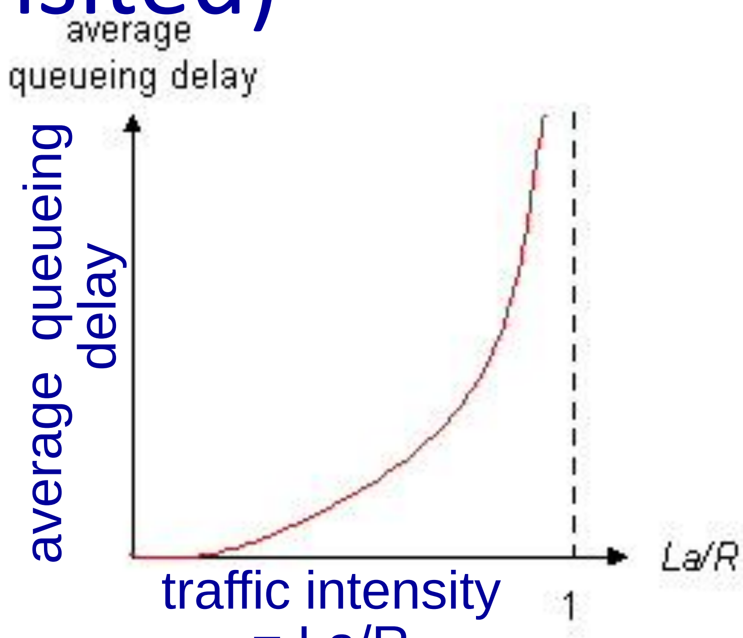
Nodal delay

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

- d_{proc} = processing delay
  - typically a few microsecs or less
- d_{queue} = queuing delay
  - depends on congestion
- d_{trans} = transmission delay
  - = L/R, significant for low-speed links
- d_{prop} = propagation delay
  - a few microsecs to hundreds of msecs

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

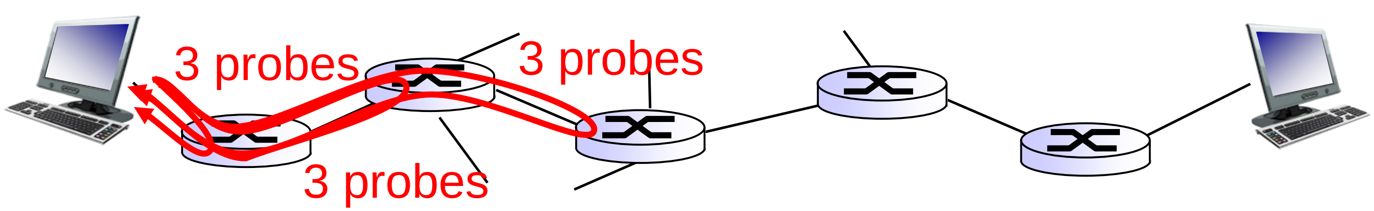
La/R ~ 0

La/R $\rightarrow$ 1

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

"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)

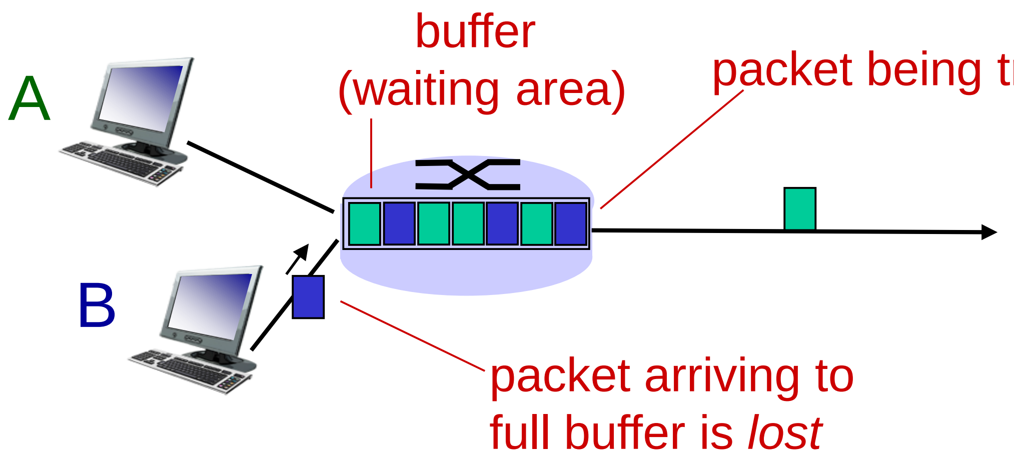
* Do some traceroutes from exotic countries at www.traceroute.org

Example of using MS Windows 7/10

```
C:\WINDOWS\System32\cmd.exe
Microsoft Windows 2000 [Version 5.00.2195]
(C) Copyright 1985-2000 Microsoft Corp.

C:\>tracert www.yahoo.com

Tracing route to www.yahoo.akadns.net [216.109.125.69]
over a maximum of 30 hops:

  1   <10 ms   <10 ms   <10 ms  il100014-rdi-l3s2-6g101-ve-127.ih.lucent.com [135.185.167.254]
  2   <10 ms   <10 ms   <10 ms  il100014-bb-abr8-4e200-ebb2.ih.lucent.com [135.2.1.7]
  3   <10 ms   <10 ms   <10 ms  130.32.118.199.in-addr.arpa [199.118.32.130]
  4    20 ms    31 ms    20 ms  199.118.34.9
  5    21 ms    40 ms    30 ms  50.32.118.199.in-addr.arpa [199.118.32.50]
  6    20 ms    20 ms    30 ms  dr-gw-ext-rtr.firewall.lucent.com [192.11.223.77]
  7    30 ms    30 ms    20 ms  border3.s7-4.lucent-9.den.pnap.net [63.251.181.73]
  8    30 ms    30 ms    30 ms  core1.ge0-0-bbnet1.den.pnap.net [216.52.40.1]
  9    30 ms    30 ms    30 ms  sl-gw14-che-0-1.sprintlink.net [160.81.54.45]
 10    30 ms    30 ms    30 ms  sl-bb21-che-9-0.sprintlink.net [144.232.15.181]
 11    40 ms    50 ms    50 ms  sl-bb21-chi-11-2.sprintlink.net [144.232.18.6]
 12    50 ms    50 ms    40 ms  sl-st20-chi-15-1.sprintlink.net [144.232.20.80]
 13    40 ms    40 ms    50 ms  so-2-1-0.edge1.Chicago1.Level3.net [209.0.225.21]
 14    40 ms    60 ms    40 ms  so-2-1-0.bbr2.Chicago1.level3.net [209.244.8.13]
 15    60 ms    70 ms    81 ms  so-0-1-0.bbr1.Washington1.level3.net [64.159.0.229]
 16    70 ms    60 ms    70 ms  gige7-1.ipcolo1.Washington1.Level3.net [64.159.18.67]
 17    70 ms    70 ms    80 ms  unknown.Level3.net [63.210.59.254]
 18    70 ms    60 ms    81 ms  vl30.bas1-m.dcn.yahoo.com [216.109.120.142]
 19    70 ms    70 ms    70 ms  w16.www.dcn.yahoo.com [216.109.125.69]

Trace complete.

C:\>_
```

Packet loss

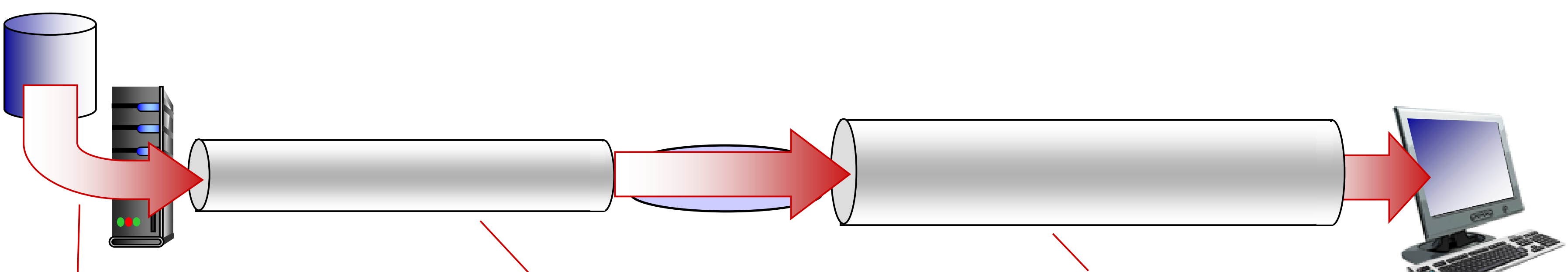
- queue (aka buffer) preceding link in buffer has finite capacity
- packet arriving to full queue dropped (aka lost)
- lost packet may be retransmitted by previous node, by source end system, or not at all



* 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



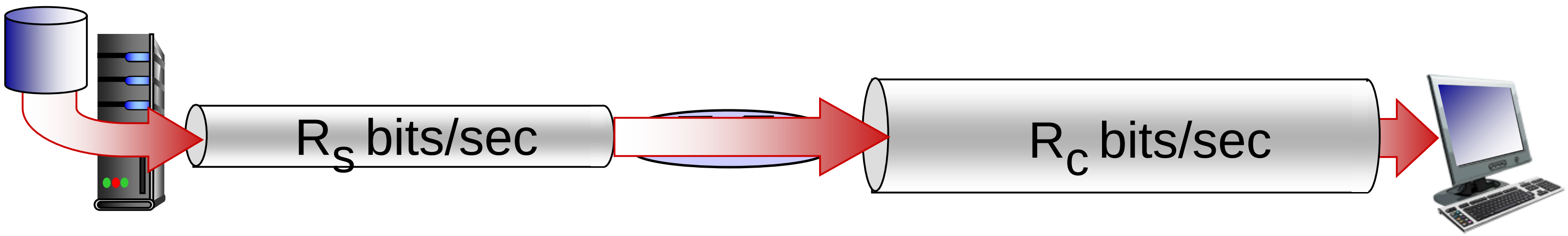
server sends bits (fluid) into pipe

pipe that can carry fluid at rate R_s bits/sec)

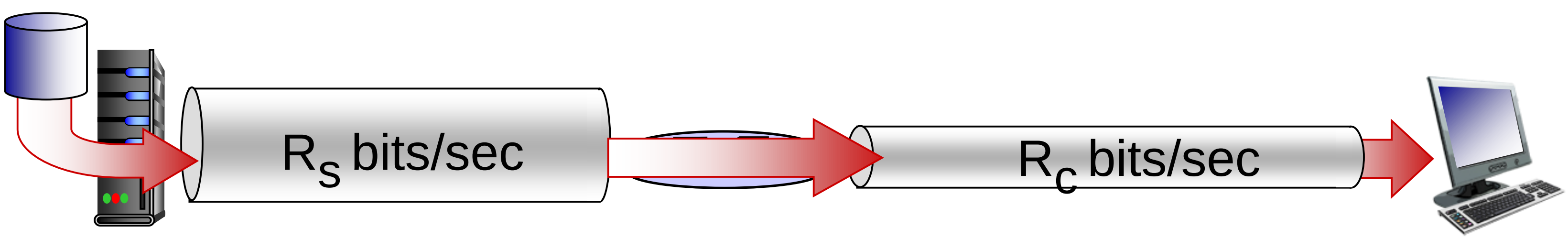
pipe that can carry fluid at rate R_c bits/sec)

Throughput (more)

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



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

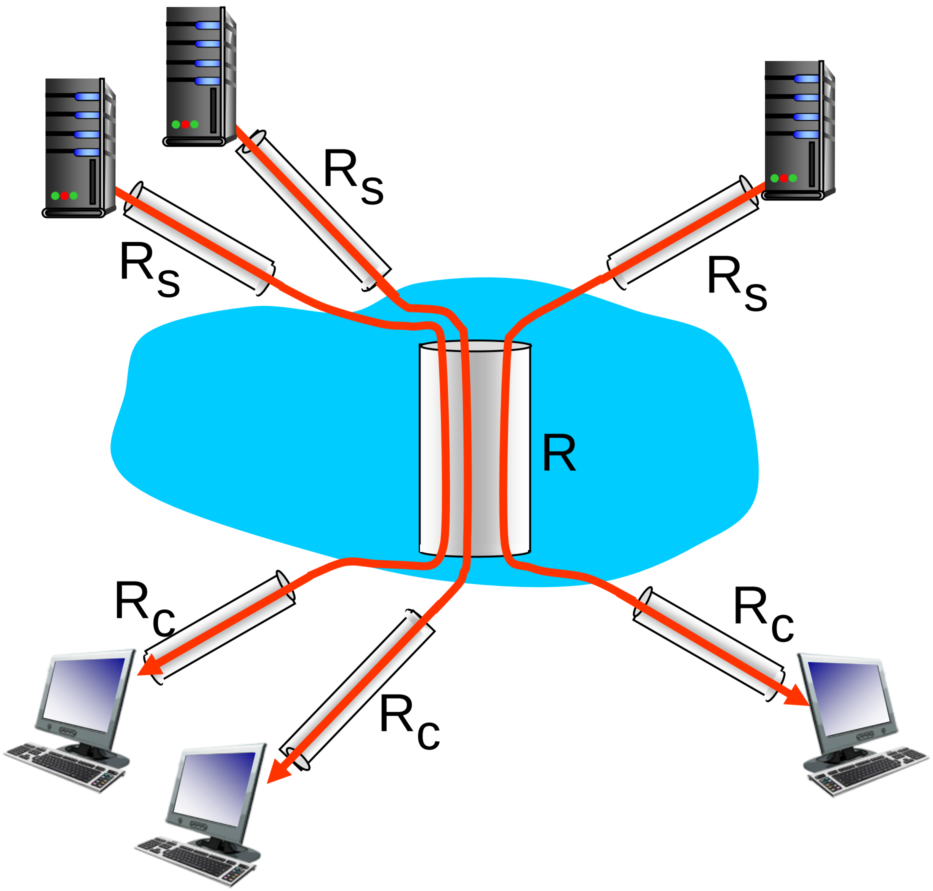


bottleneck link

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

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

Protocol "layers"

Networks are complex, with many "pieces":

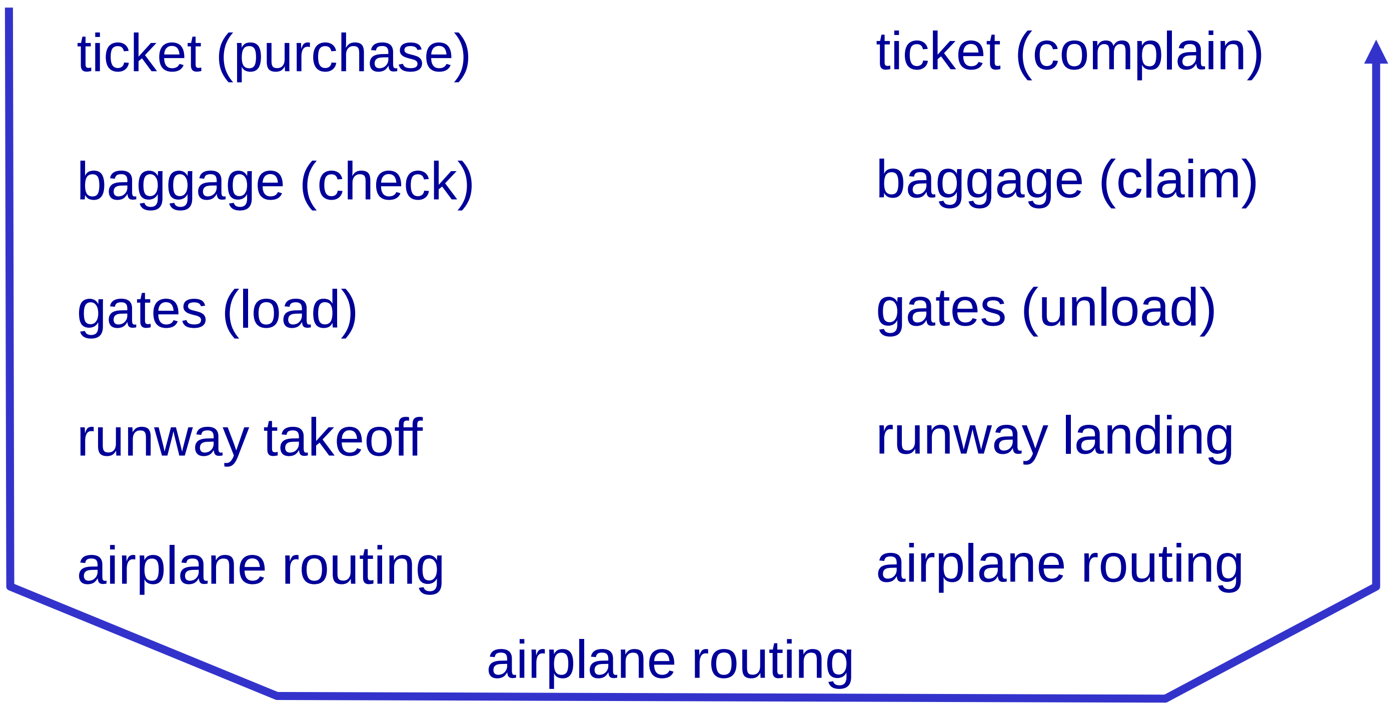
- hosts
- routers
- links of various media
- applications
- protocols
- hardware, software

Question:

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

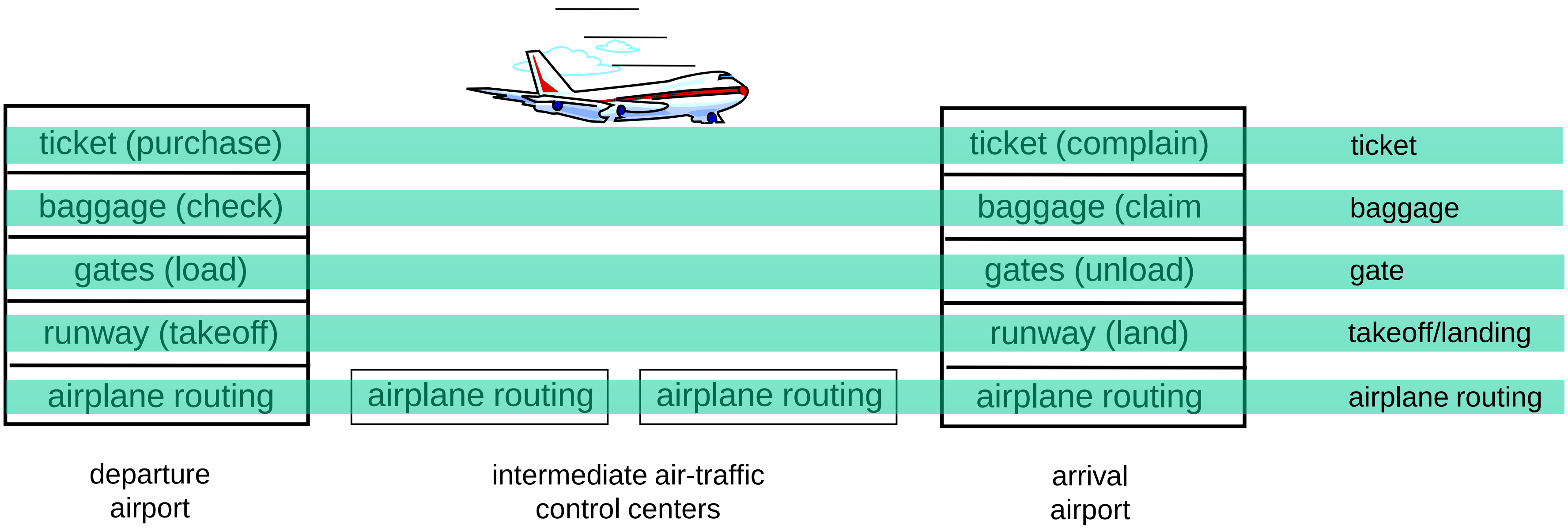
.... or at least our discussion of networks?

Organization of air travel



- a series of steps

Layering of airline functionality



layers: each layer implements a service

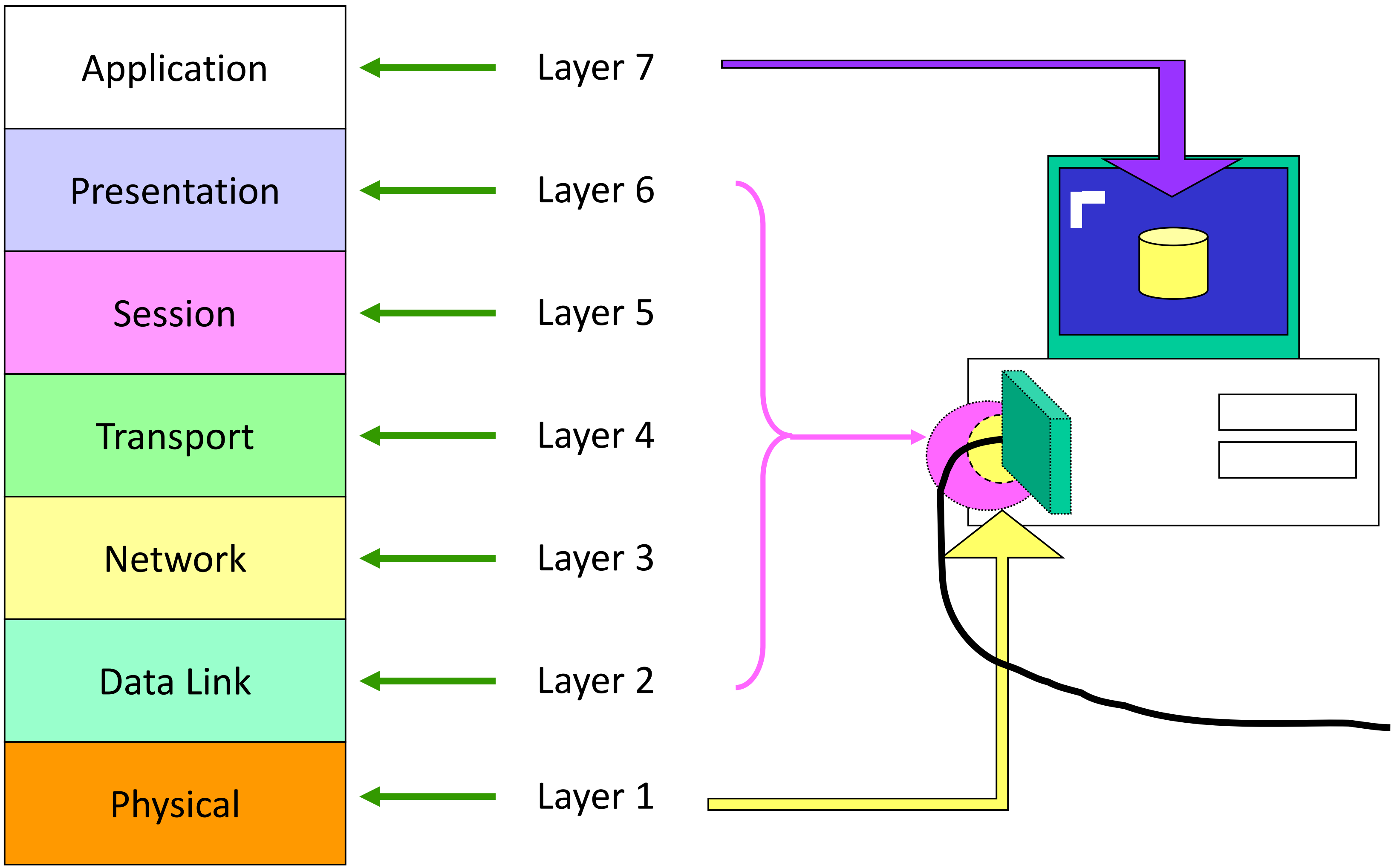
- via its own internal-layer actions
- relying on services provided by layer below

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 gate procedure doesn't affect rest of system
- layering considered harmful?

OSI Reference Model Protocol Stack



OSI RM

1. Physical Layer

Mechanical: connector size,shape

Electrical: address voltage level and timing

Functional: defines meaning of interface's interchange circuits

Procedual: methods of operation

RS-232

2. Data link Layer

Reliable information across the physical link

Functional and procedural means to transfer data between network entities and to detect and possibly correct errors which may occur in the physical layer.

HDLC, LAPB, BSC

3. Network layer

The network layer provides independence from the data transfer technology and independence from relaying and routing considerations.

3A: subnetwork access functions e.g.) X.25

3B: subnetwork convergence functions - subnet enhancement

3C: concatenation and routing functions - internetworking

OSI RM (continued)

4. Transport layer

To provide transparent transfer of data between end systems.

End - to - end significance

5. Session layer

Provides the structure for controlling the communication.

Interactions between application process - two way simultaneous, two way alternate operation, major/minor synchronization points, token management.

Setting up, maintaining/closing down a session.

OSI RM (continued)

6. Presentation layer

To provide independence to application processes from differences in data representation. It is responsible for the syntax of data during transfer.

If two computers use different presentation standard such as different character sets or codes:

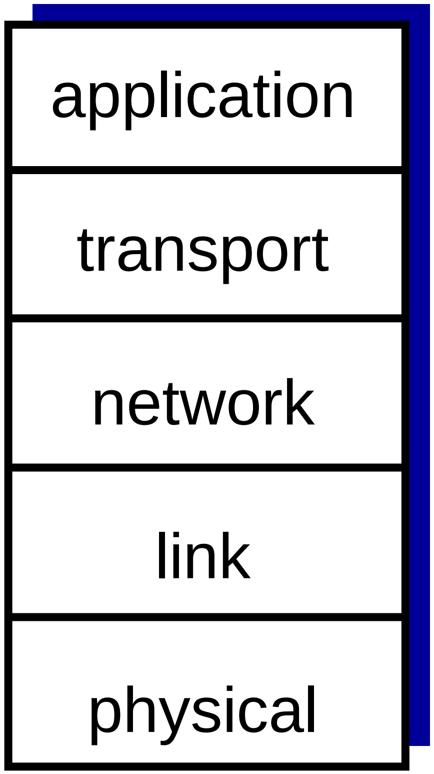
e.g. UNIX: new line has one ASCII char. <carriage return>
DOS: uses two ASCII chars. <line feed> + <carriage return>
P. layer converts from one computer to another to display correctly.

7. Application layer

Concerned with the semantics of the applications.
It is the user interface.
E-mail, File transfer, Terminal control, virtual terminal.

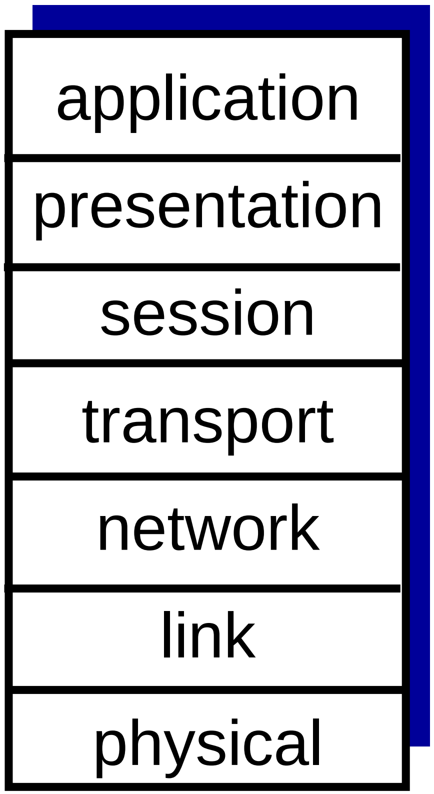
Internet protocol stack

- *application:* supporting network applications
  - FTP, SMTP, HTTP
- *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, 802.111 (WiFi), PPP
- *physical:* bits "on the wire"

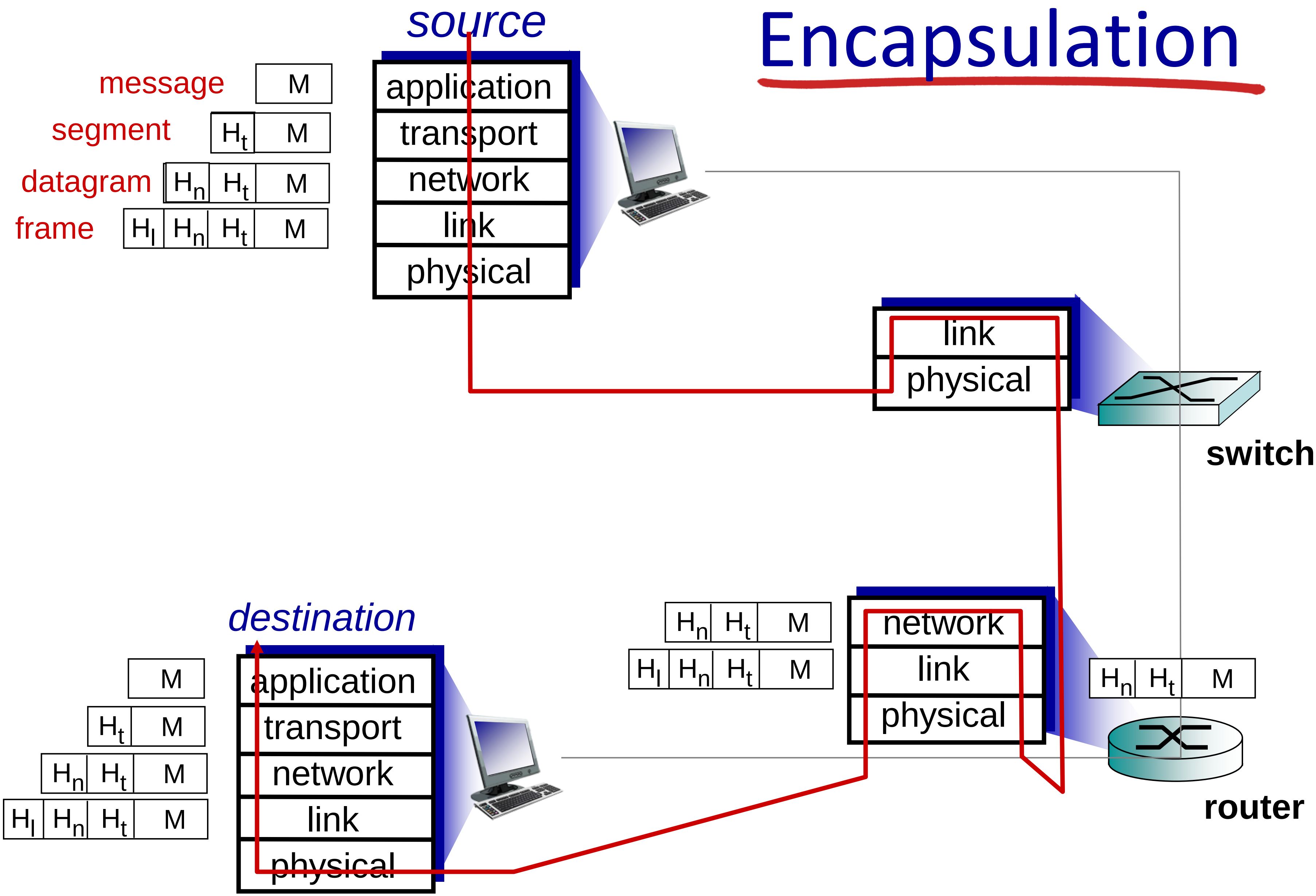


ISO/OSI reference model

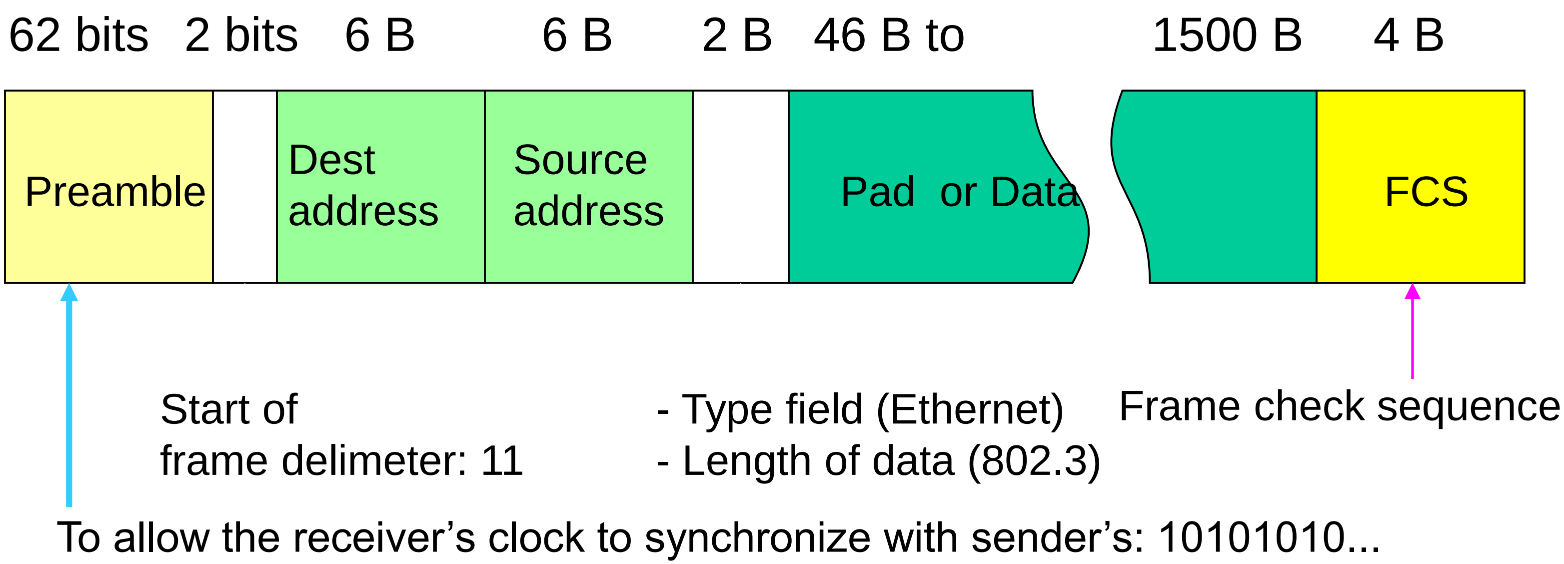
- *presentation:* allow applications to interpret meaning of data, e.g., encryption, compression, machine-specific conventions
- *session:* synchronization, checkpointing, recovery of data exchange
- Internet stack "missing" these layers!
  - these services, *if needed,* must be implemented in application
  - needed?



Encapsulation



Frame Format



Minimum frame size: 64 bytes (6 + 6 + 2 + 46 + 4)

Maximum frame size: 1518 bytes (6 + 6 + 2 + 1500 + 4)

* excluding preamble and SOF

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

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!

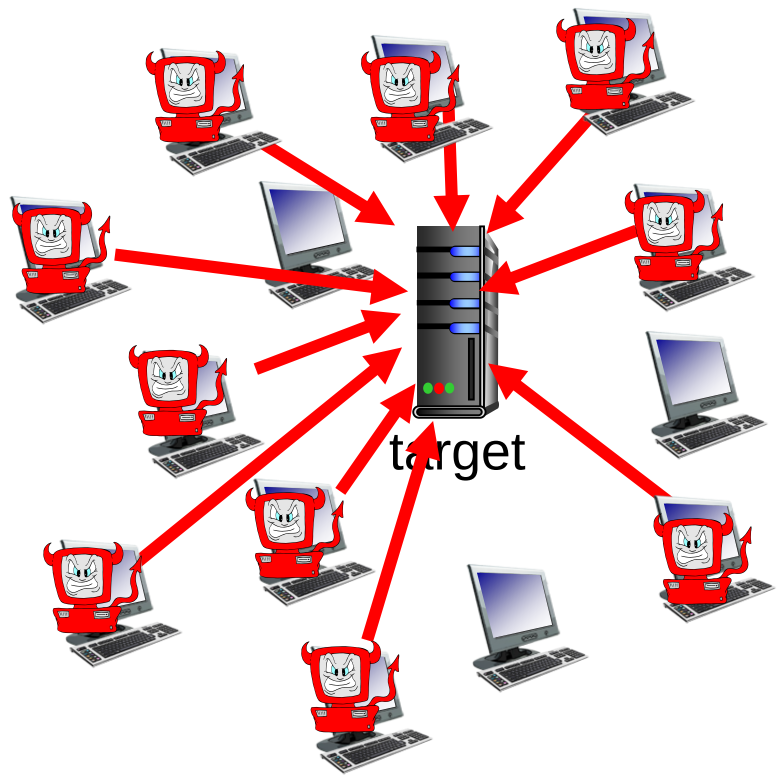
Bad guys: put malware into hosts via Internet

- malware can get in host from:
  - *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 malware can record keystrokes, web sites visited, upload info to collection site
- infected host can be enrolled in botnet, used for spam. 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

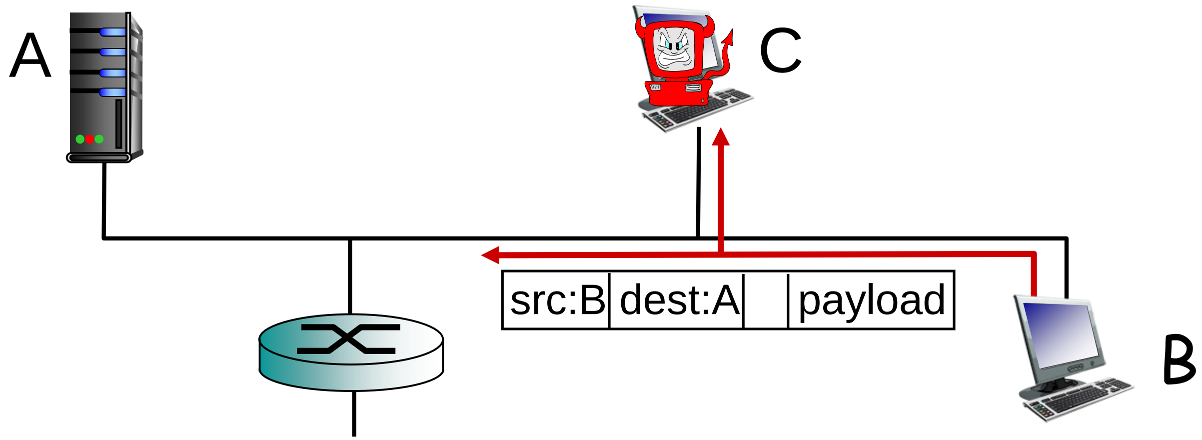
1. select target
2. break into hosts around the network (see botnet)
3. send packets to target from compromised hosts



Bad guys can sniff packets

packet "sniffing":

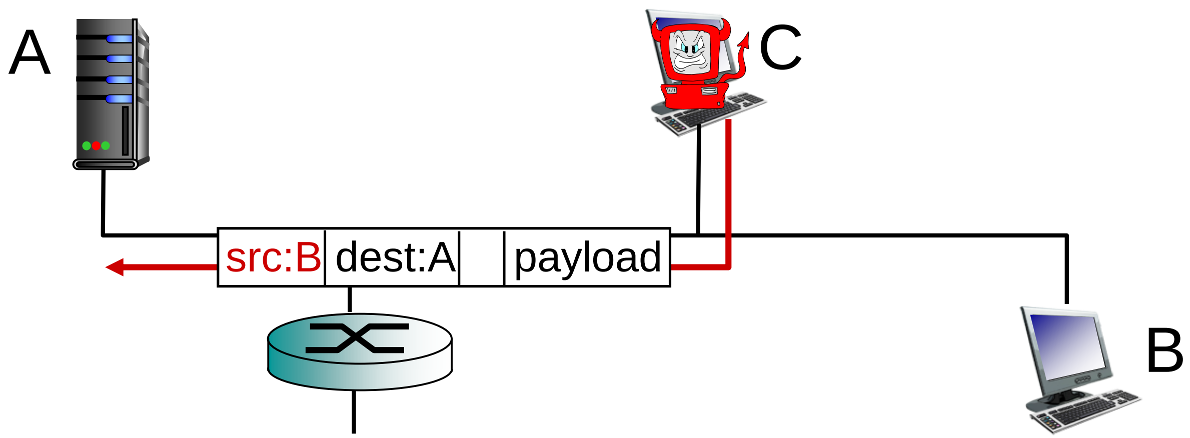
- broadcast media (shared ethernet, wireless)
- promiscuous network interface reads/records all packets (e.g., including passwords!) passing by



- 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



… lots more on security (throughout, CS544)

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

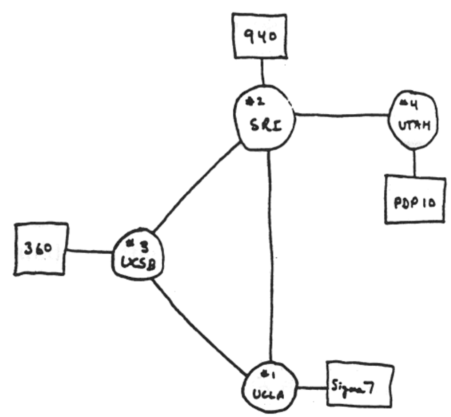
1.7 history

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 public demo
  - NCP (Network Control Protocol) first host-host protocol
  - first e-mail program
  - ARPAnet has 15 nodes



THE ARPA NETWORK

Internet history

1972-1980: Internetworking, new and proprietary nets

- 1970: ALOHAnet satellite network in Hawaii
- 1974: Cerf and Kahn - architecture for interconnecting networks
- 1976: Ethernet at Xerox PARC
- 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, 2000's: commercialization, the Web, new apps

- early 1990's: ARPAnet decommissioned
- 1991: NSF lifts restrictions on commercial use of NSFnet (decommissioned, 1995)
- early 1990s: 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
- 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)

Introduction: summary

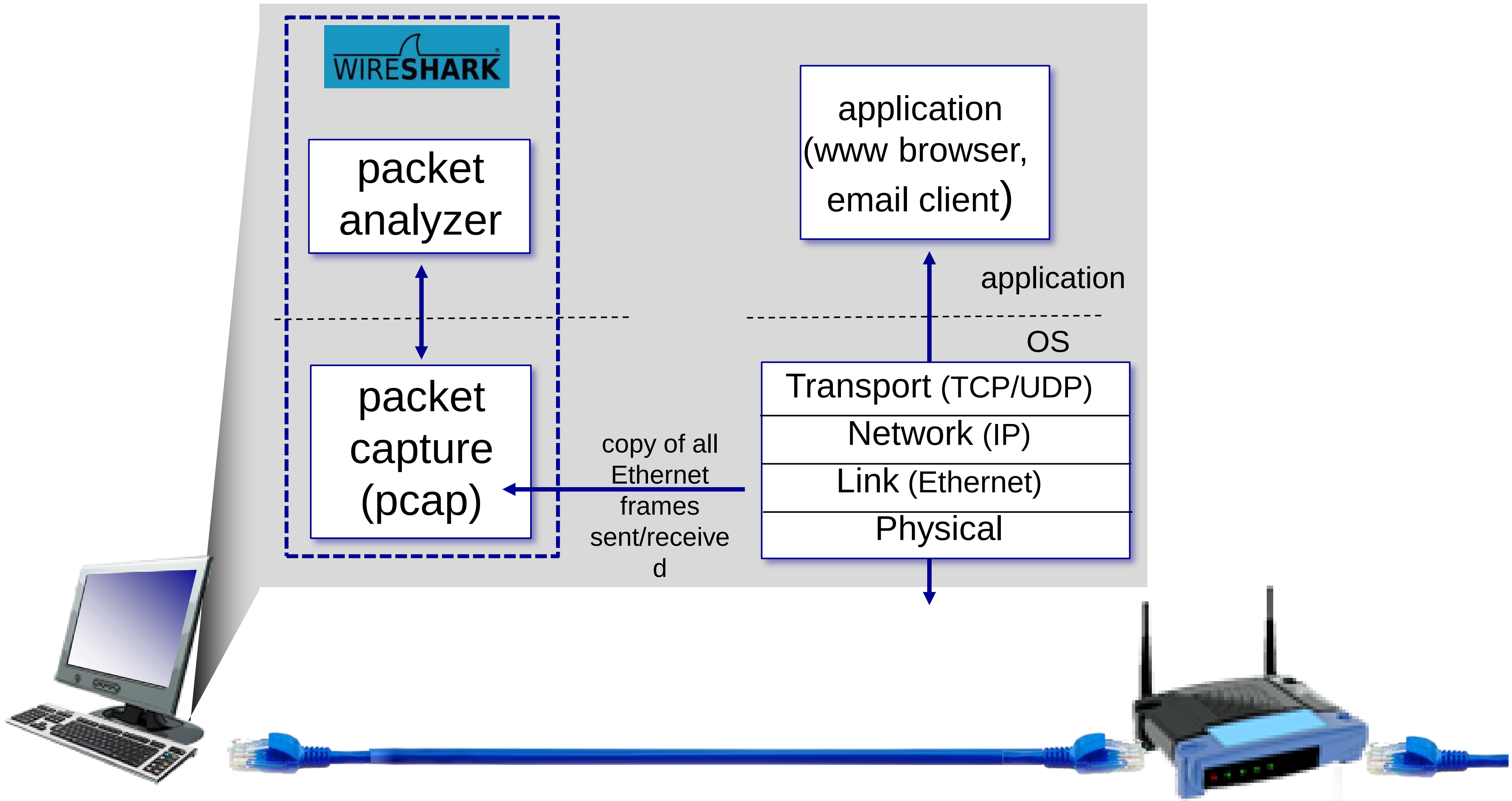
covered a "ton" of material!

- Internet overview
- what's a protocol?
- network edge, core, access network
  - packet-switching versus circuit-switching
  - Internet structure
- performance: loss, delay, throughput
- layering, service models
- security
- history

you now have:

- context, overview, "feel" of networking
- more depth, detail *to follow!*

Chapter 1
Additional Slides


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