DIPARTIMENTO DI INFORMATICA
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SAPIENZA UNIVERSITÀ DI ROMA

Reti di Elaboratori

Corso di Laurea in Informatica

Università degli Studi di Roma “La Sapienza”

Canale A-L e M-Z

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Thanks also to Antonio Capone, Politecnico di Milano, Giuseppe Bianchi and Francesco LoPresti, Un. di Roma Tor Vergata

Chapter 1: roadmap

1.1 What *is* the Internet?

1.2 Network edge

- end systems, access networks, links

1.3 Network core

- circuit switching, packet switching, network structure

1.4 Delay, loss and throughput in packet-switched networks

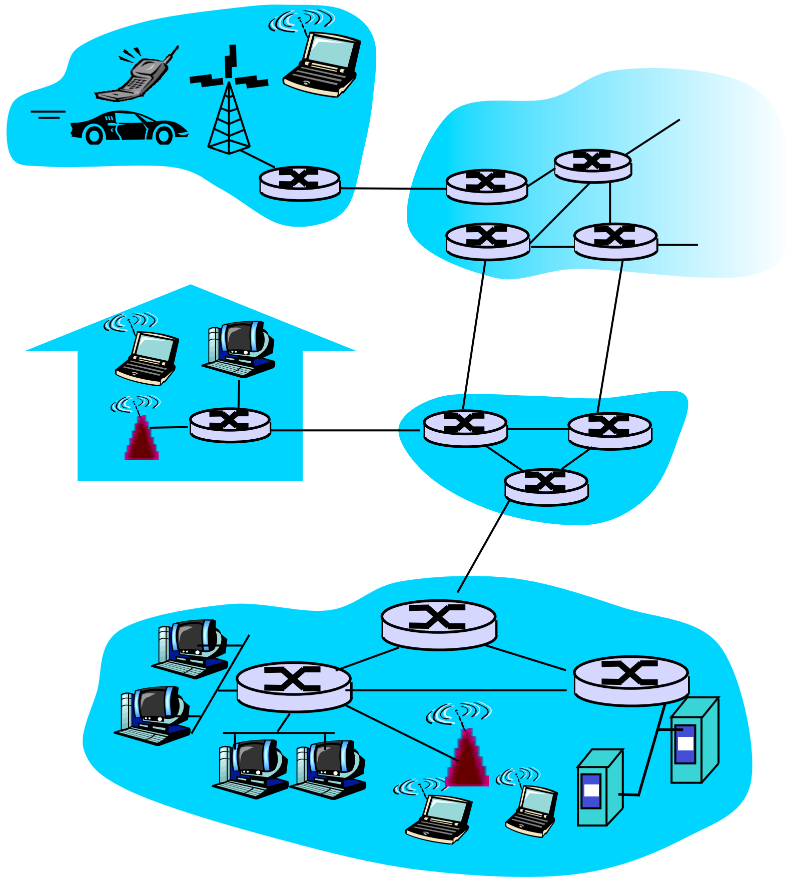
1.5 Protocol layers, service models

1.6 Networks under attack: security

1.7 History

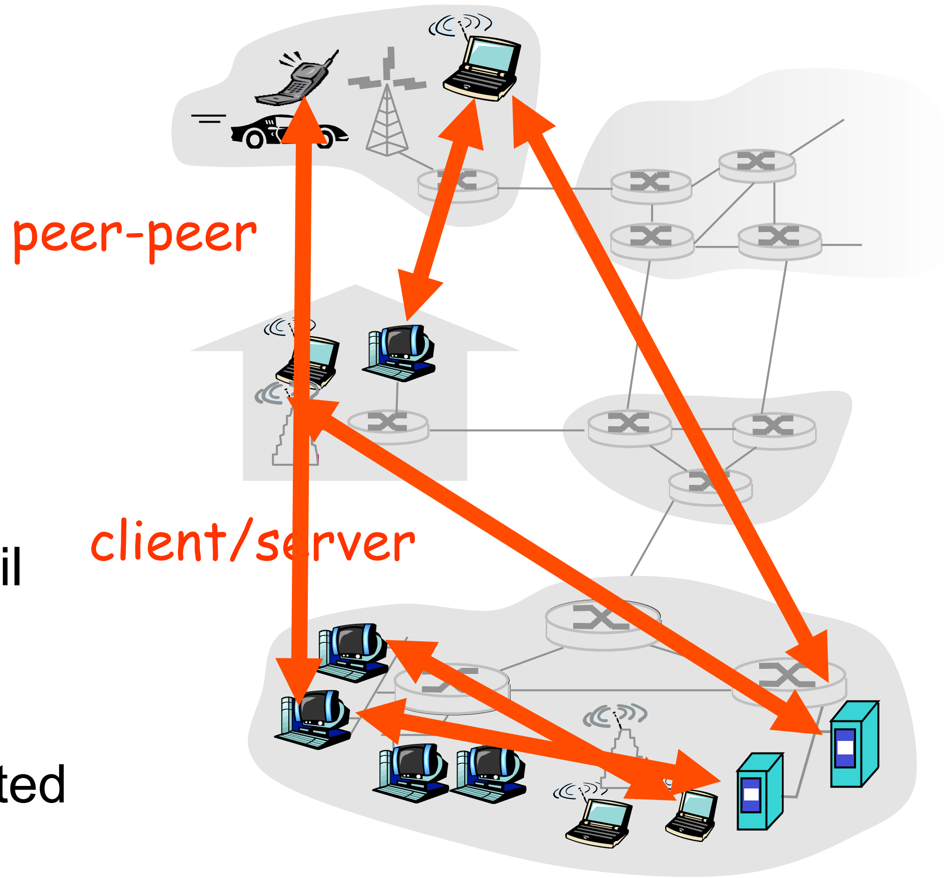
A closer look at network structure:

- network edge: applications and hosts
- access networks, physical media: wired, wireless communication links
- network core:
  - interconnected routers
  - network of networks



The network edge:

- end systems (hosts):
  - run application programs
  - e.g. Web, email
  - at "edge of network"
- client/server model
  - client host requests, receives service from always-on server
  - e.g. Web browser/server; email client/server
- peer-peer model:
  - minimal (or no) use of dedicated servers
  - e.g. Skype, BitTorrent



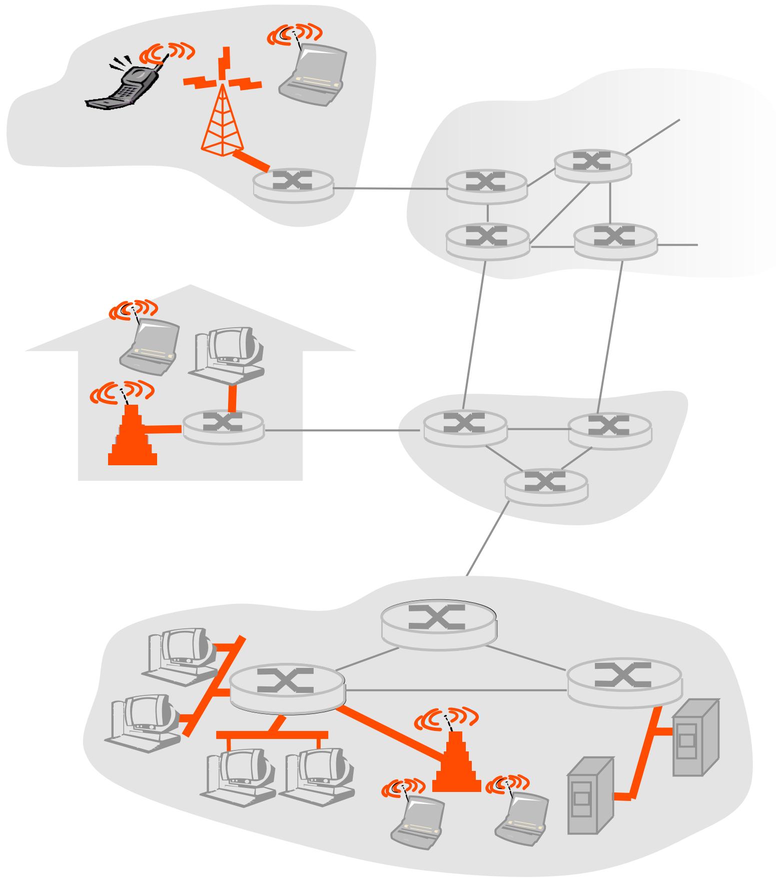
Access networks and physical media

Q: How to connect end systems to edge router?

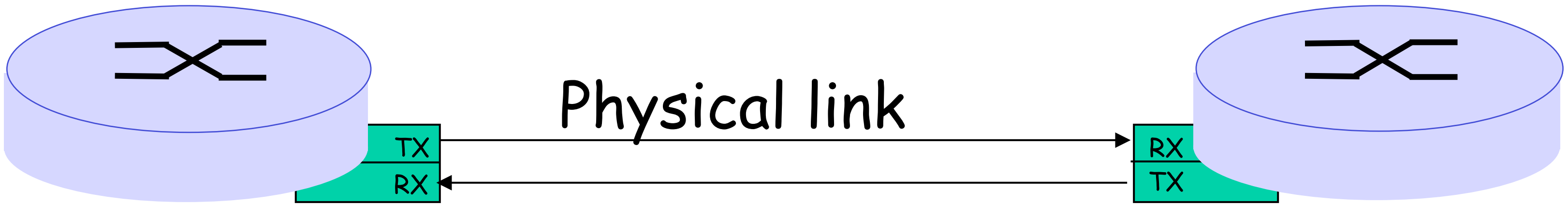
- residential access nets
- institutional access networks (school, company)
- mobile access networks

Keep in mind:

- bandwidth (bits per second) of access network?
- shared or dedicated?
- reliable/unreliable (bit error rates)

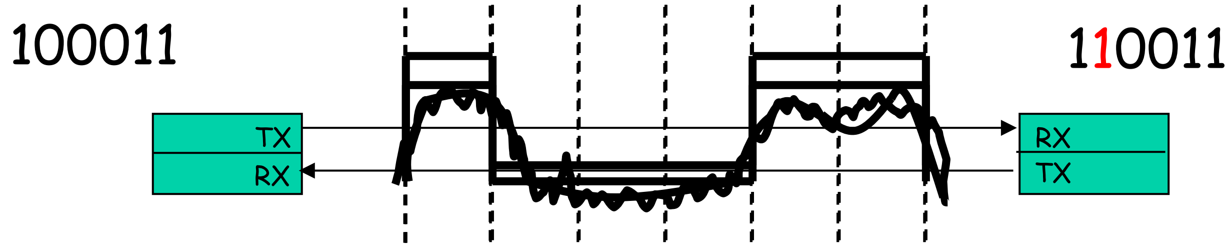


Transmission across a physical link



- Bits: propagate between transmitter and receiver
- 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

Transmission across a physical link

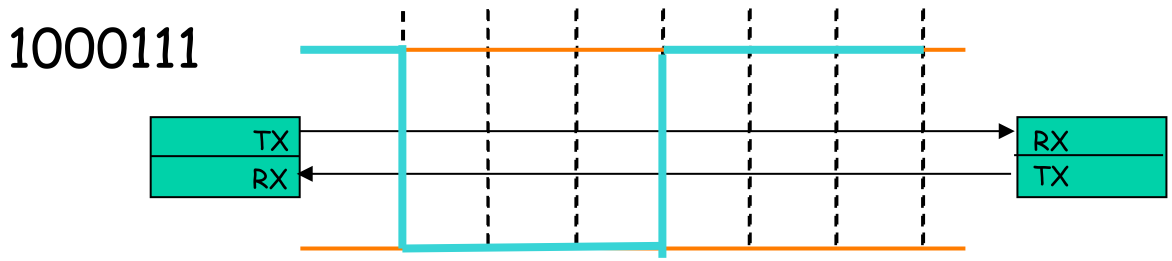


- Bit sequence modulates a suitable waveform which is sent across the link
  - How and which depends on the medium
- As the signal travels it experiences
  - Attenuation (absorption)
  - Distortion (limited bandwidth (frequency))
  - Noise (interference, thermal noise)
  - Influenced by medium, bit rate and distance
- Received sequence may be incorrect!!!

Codifica NRZ

- Codifica NRZ (Non Return to Zero)

Ogni bit ha associato un valore stabile per la sua intera durata (1: High; 0: Low)

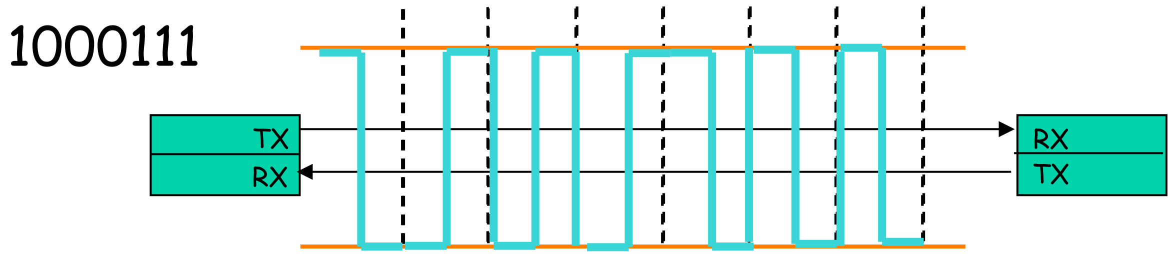


Problemi di sincronizzazione del ricevitore (nessuna transizione nel caso di sequenze di zeri o di uni)→ NRZ 5B6B o 4B5B

Codifica Manchester

- Codifica Manchester

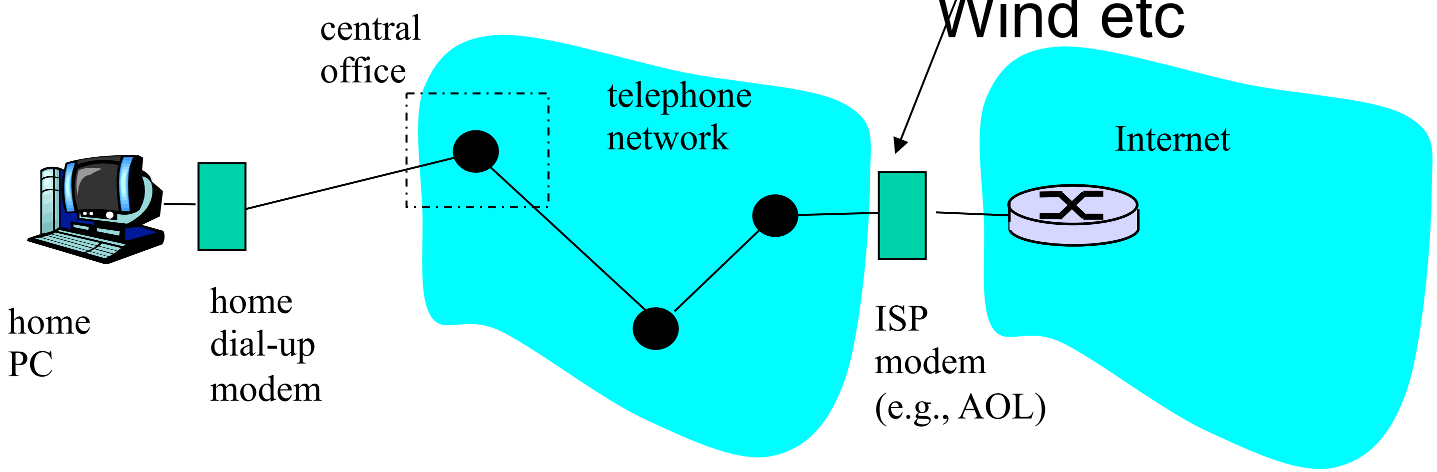
Una transizione basso-alto (codifica dello zero) o alto-basso (codifica del valore uno) in corrispondenza di ogni bit



Usato in Ethernet 10Mbps e Token Ring

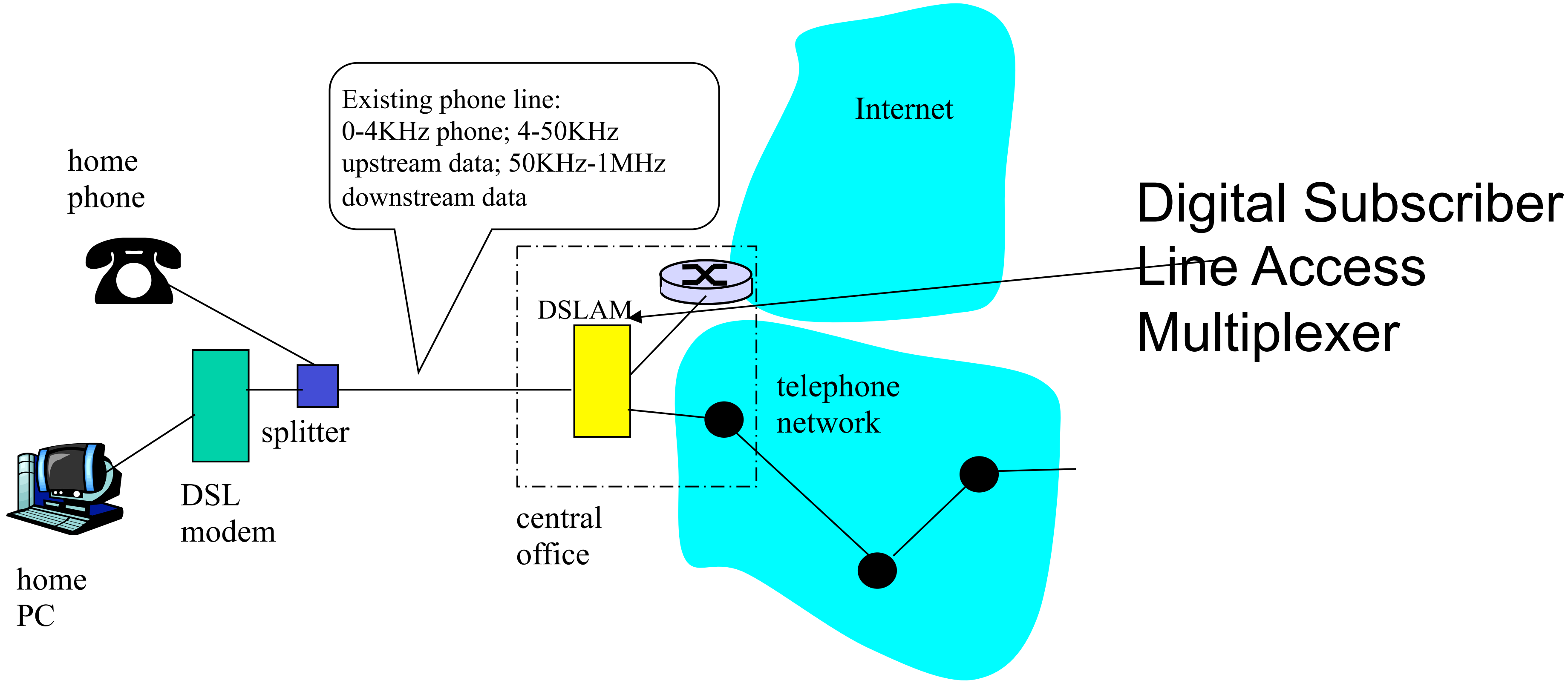
Dial-up Modem

ISP=Internet Service Provider
Es. Telecom, Tiscali, Fastweb, Wind etc



- 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"

Digital Subscriber Line (DSL)

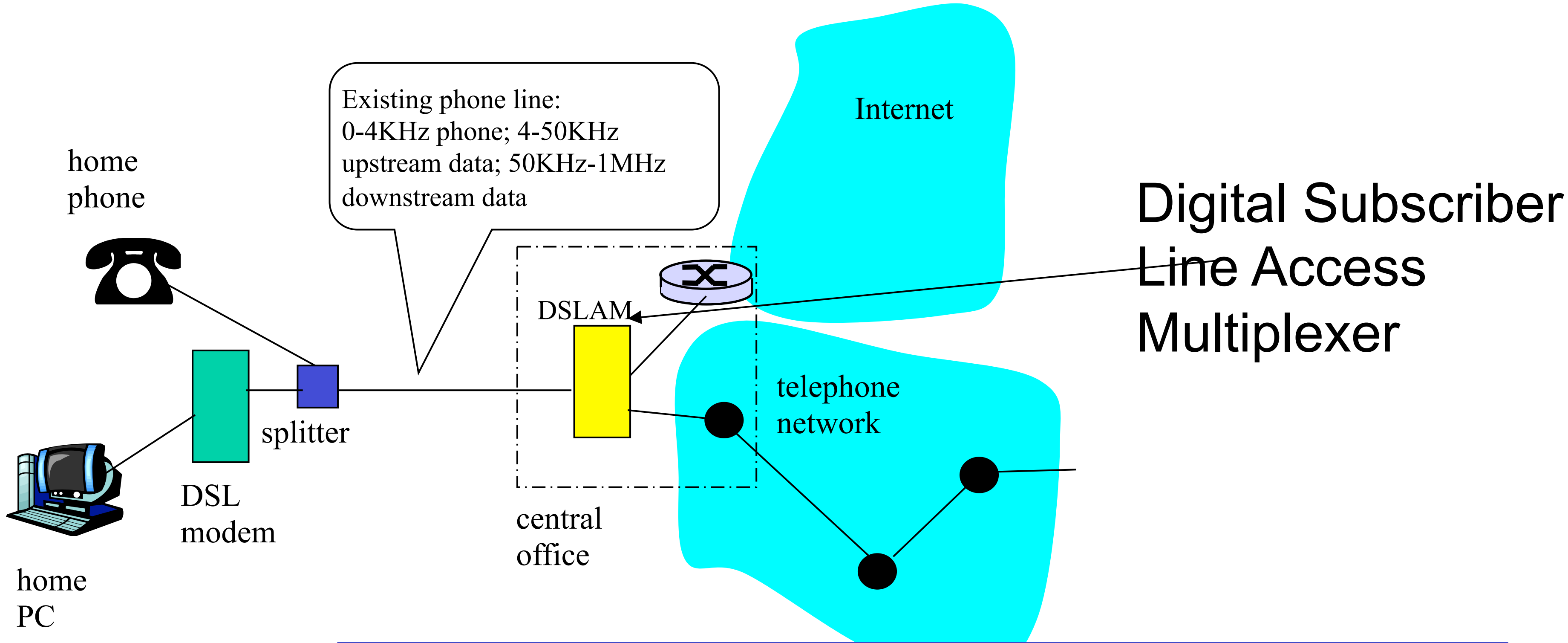


- Also uses existing telephone infrastruture
- up to 1 Mbps upstream (typically < 256 kbps)
- up to 8 Mbps downstream (typically < 1 Mbps)
- dedicated physical line to telephone central office

ADSL loops extender

- An **ADSL loop extender** or **ADSL repeater** is a device placed midway between the subscriber and central office by the telephone company to extend the distance and increase the channel capacity of their DSL connection.
- In some cases, service can now be established as far as 10 miles from the Central Office (factor of 2 improvement)

Digital Subscriber Line (DSL)



- Also uses exi
- up to 1 Mbps
- up to 8 Mbps
- dedicated phy

Speed significantly increased in the last few years
- **technologies more robust to interference;**
- **lower distance from DSM modem to DSLAM**

is expected to raise speed to 1Gbps by 2016)

Residential access: cable modems

- Does not use telephone infrastructure
  - Instead uses cable TV infrastructure
- HFC: hybrid fiber coax
  - asymmetric: up to 30Mbps downstream, 2 Mbps upstream
- network of cable and fiber attaches homes to ISP router
  - homes share access to router
  - unlike DSL, which has dedicated access

Residential access: cable modems

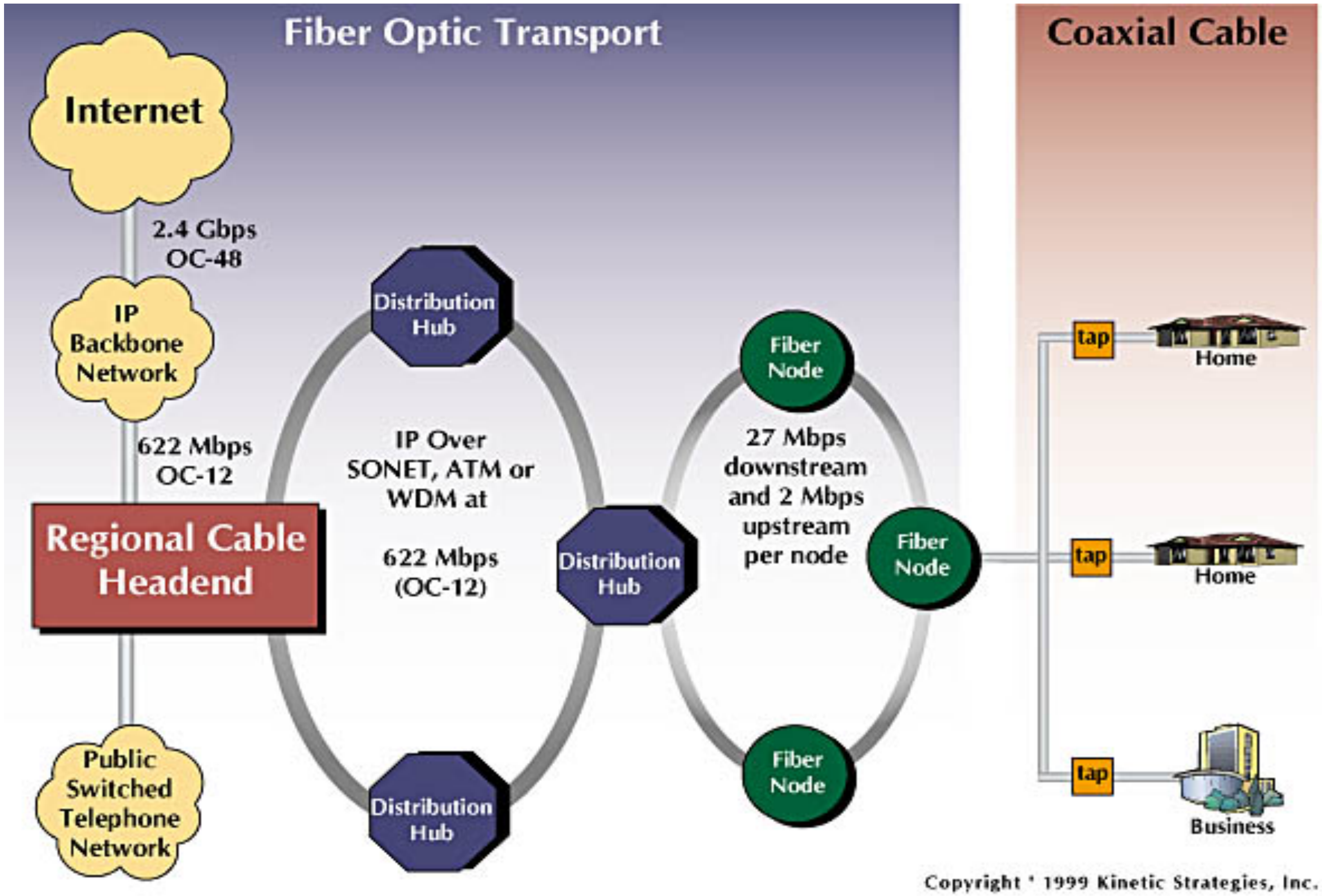
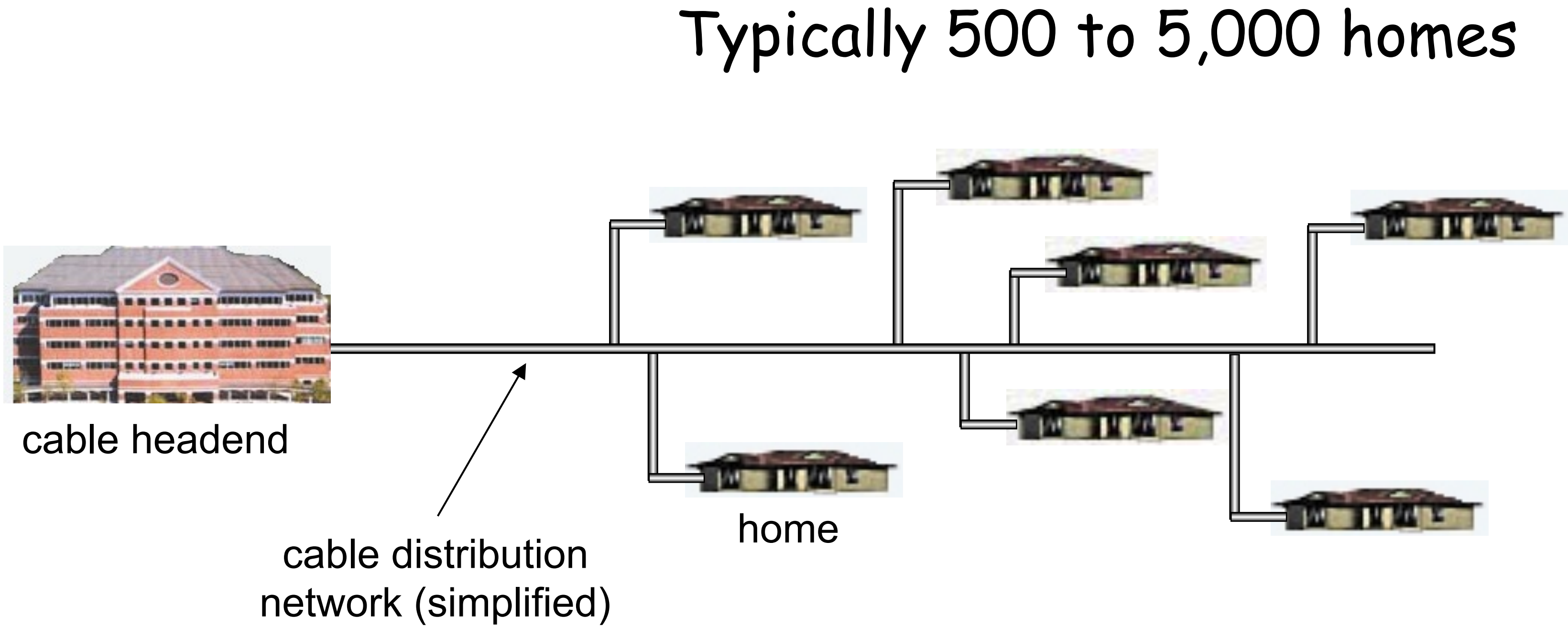
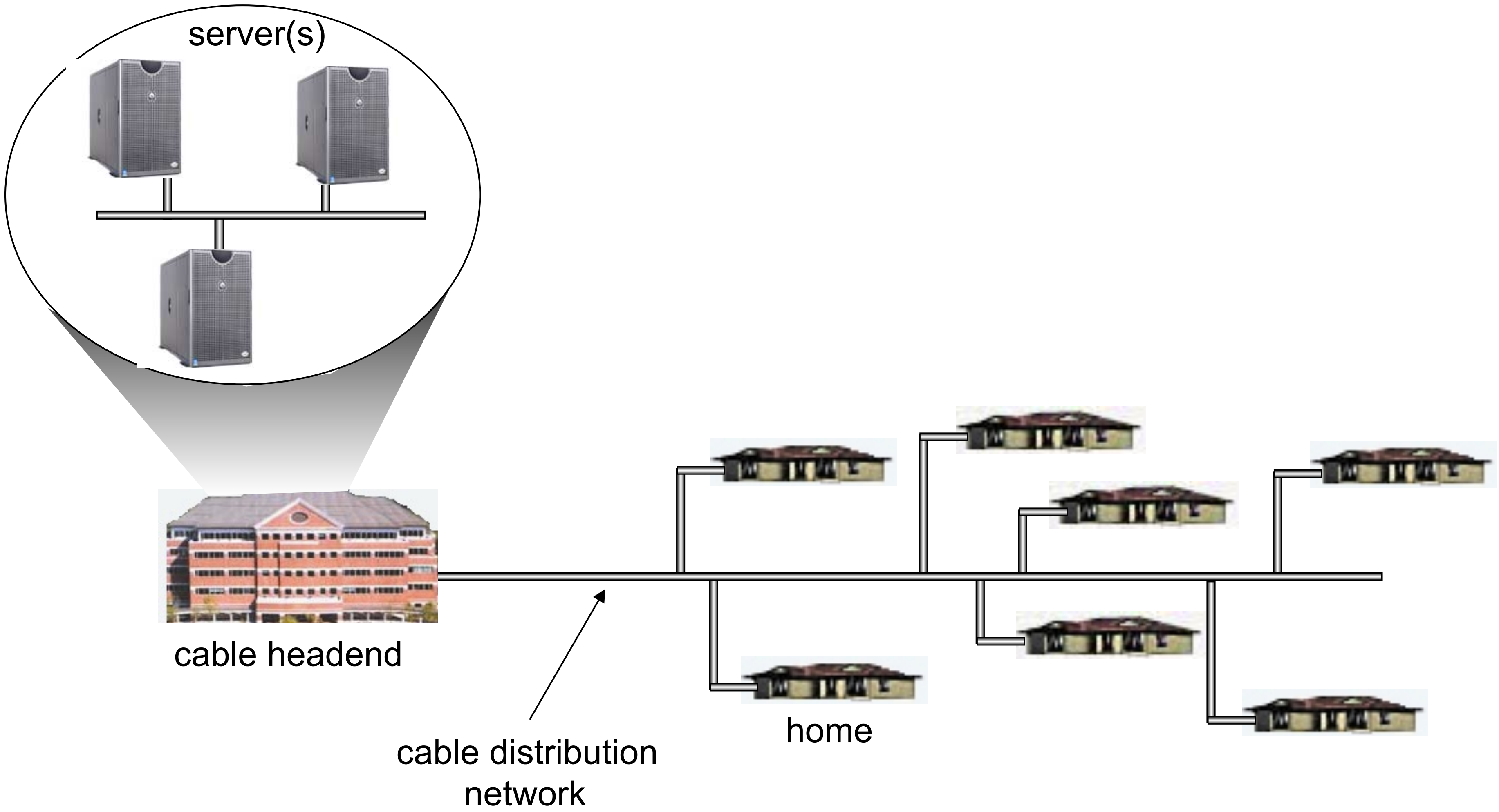


Diagram: http://www.cabledatacomnews.com/cmic/diagram.html

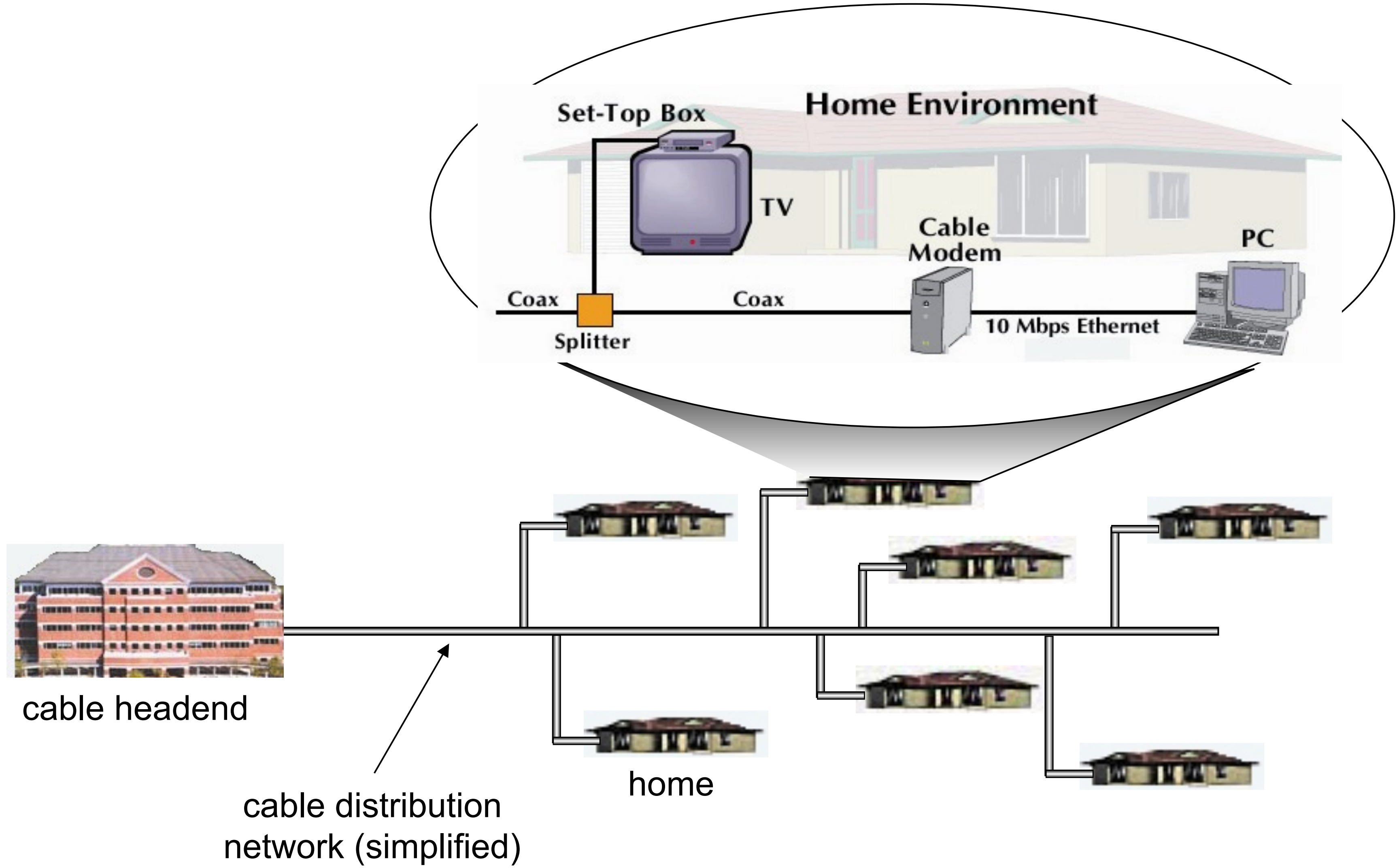
Cable Network Architecture: Overview



Cable Network Architecture: Overview

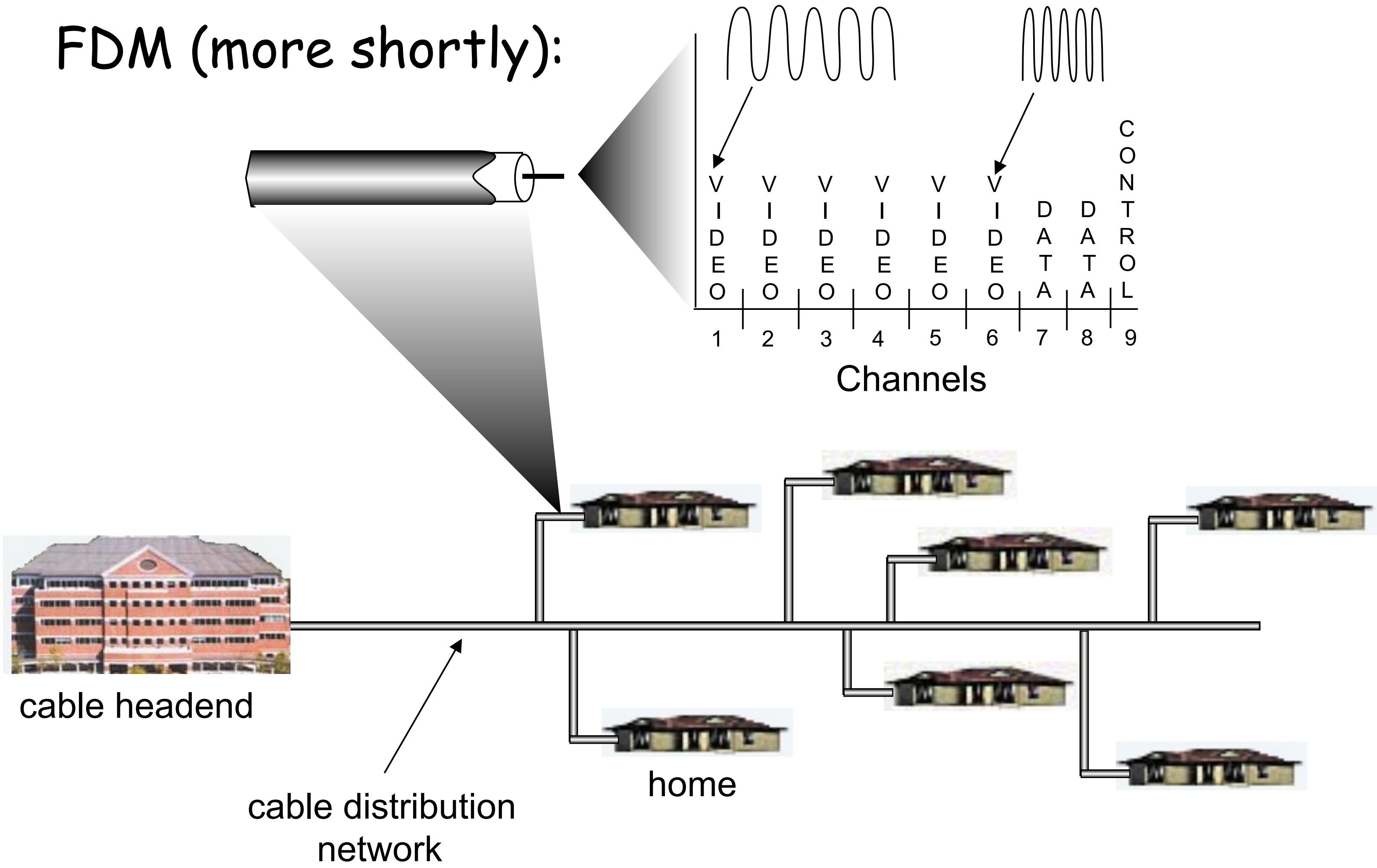


Cable Network Architecture: Overview

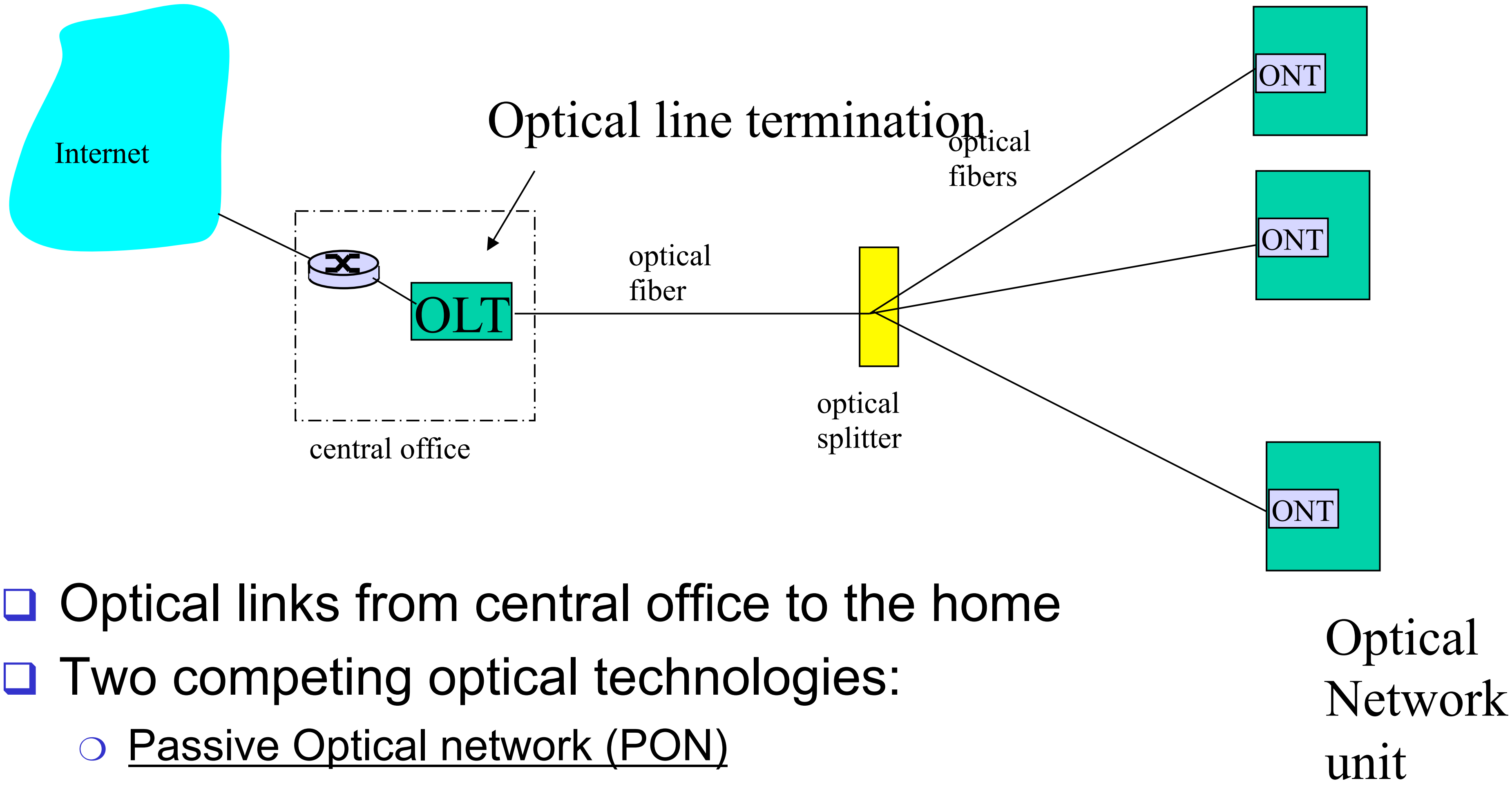


Cable Network Architecture: Overview

FDM (more shortly):

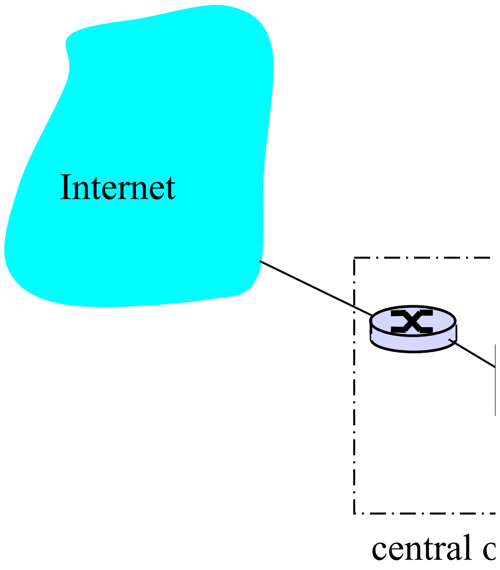


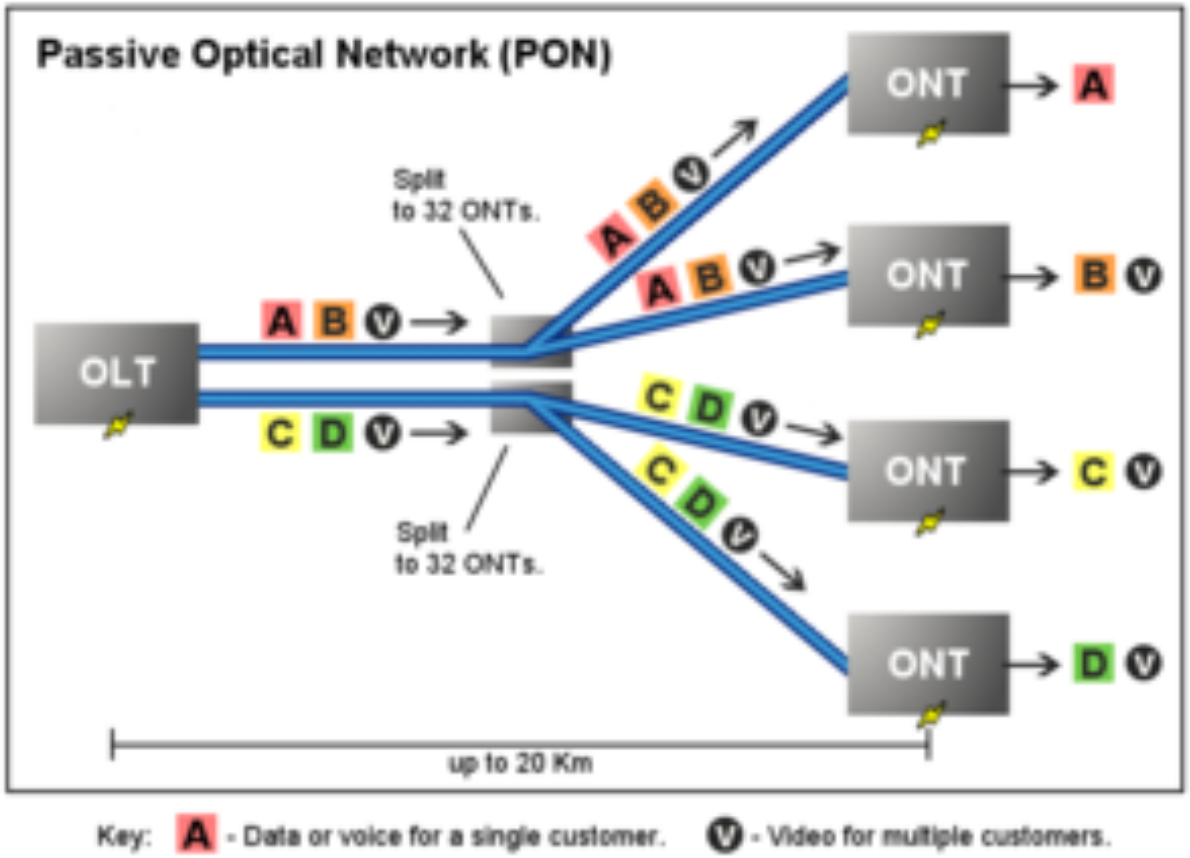
Fiber to the Home



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

Fiber to the Home

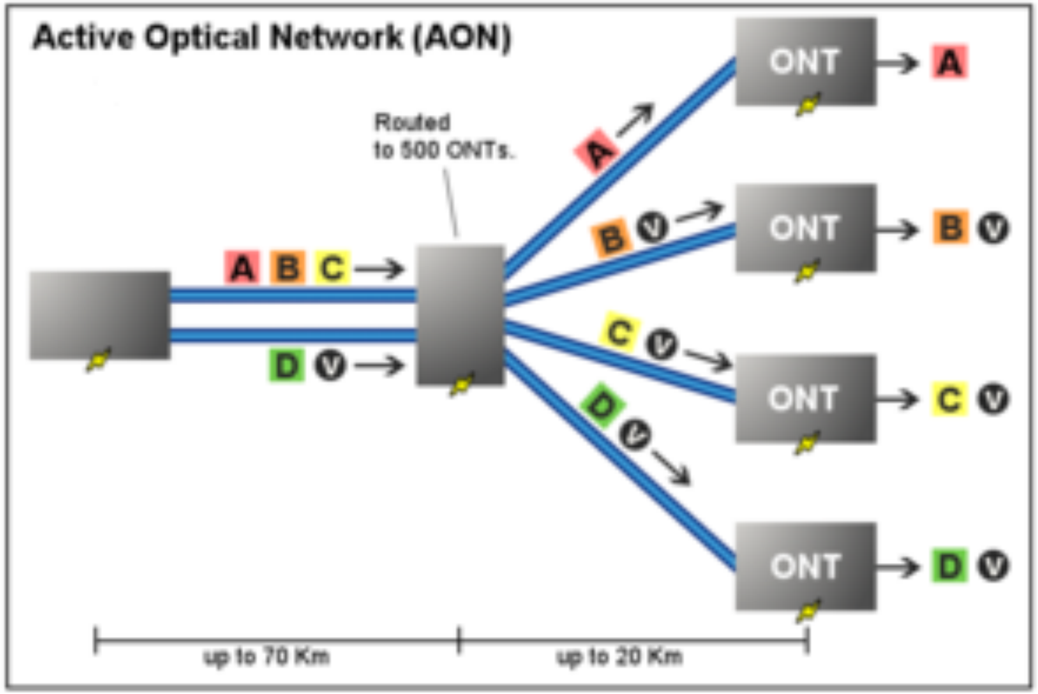




- Optical links fro
- Two competing
  - Passive Optical network (PON)
  - Active Optical Network (PAN)
- Much higher Internet rates; fiber also carries television and phone services

Active Optical Networks

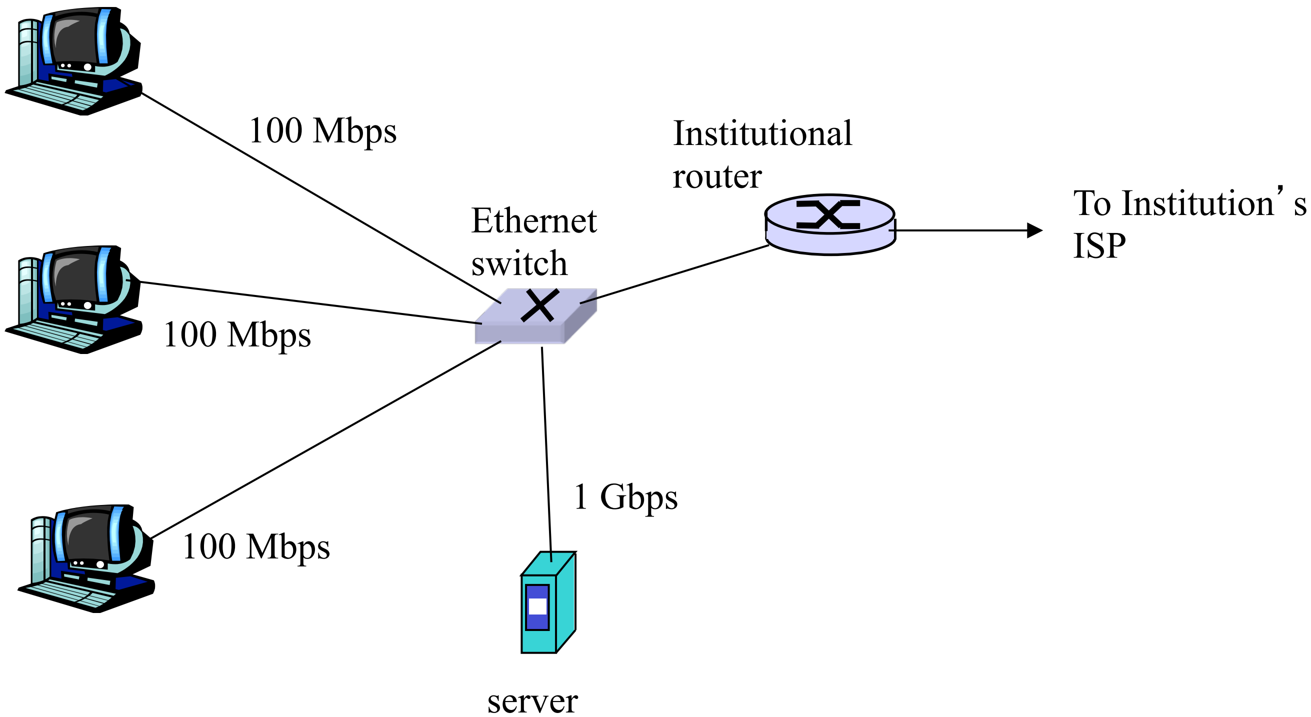
- An active optical system uses electrically powered switching equipment, such as a router or a switch aggregator, to manage signal distribution and direct signals to specific customers.
- In such a system, a customer may have a dedicated fiber running to his or her house.



Active vs Passive Optical Networks

- Passive optical networks, or PONs, have some distinct advantages.
  - They're efficient, in that each fiber optic strand can serve up to 32 users
  - PONs have a low building cost relative to active optical networks along with lower maintenance costs. In active optical networks one aggregator is required every 48 subscribers.
- Passive optical networks also have some disadvantages.
  - They have less range than an active optical network.
  - PONs also make it difficult to isolate a failure when they occur.
  - Because the bandwidth in a PON is not dedicated to individual subscribers, data transmission speed may slow down during peak usage times.

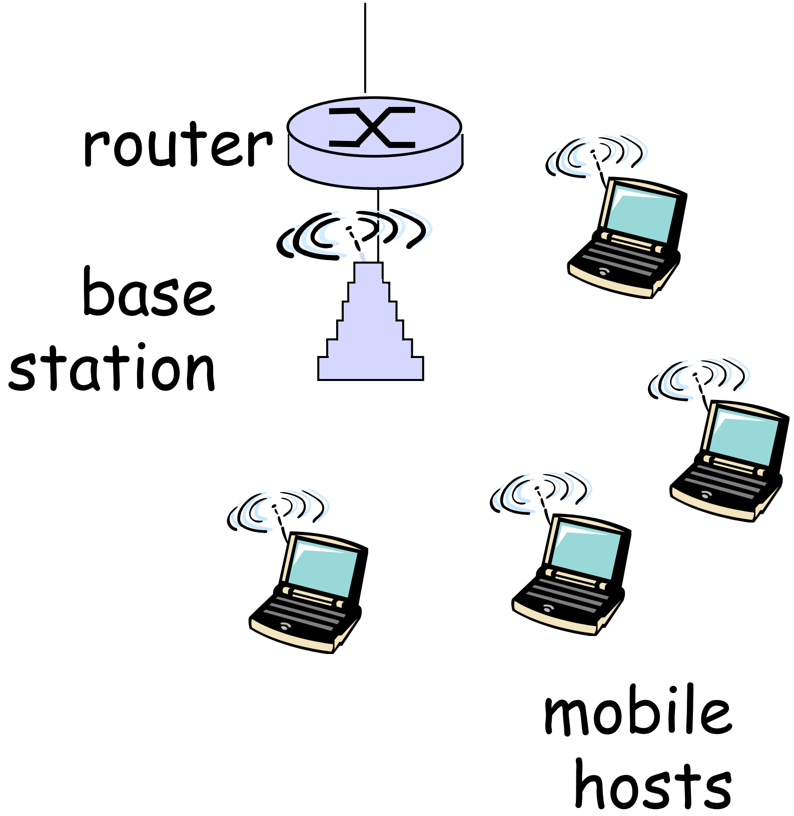
Ethernet Internet access



- Typically used in companies, universities, etc
- 10 Mbs, 100Mbps, 1Gbps, 10Gbps Ethernet
- Today, end systems typically connect into Ethernet switch

Wireless access networks

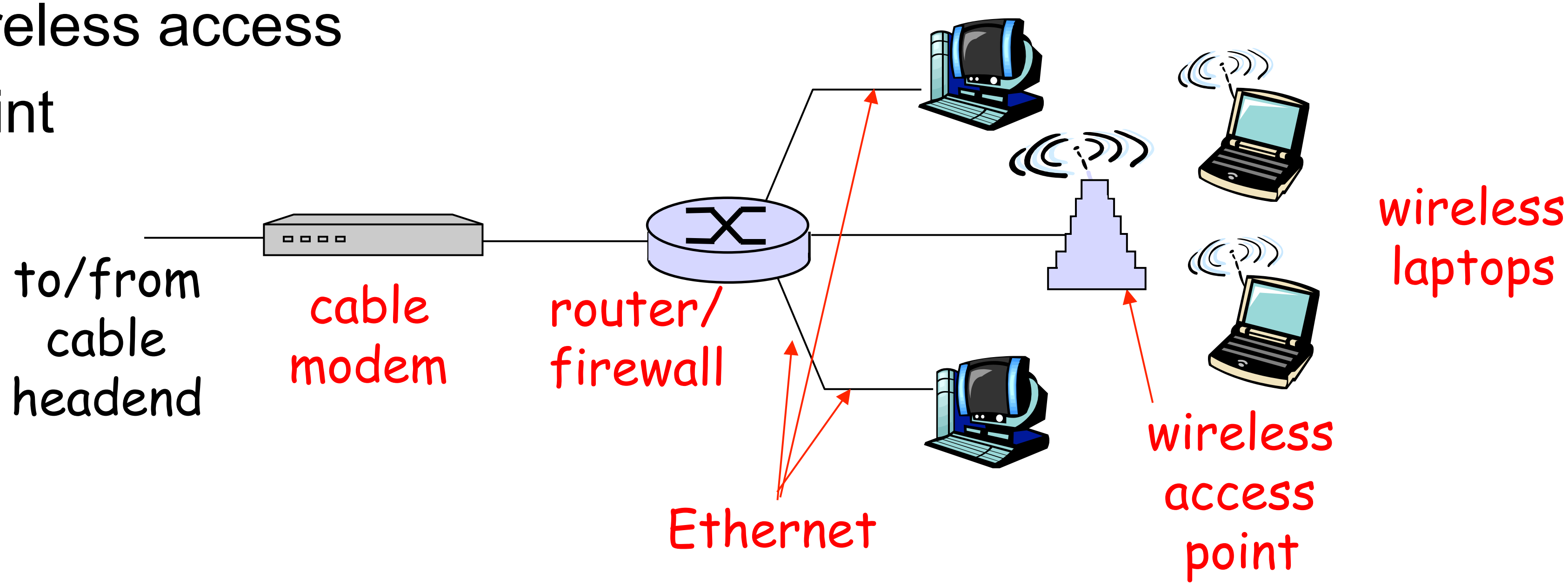
- shared *wireless* access network connects end system to router
  - via base station aka "access point"
- wireless LANs:
  - 802.11b/g (WiFi): 11 or 54 Mbps
- wider-area wireless access
  - provided by telco operator
  - ~1Mbps over cellular system (EVDO, HSDPA), several tens Mbps LTE
  - WiMAX (10's Mbps) over wide area
  - Next to come: 5G systems



Home networks

Typical home network components:

- DSL or cable modem
- router/firewall/NAT
- Ethernet
- wireless access point

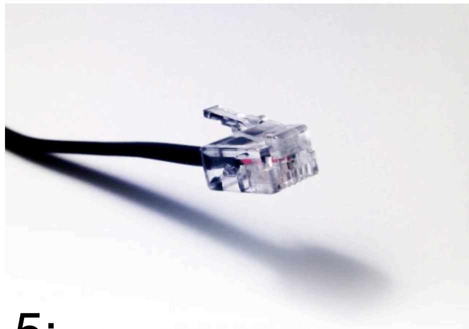


Physical Media

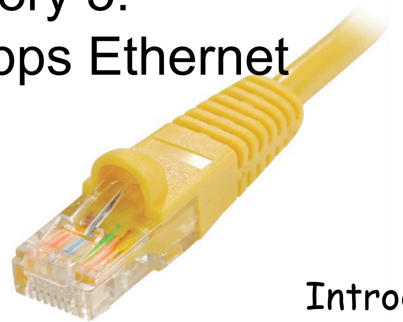
- Bit: propagates between transmitter/rcvr pairs
- physical link: what lies between transmitter & receiver
- guided media:
  - signals propagate in solid media: copper, fiber, coax
- unguided media:
  - signals propagate freely, e.g., radio

Twisted Pair (TP)

- two insulated copper wires
  - Category 3: traditional phone wires, 10 Mbps Ethernet



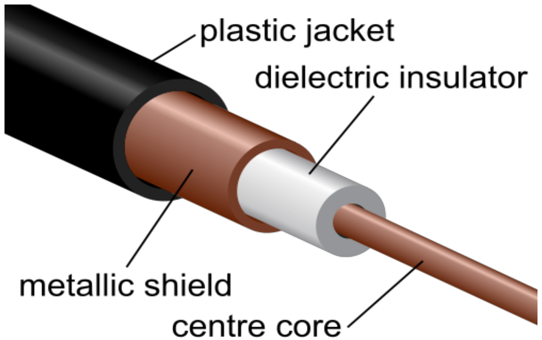
  - Category 5: 100Mbps Ethernet



Physical Media: coax, fiber

Coaxial cable:

- two concentric copper conductors
- bidirectional
- baseband:
  - single channel on cable
  - legacy Ethernet
- broadband:
  - multiple channels on cable
  - HFC



http://commons.wikimedia.org/wiki/File:Coaxial_cable_cutaway.svg

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 Gps, but experimented up to tens of terabps)
- low error rate: repeaters spaced far apart ; immune to electromagnetic noise

http://www.macmynd.com/storage/misc-pics/fiber_optic_cable.jpg

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 cellular: ~ 1 Mbps
- satellite
  - Kbps to 45Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus low altitude
    - (500 Km dalla superficie terrestre, servono costellazioni di satelliti)

Physical media performance evolution (update: 2014) –On the move

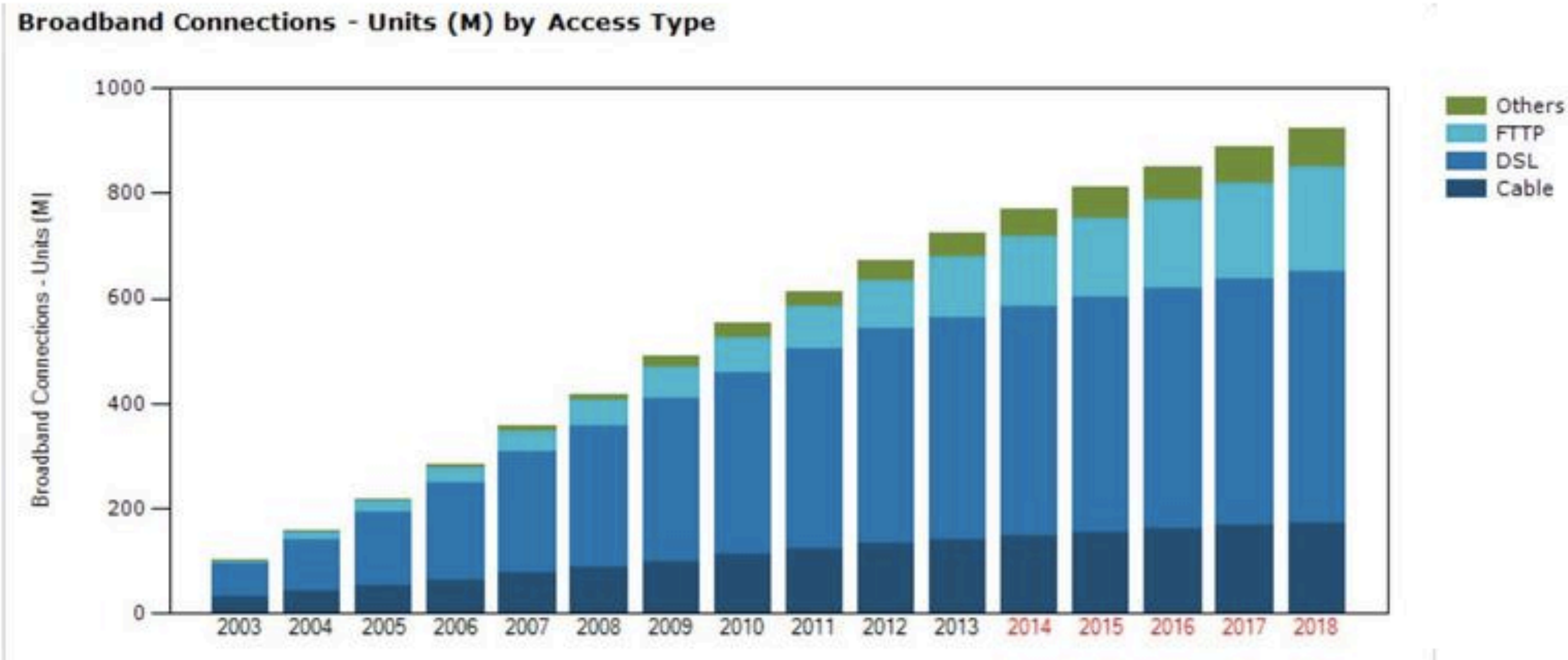
Generation		Technology	Maximum Download Speed	Typical Download Speed
2G	G	GPRS	0.1Mbit/s	<0.1Mbit/s
	E	EDGE	0.3Mbit/s	0.1Mbit/s
3G	3G	3G (Basic)	0.3Mbit/s	0.1Mbit/s
	H	HSPA	7.2Mbit/s	1.5Mbit/s
	H+	HSPA+	21Mbit/s	4Mbit/s
	H+	DC-HSPA+	42Mbit/s	8Mbit/s
4G	4G LTE	LTE	100Mbit/s	15Mbit/s

Physical media performance evolution (update: 2014) –Access technologies

WiFi, Ethernet, Fiber to the “home”, DSL…Maximum current speeds or technologies tested to enter the market within a couple of years

- DSL (G.Fast technology) 1Gbps
  - By 2016
  - Combined with fiber; access to broadband network within 50m to reach such speeds
- Ethernet: 25Gbps (40Gbps under standardization). With more lines: currently 100Gbps, standards towards 400Gbps
- WiFi IEEE 802.11ac Up to 1Gbps to come
- Fiber
  - Technologies tested up to few tens of terabps
  - 1Gbps per home more than enough (current threshold per user satisfaction >10Mbps)
- Cellular systems evolution
  - Tens-hundred of Mbps

Physical media performance evolution (update: 2014)—different types of media

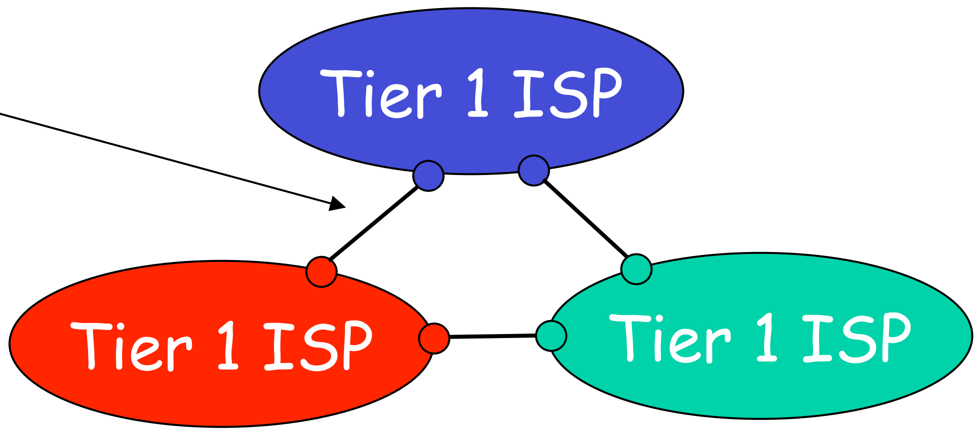


DSL is the most widely used broadband connection technology, and it's growing, but fiber-optic links are growing faster.

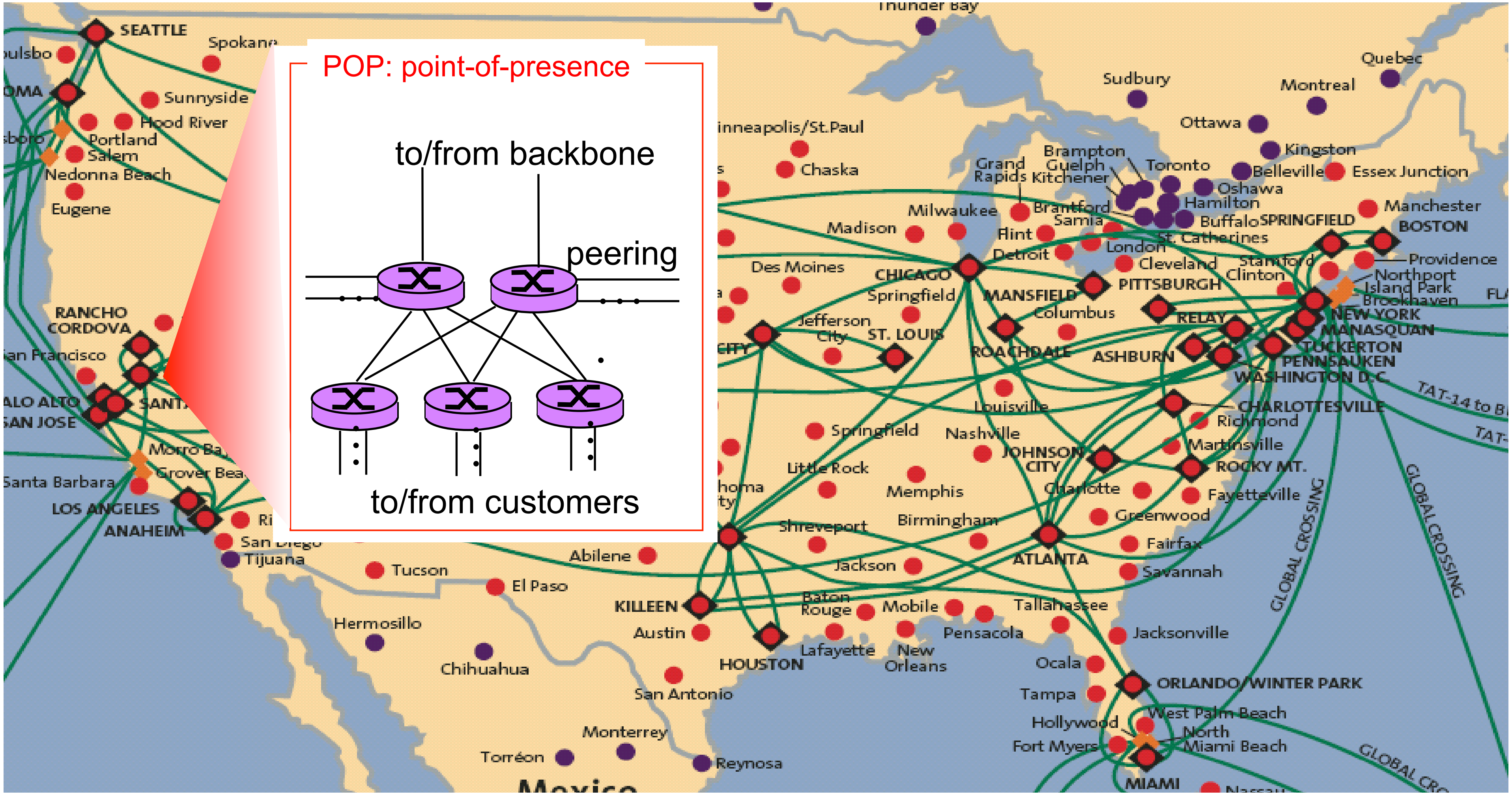
Internet structure: network of networks

- roughly hierarchical
- at center: "tier-1" ISPs (e.g., Verizon, Sprint, AT&T, Cable and Wireless), national/international coverage
  - treat each other as equals

Tier-1 providers interconnect (peer) privately

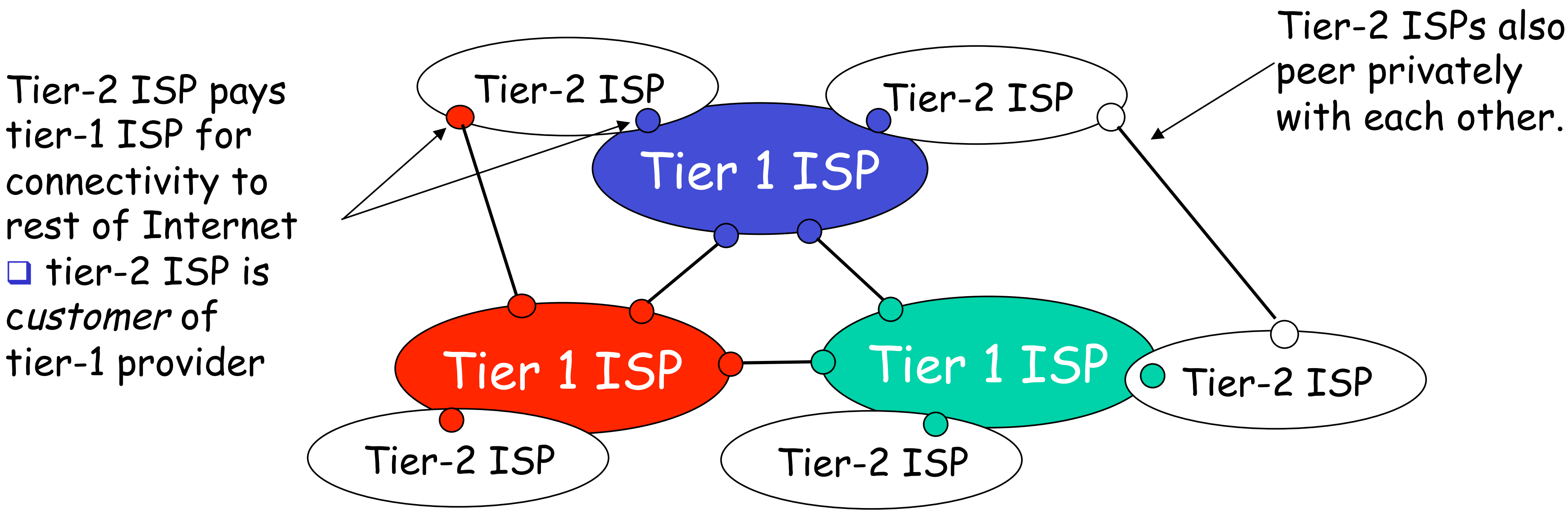


Tier-1 ISP: e.g., Sprint



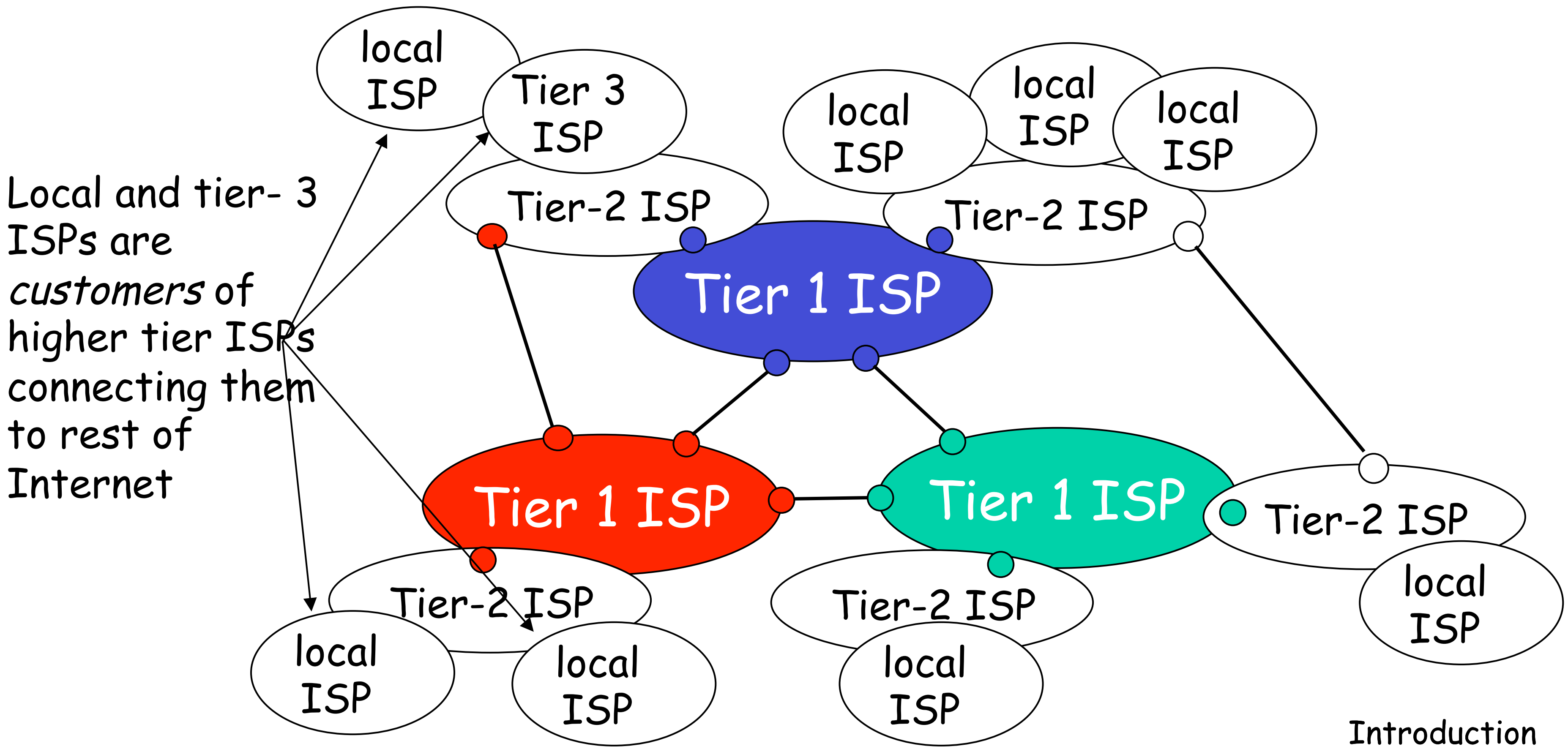
Internet structure: network of networks

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



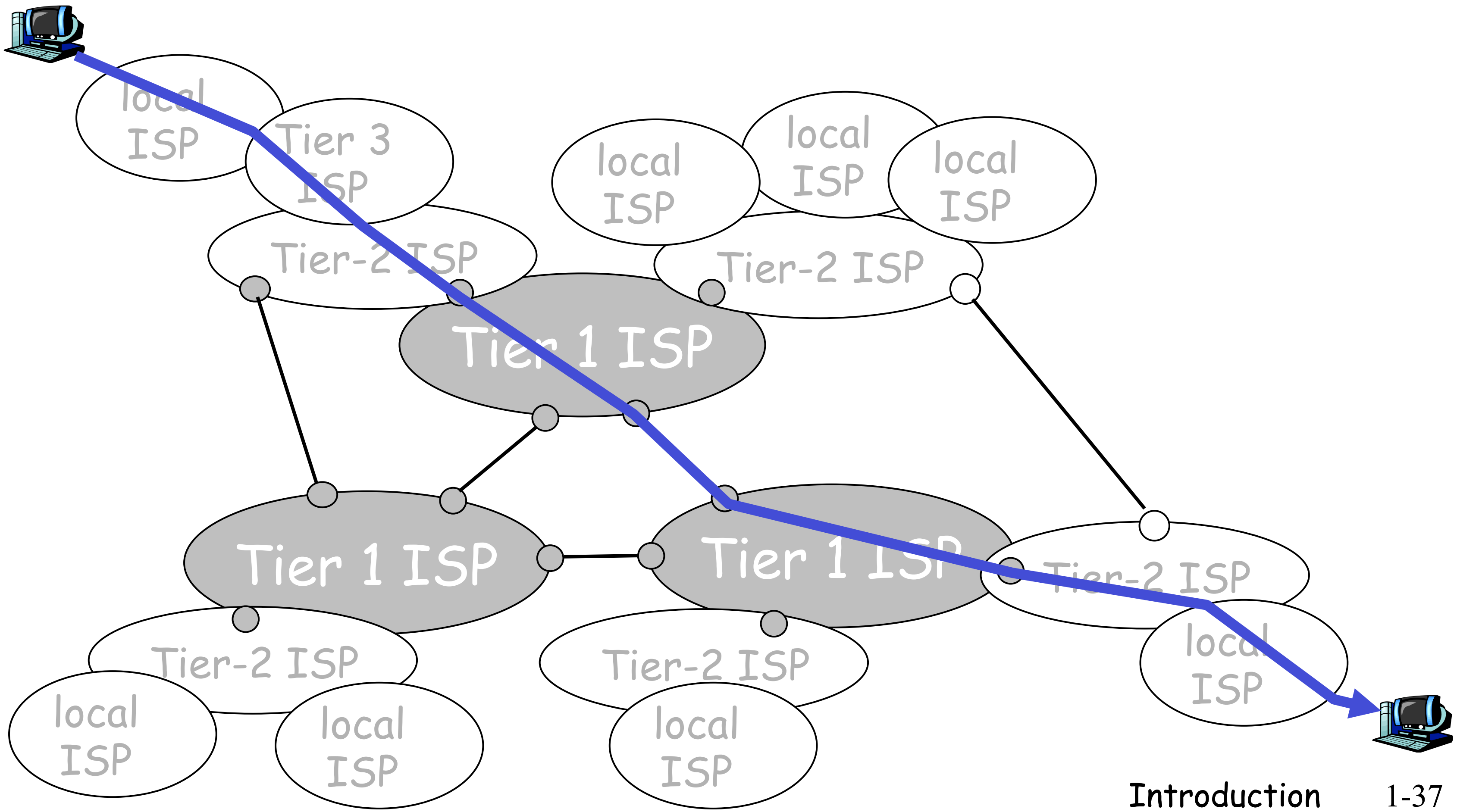
Internet structure: network of networks

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

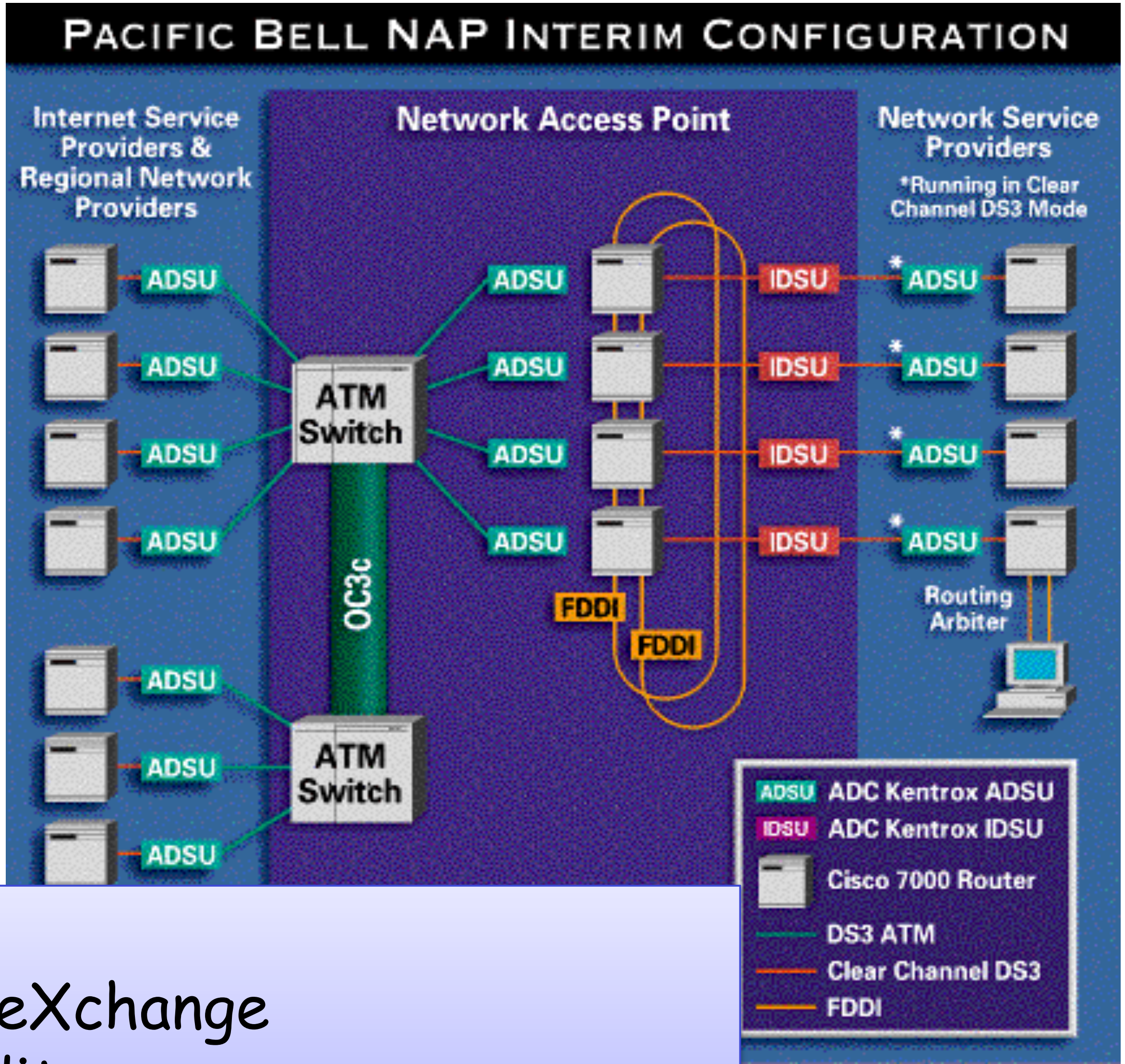


Internet structure: network of networks

- a packet passes through many networks!



A NAP: just another router...?



Pacific Bell S. Francisco NAP

In Italia:
-MIX Milan Internet eXchange
-NaMeX Nautilus Mediterranean Exchange Point

Chapter 1: roadmap

1.1 What *is* the Internet?
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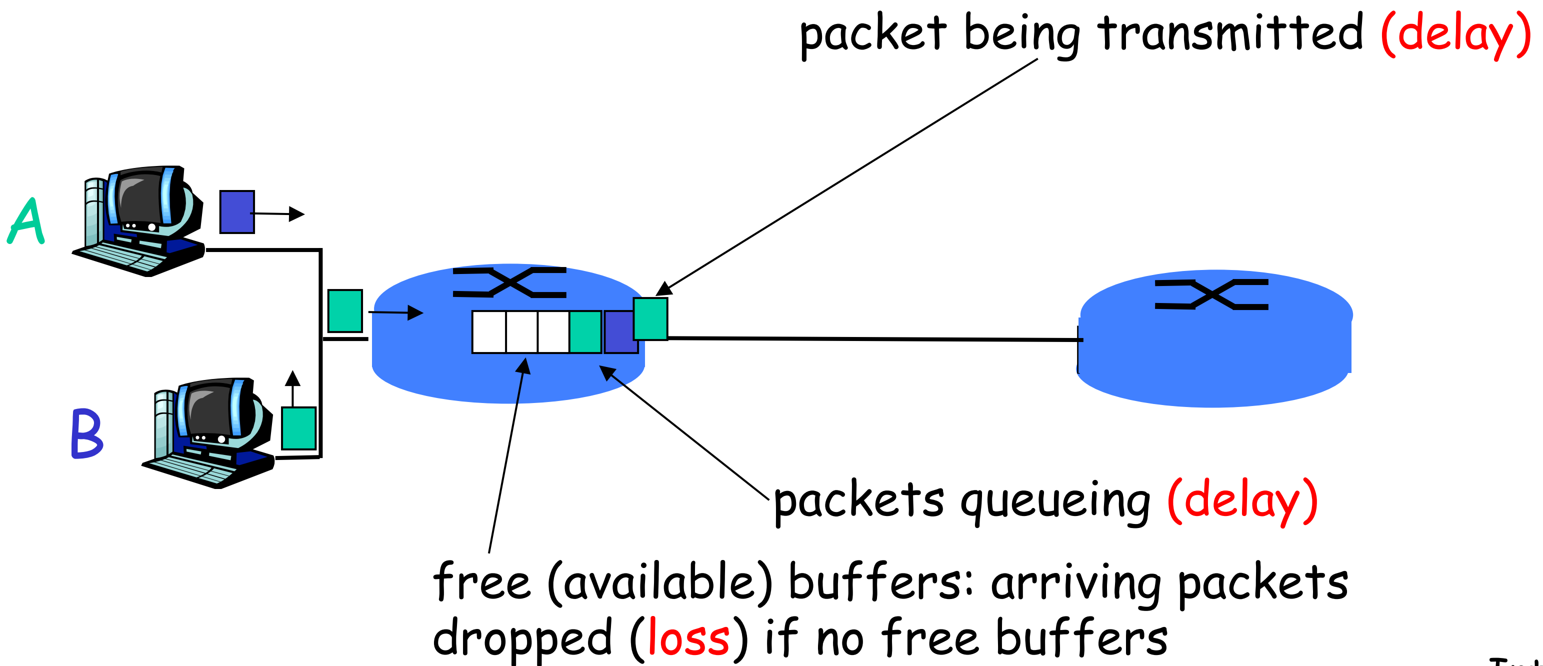
1.4 Network access and physical media
1.5 Internet structure and ISPs
1.6 Delay & loss in packet-switched networks
1.7 Protocol layers, service models
1.8 History

How do loss and delay occur?

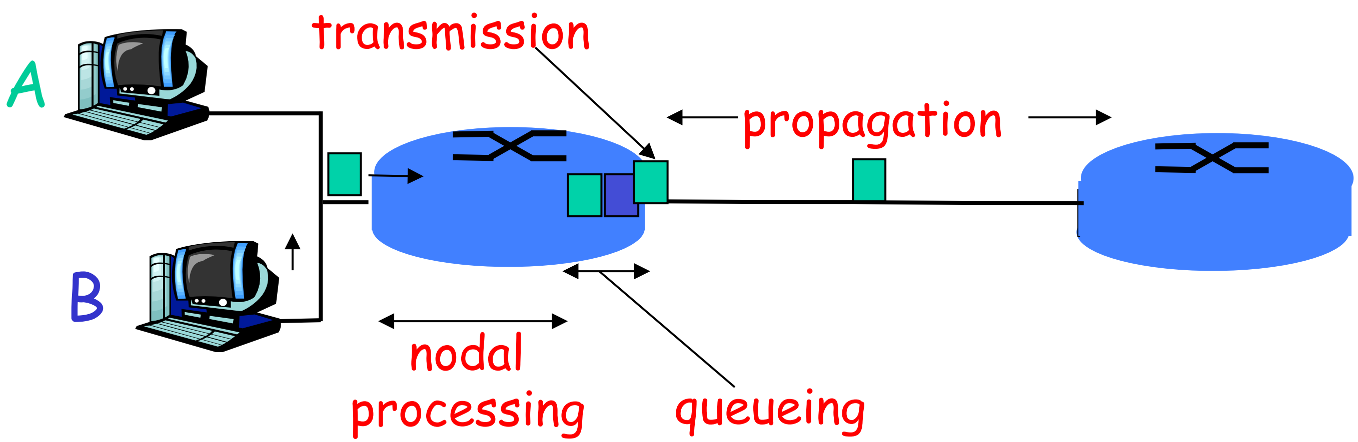
packets *queue* in router buffers

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



Four sources of packet delay

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



Delay in packet-switched networks

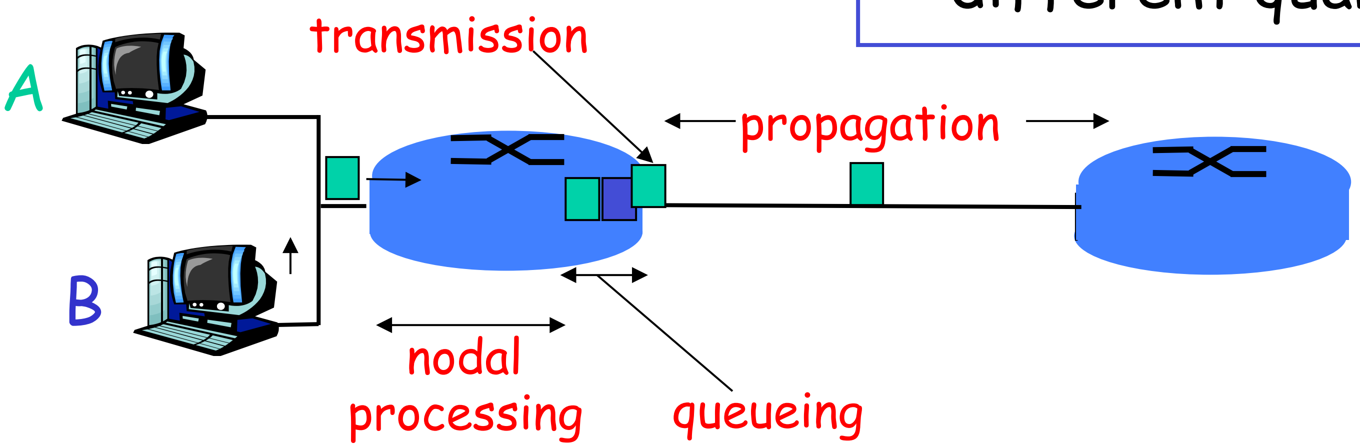
3. Transmission delay:

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

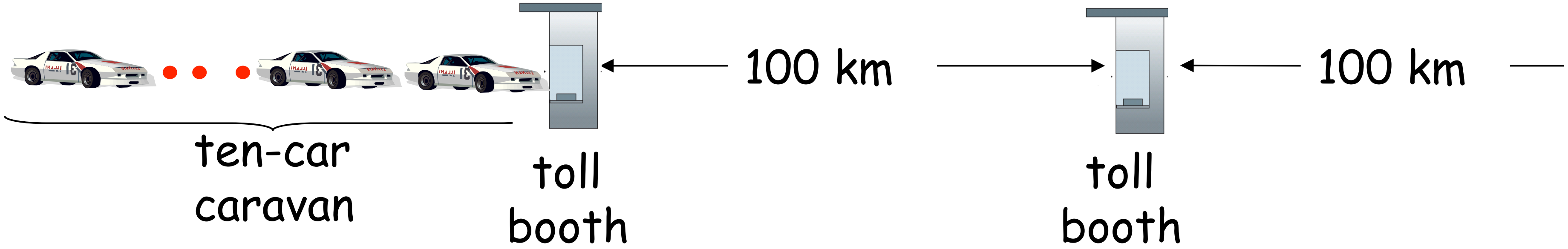
4. Propagation delay:

- d = length of physical link
- s = propagation speed in medium (~2×10^8 m/sec)
- propagation delay = d/s

Note: s and R are *very* different quantities!

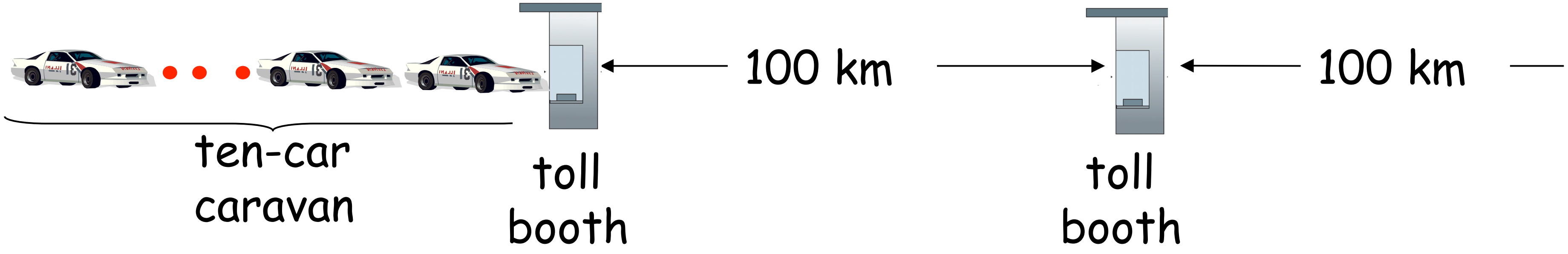


Caravan analogy



- cars "propagate" at 100 km/hr
- toll booth takes 12 sec to service car (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)



- Cars now "propagate" at 1000 km/hr
- Toll booth now takes 1 min to service a car
- Q: Will cars arrive to 2nd booth before all cars serviced at 1st booth?
- Yes! After 7 min, 1st car at 2nd booth and 3 cars still at 1st booth.
- 1st bit of packet can arrive at 2nd router before packet is fully transmitted at 1st router!
  - See Ethernet applet at AWL Web site

Nodal delay

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

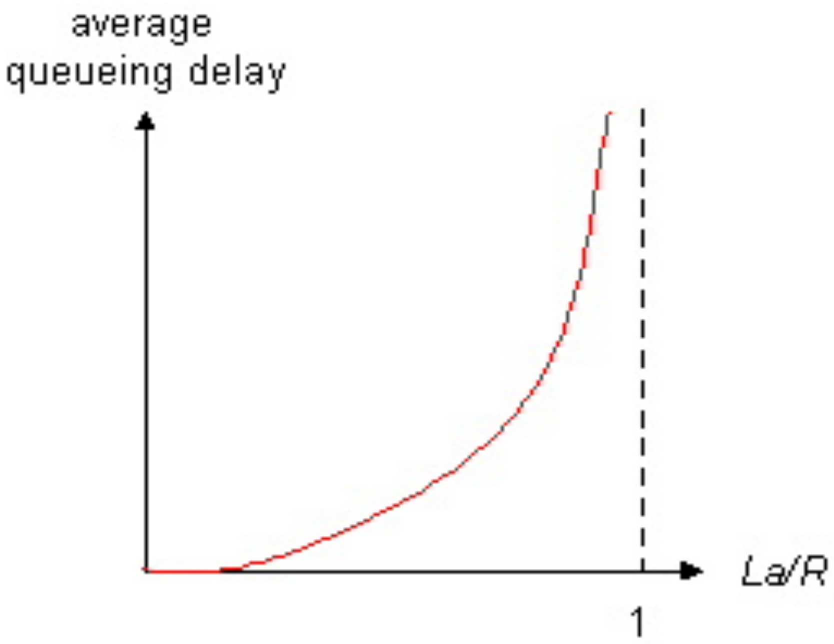
- d_{proc} = processing delay
  - typically a few microsecs or less
- d_{queue} = queuing delay
  - depends on congestion
- d_{trans} = transmission delay
  - = L/R, significant for low-speed links
- d_{prop} = propagation delay
  - a few microsecs to hundreds of msecs

Delay for each hop!!!

Queueing delay (revisited)

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

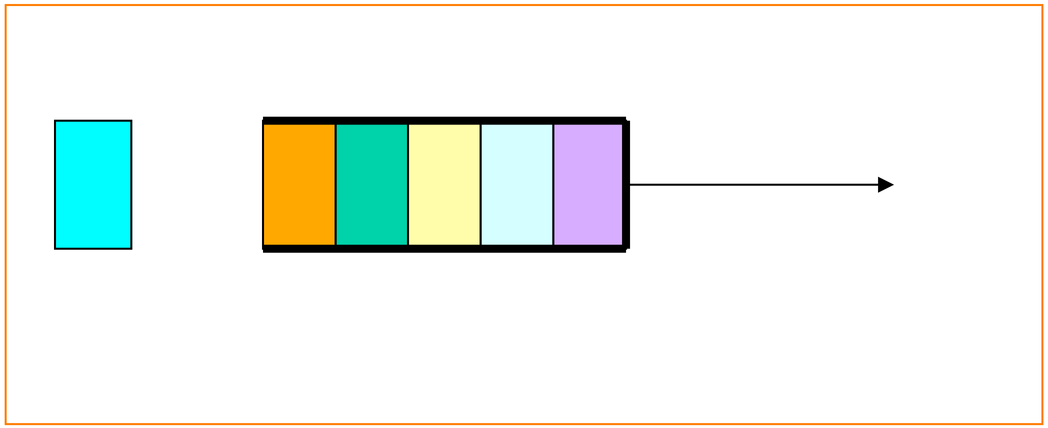
traffic intensity = La/R

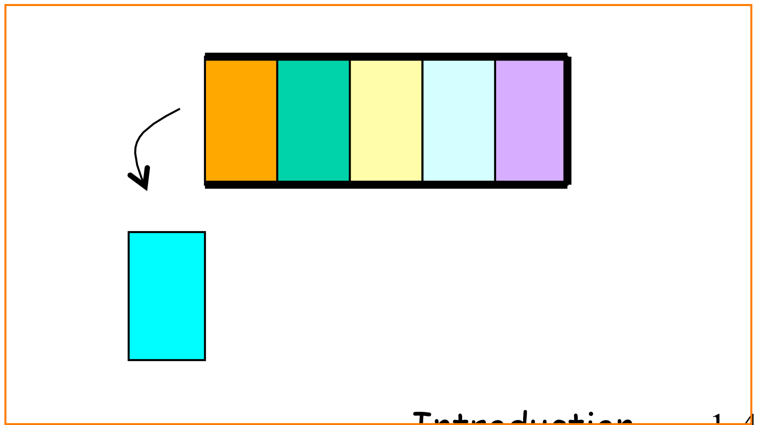


- La/R ~ 0: average queueing delay small
- La/R -> 1: delays become large
- La/R > 1: more "work" arriving than can be serviced, average delay infinite!

Packet loss

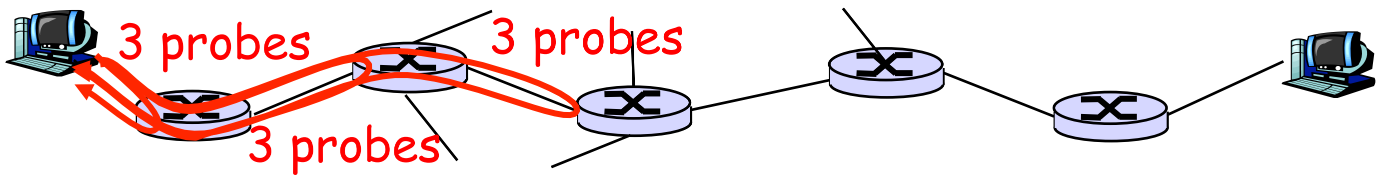
- queue (→buffer) preceding link in buffer has finite capacity
- when packet arrives to full queue, packet is dropped (→lost)
- lost packet may be retransmitted by previous node, by source end system, or not retransmitted at all





"Real" Internet delays and routes

- What do "real" Internet delay & loss look like?
- Trace route program: provides delay measurement from source to router along end-end Internet path towards destination. For all *i:*
  - sends three packets that will reach router *i* on path towards destination
  - router *i* will return packets to sender
  - sender times interval between transmission and reply.



"Real" Internet delays and routes

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

Three delay measements 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

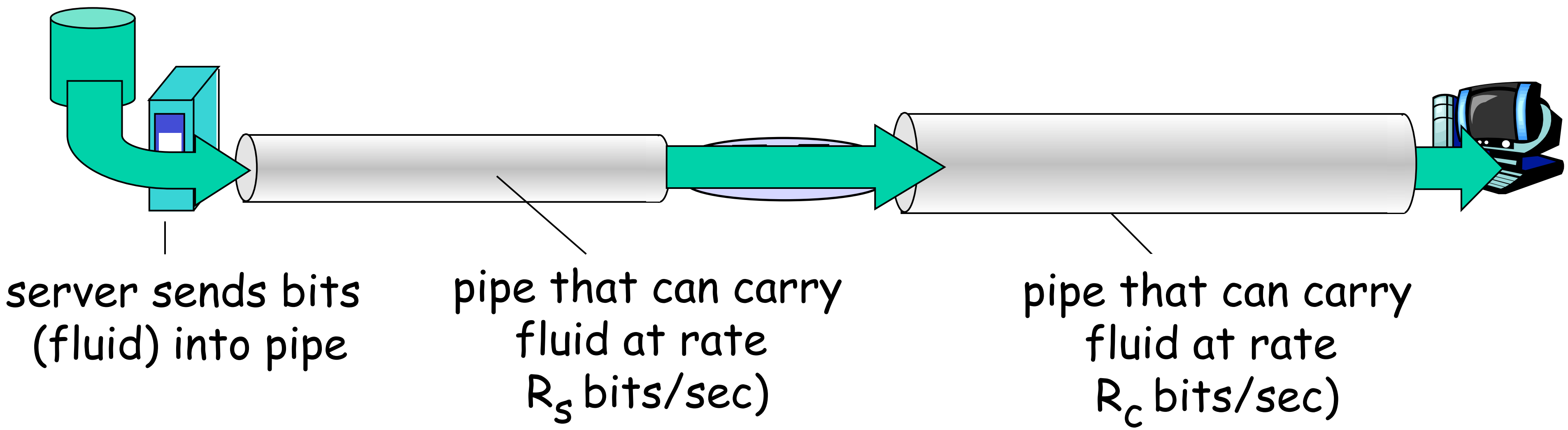
trans-oceanic link

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

Name and address of router, round trip delays (3 samples)

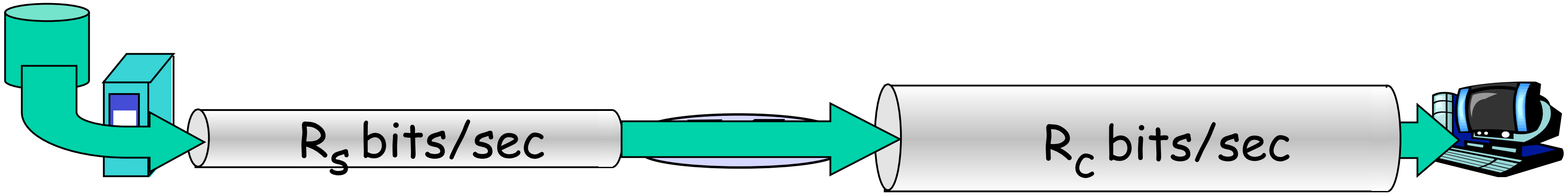
Throughput

- *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

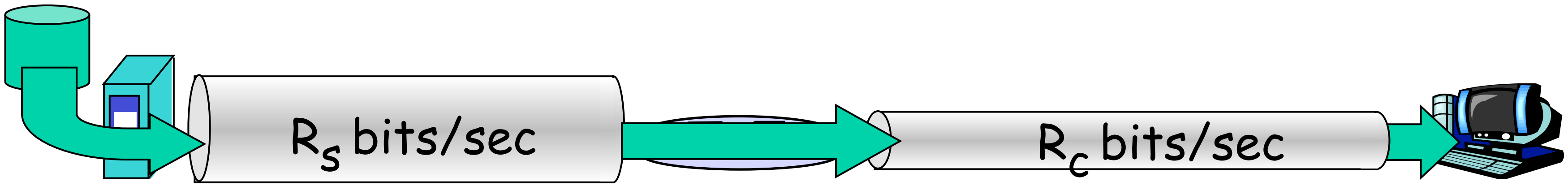


Throughput (more)

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



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

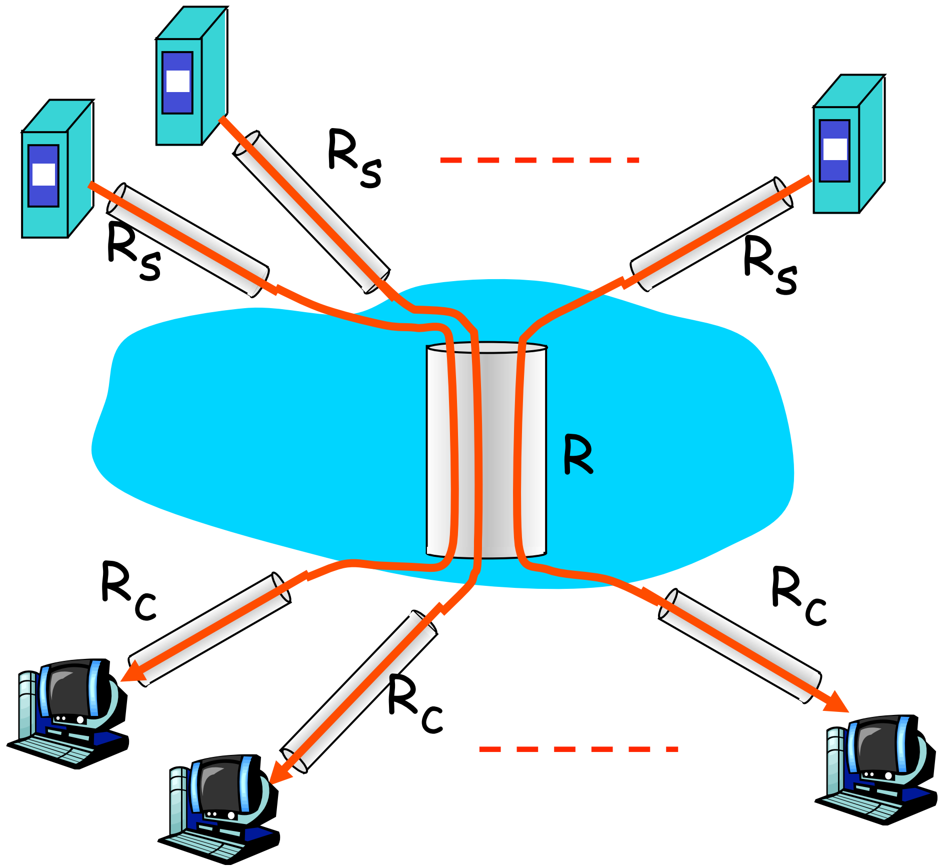


bottleneck link

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