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# Reti di Elaboratori

Corso di Laurea in Informatica
Università degli Studi di Roma "La Sapienza"
Canale A-L Prof.ssa Chiara Petrioli


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

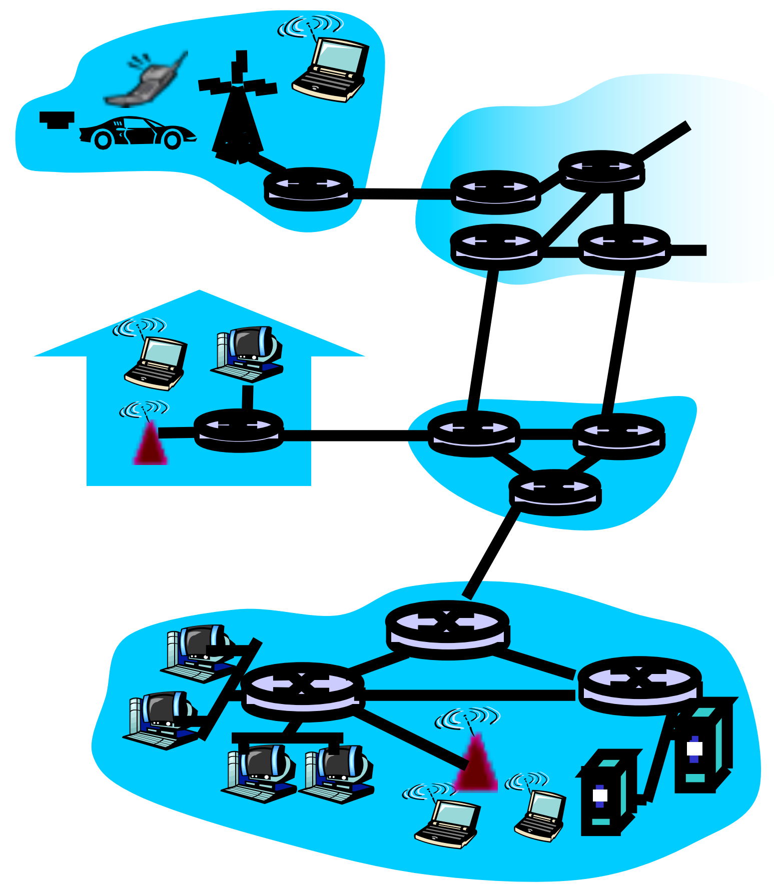
1.5 Protocol layers, service models

1.6 Networks under attack: security

1.7 History

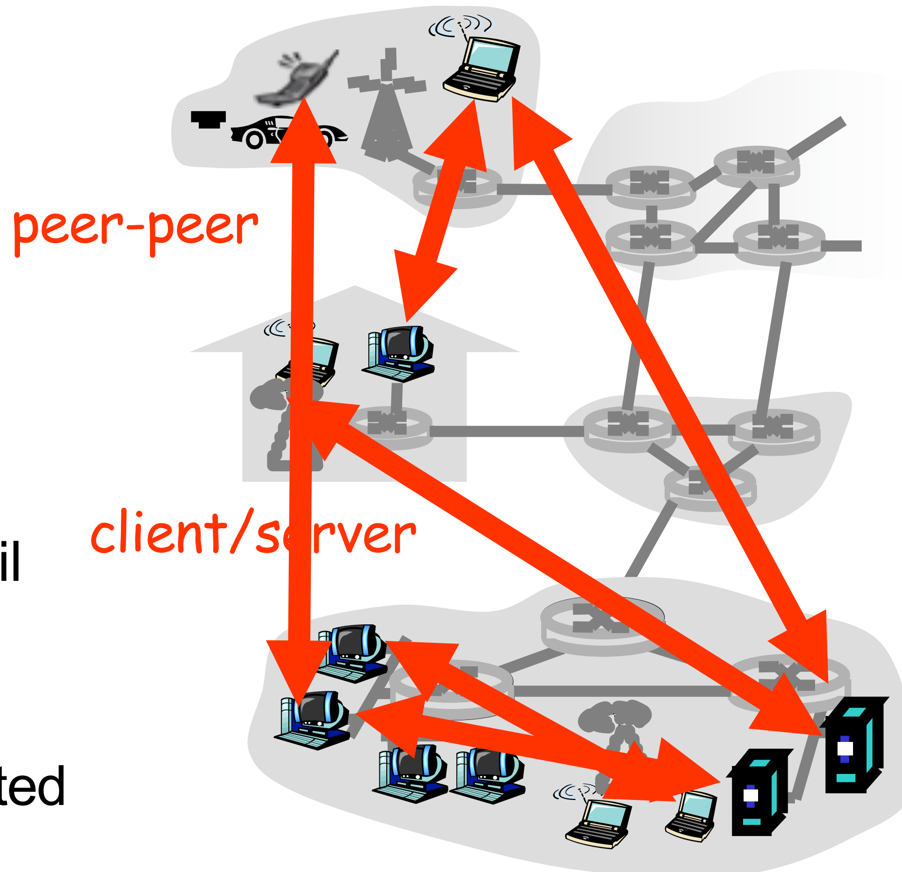
# A closer look at network structure:

- 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



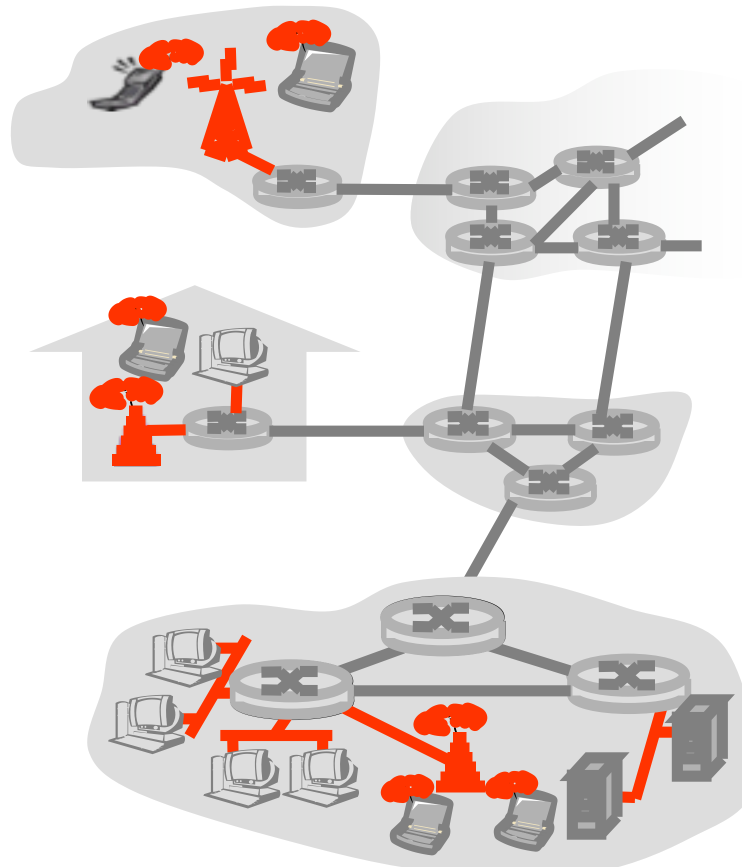
# Access networks and physical media

*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?



# 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

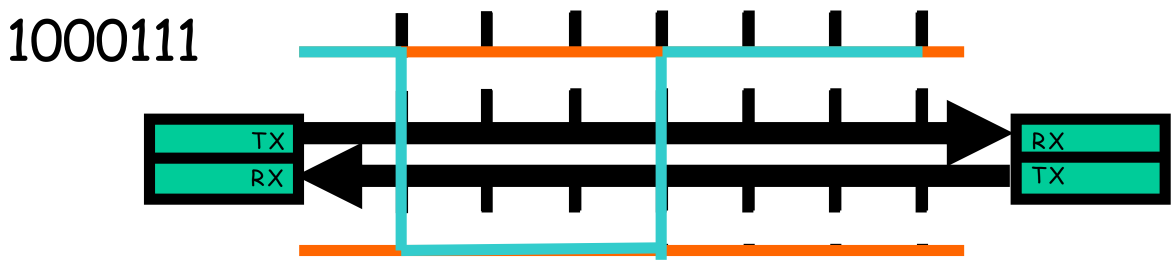
# Transmission across a physical link


- 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)

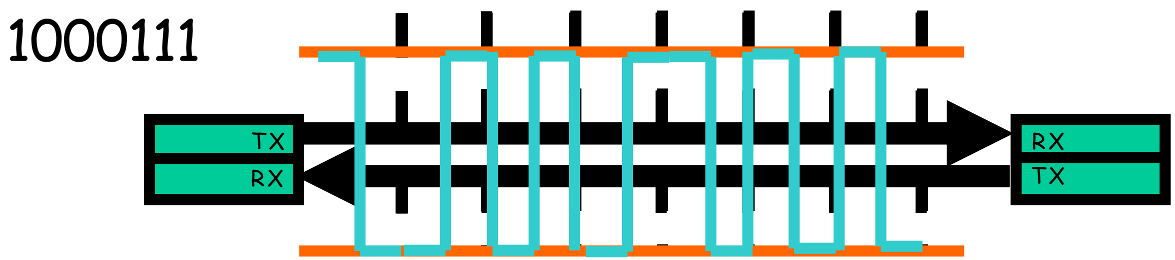



Problemi di sincronizzazione del ricevitore (nessuna transizione nel caso di sequenze di zeri o di uni)→ NRZ 5B6B o 4B5B

# Codifica Manchester

- Codifica Manchester

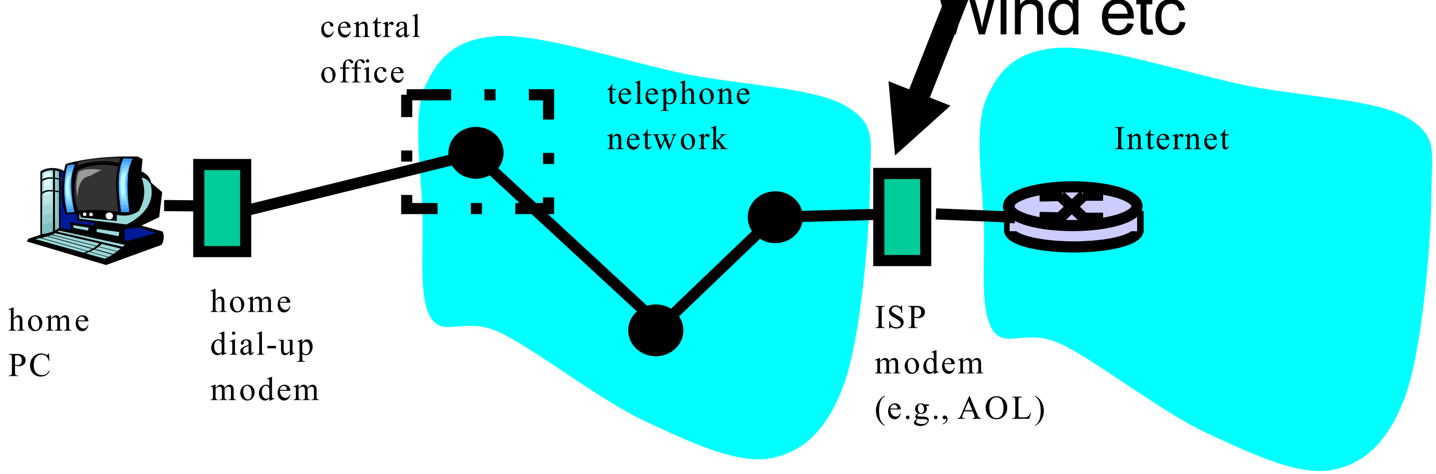
Una transizione basso-alto (codifica dello zero) o alto-basso (codifica del valore uno) in corrispondenza di ogni bit




Usato in Ethernet 10Mbps e Token Ring

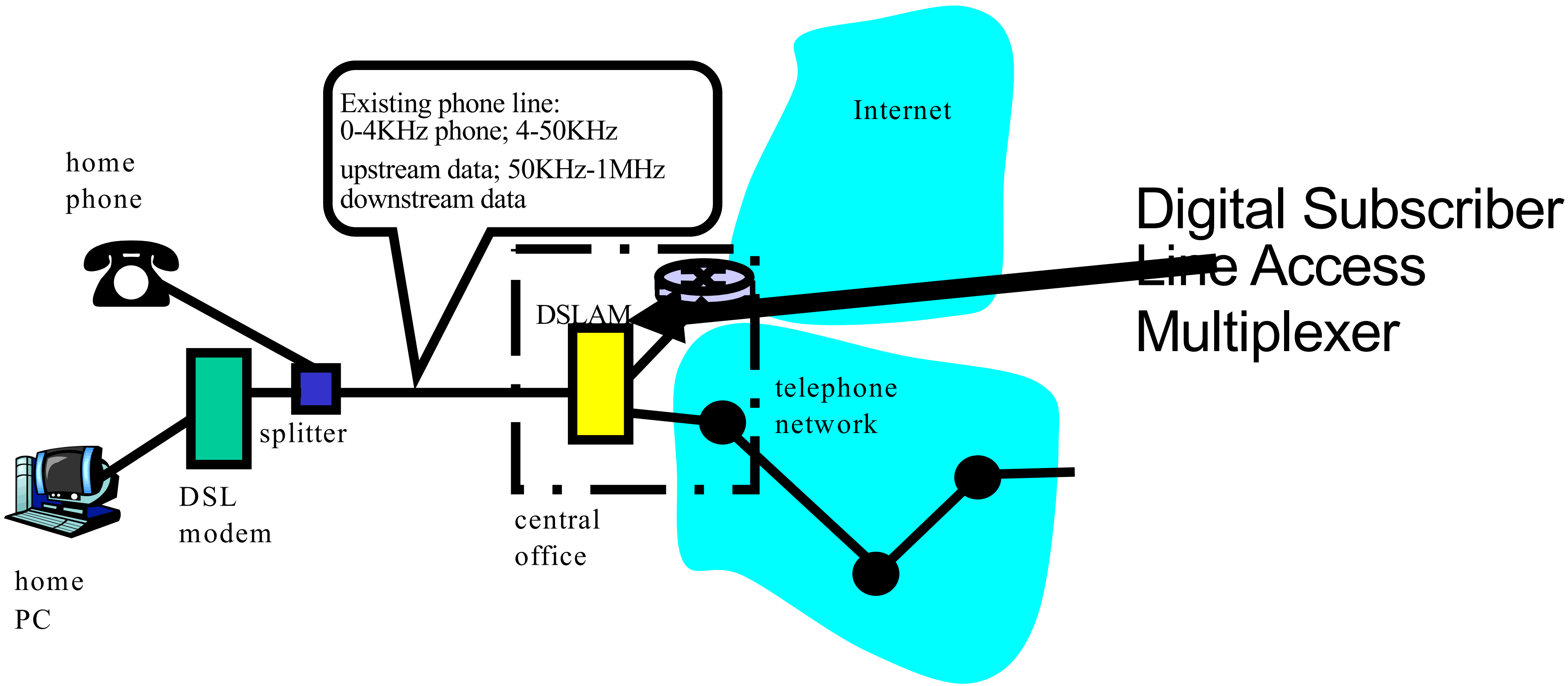
# Dial-up Modem

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 (today typically < 256 kbps)
- up to 8 Mbps downstream (today 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)

# 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

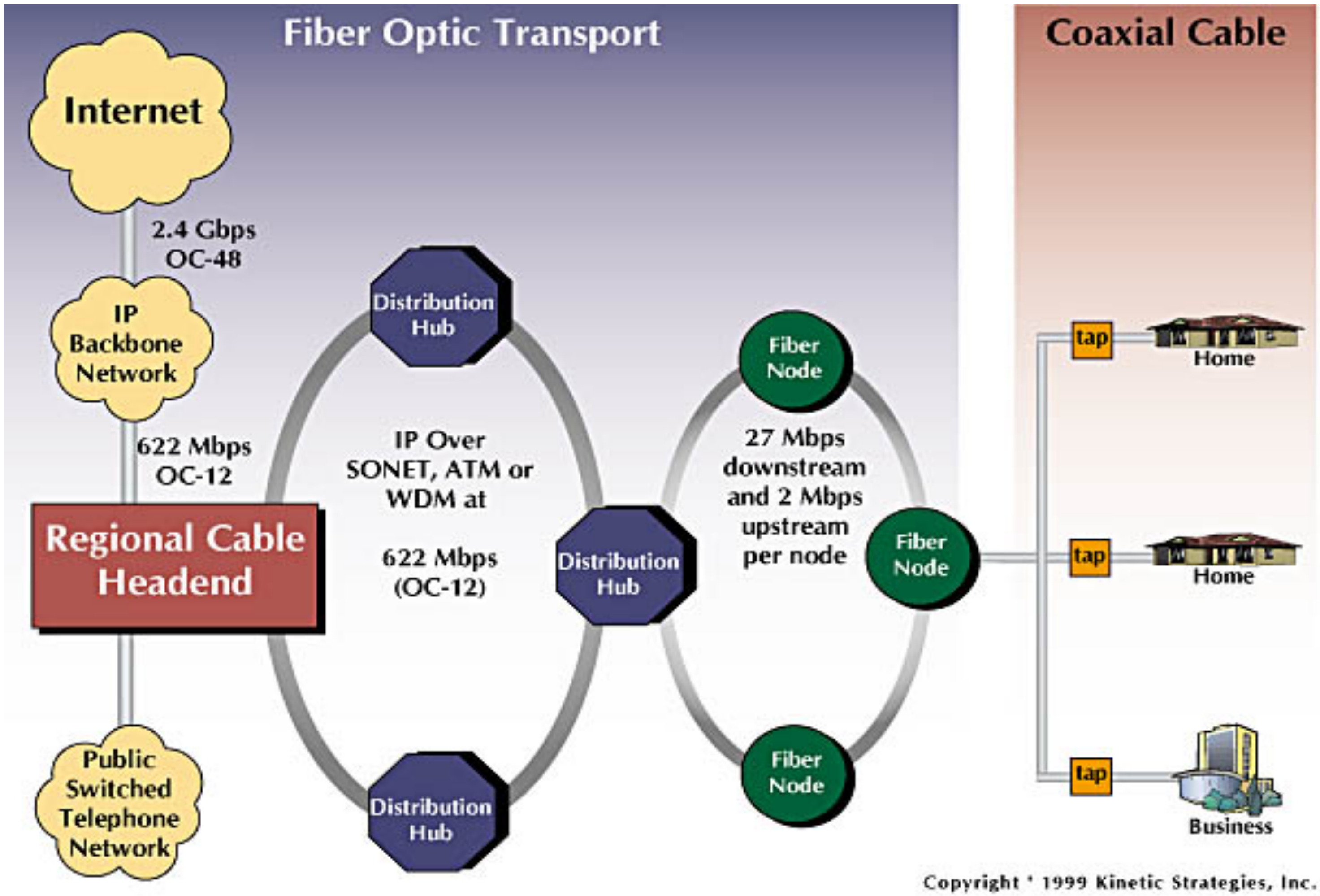
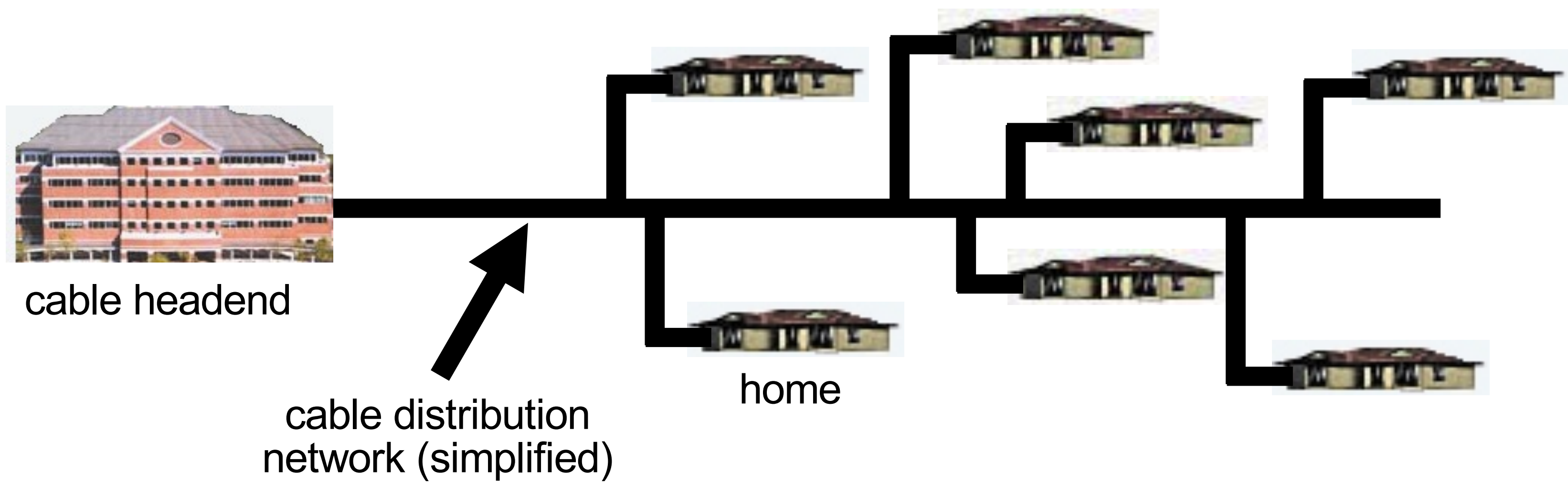


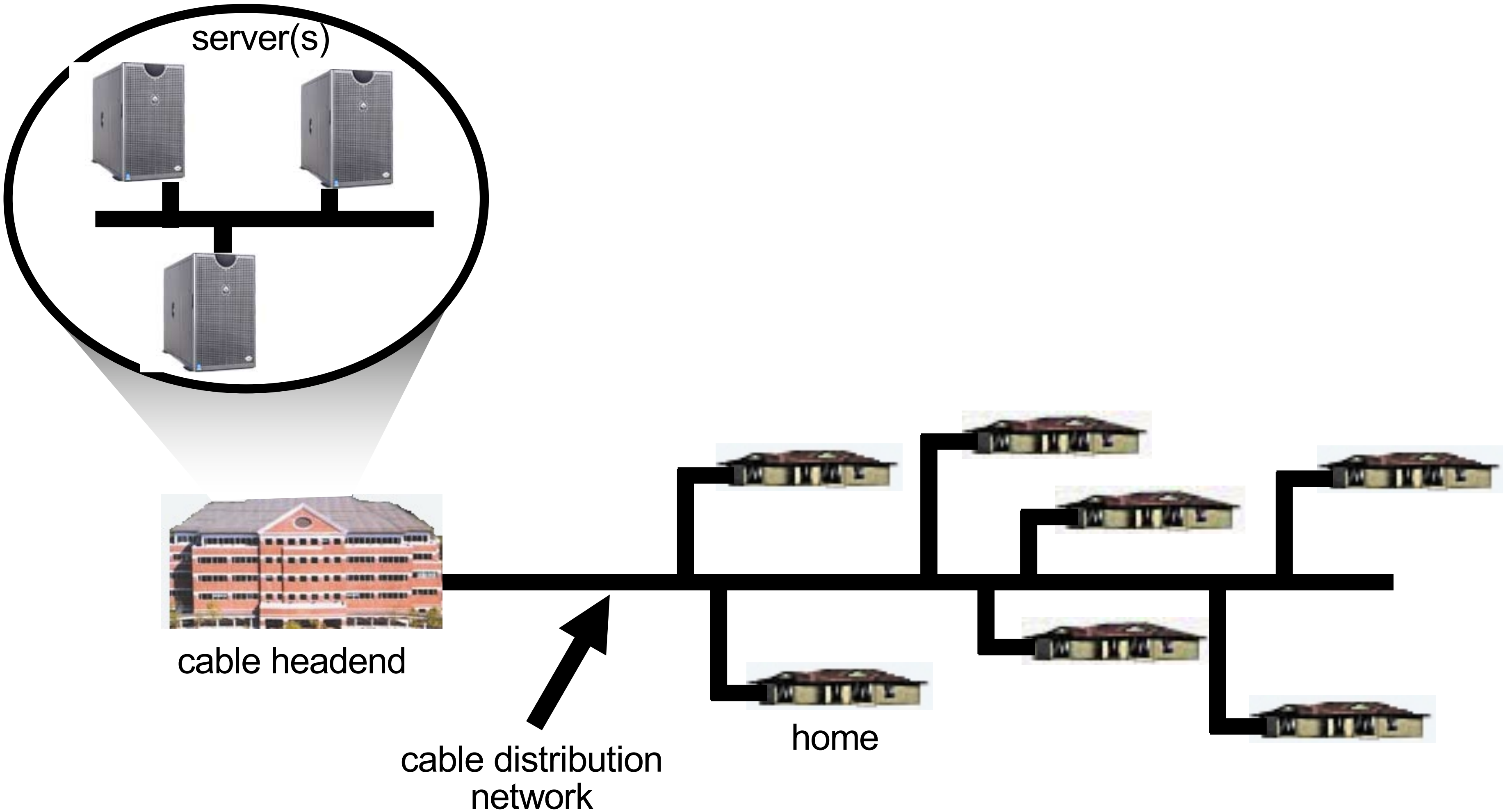

Diagram: http://www.cabledatacomnews.com/cmic/diagram.html

# Cable Network Architecture: Overview

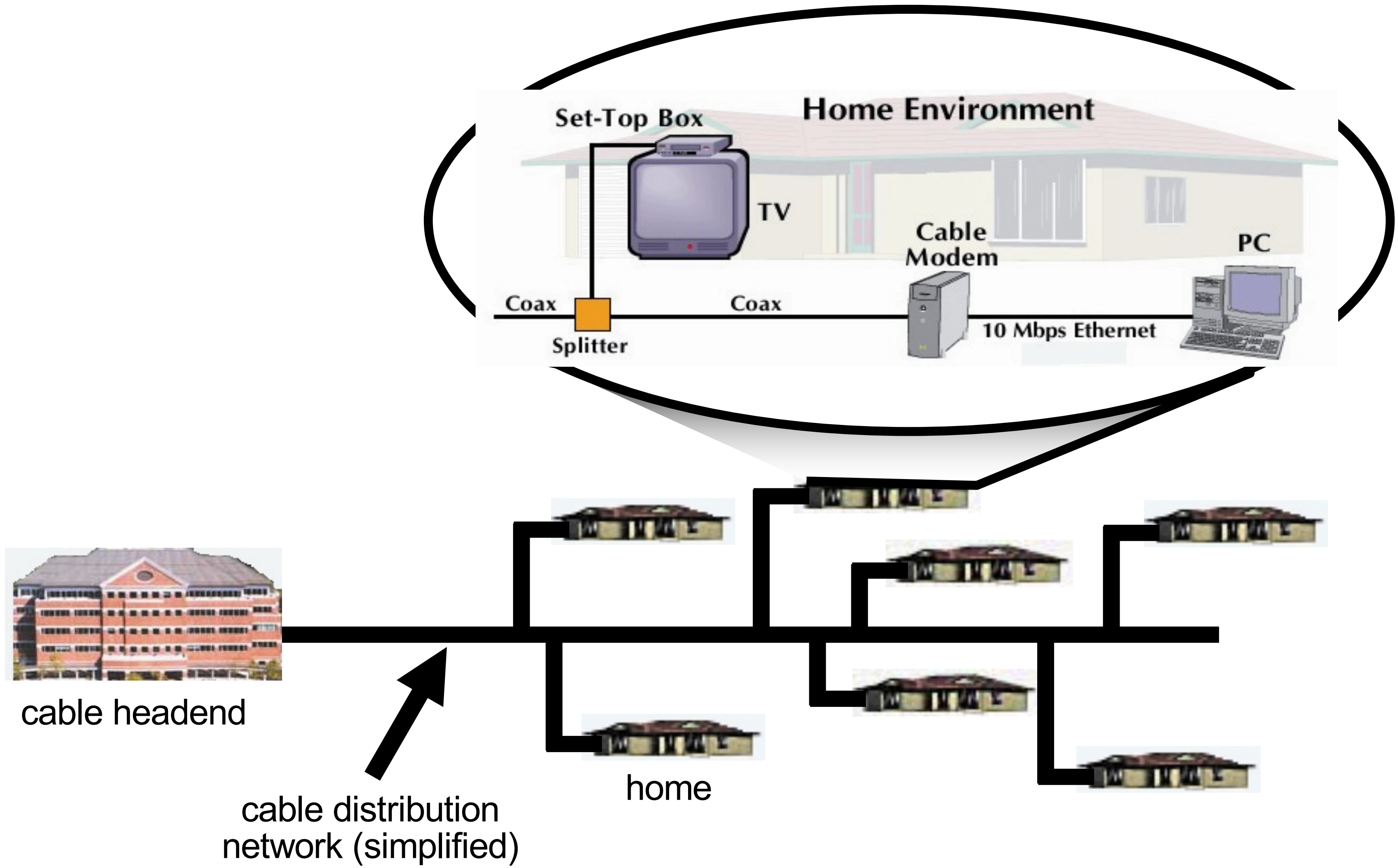
Typically 500 to 5,000 homes



# Cable Network Architecture: Overview

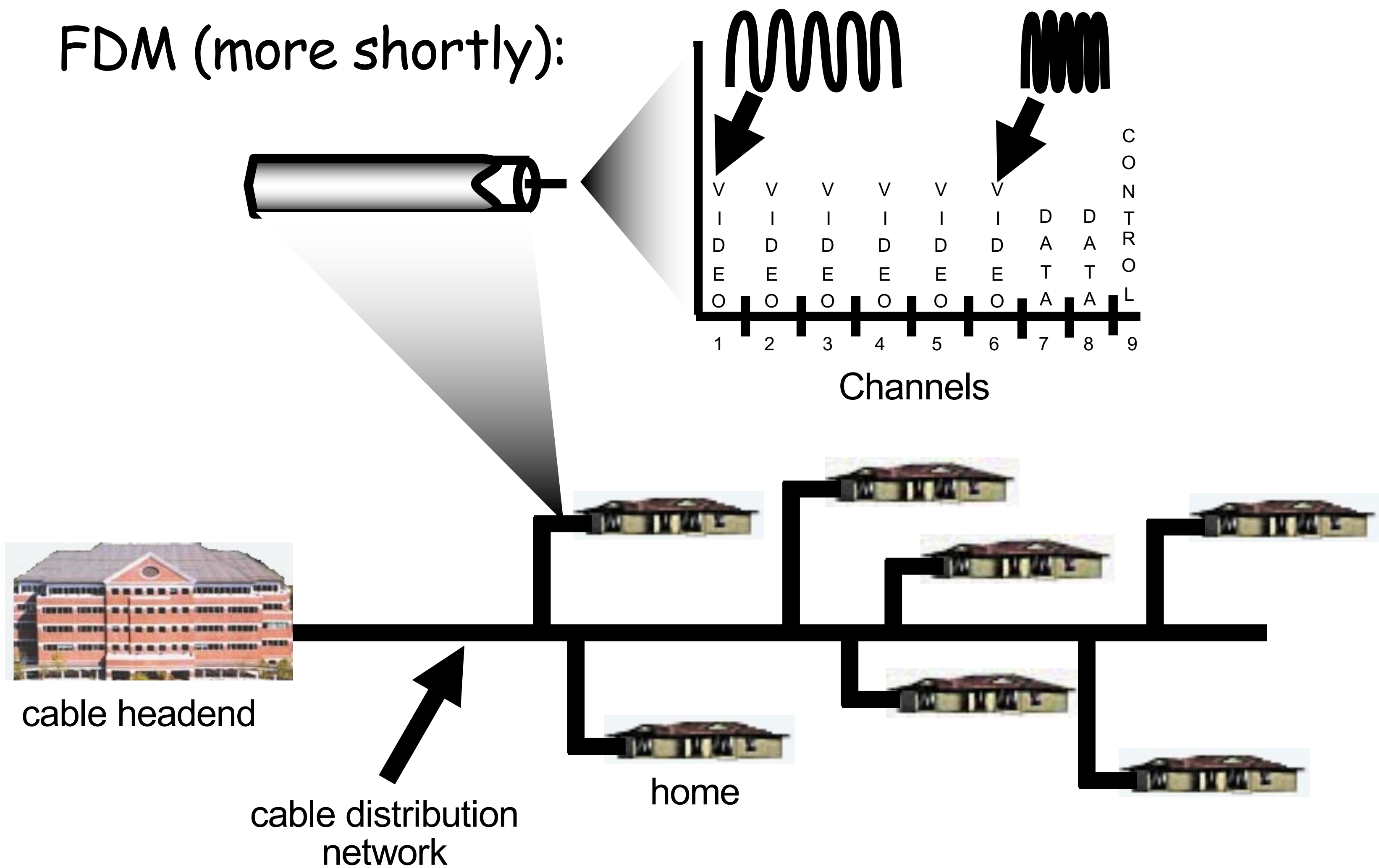


# Cable Network Architecture: Overview

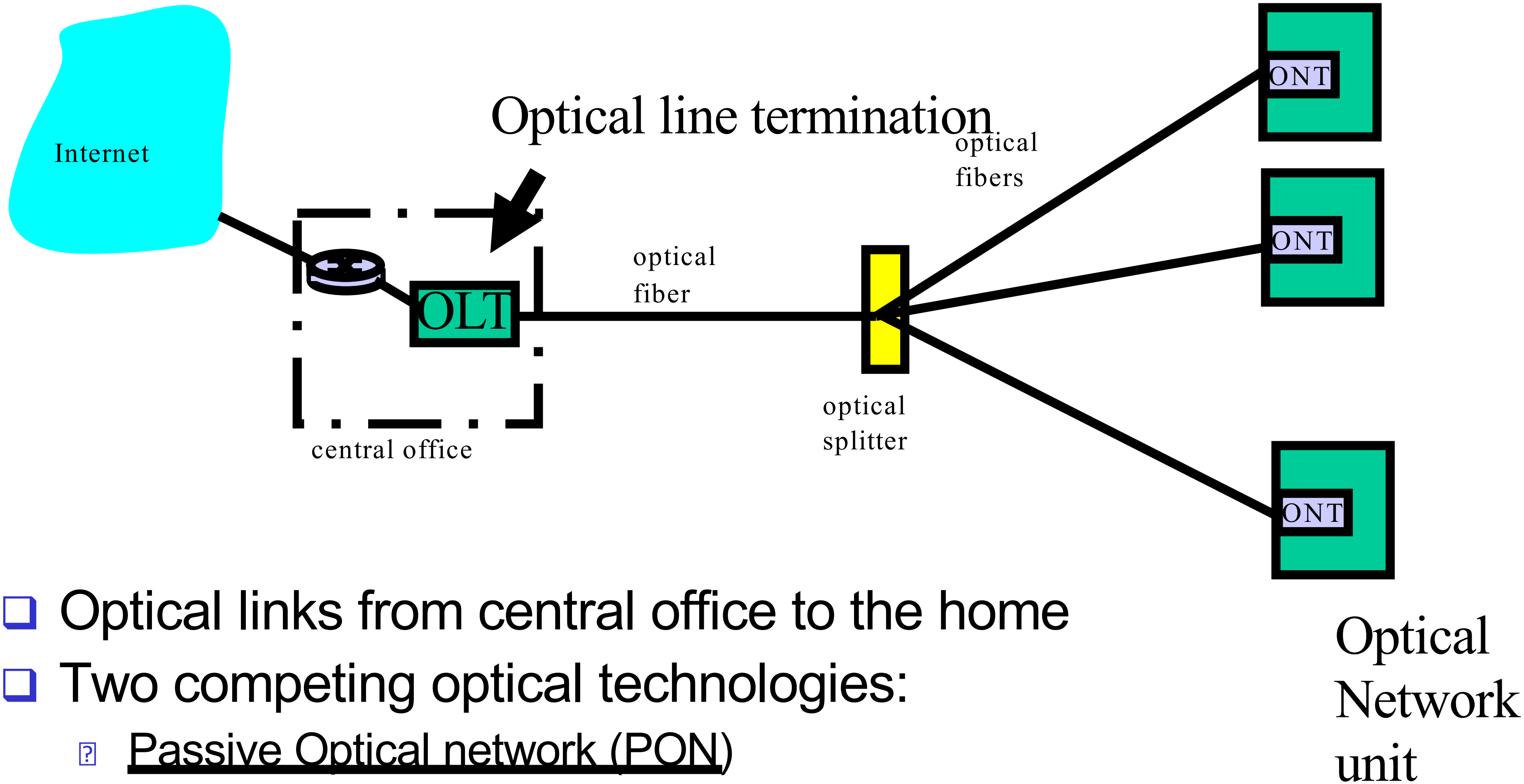


# Cable Network Architecture: Overview

FDM (more shortly):

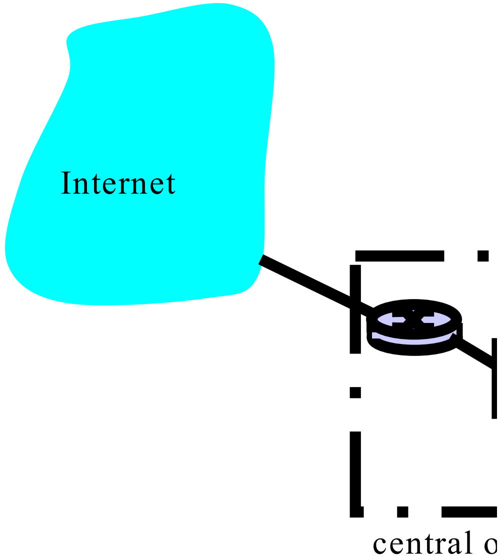


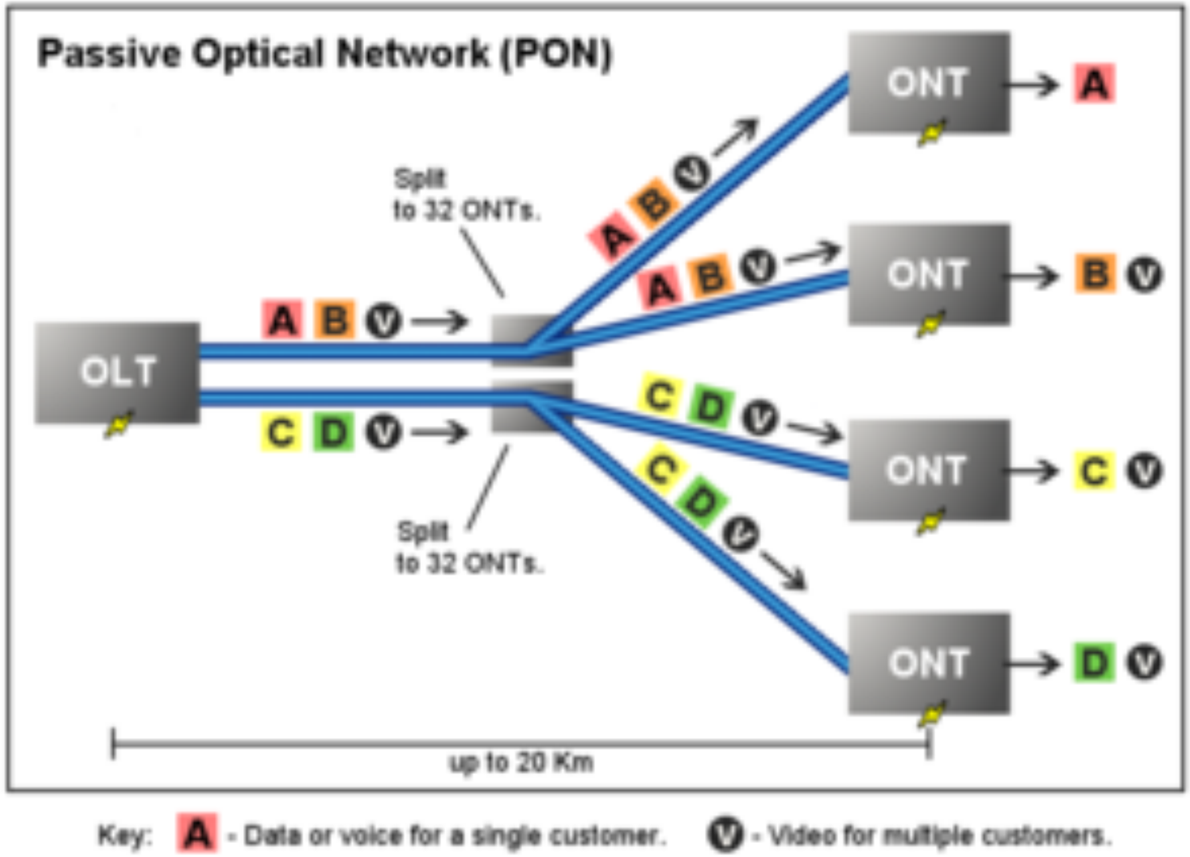
# Fiber to the Home




- 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



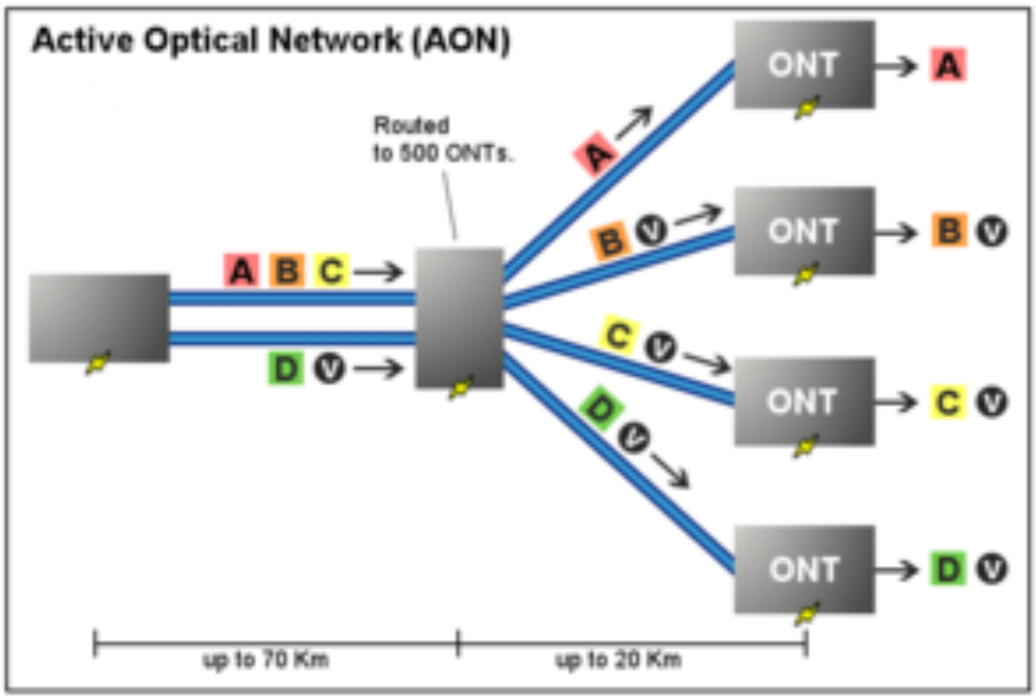




- Optical links fro
- Two competing
  - Passive Optical network (PON)
  - Active Optical Network (PAN)
- Much higher Internet rates; fiber also carries television and phone services

cal
Network
unit

# Active Optical Networks

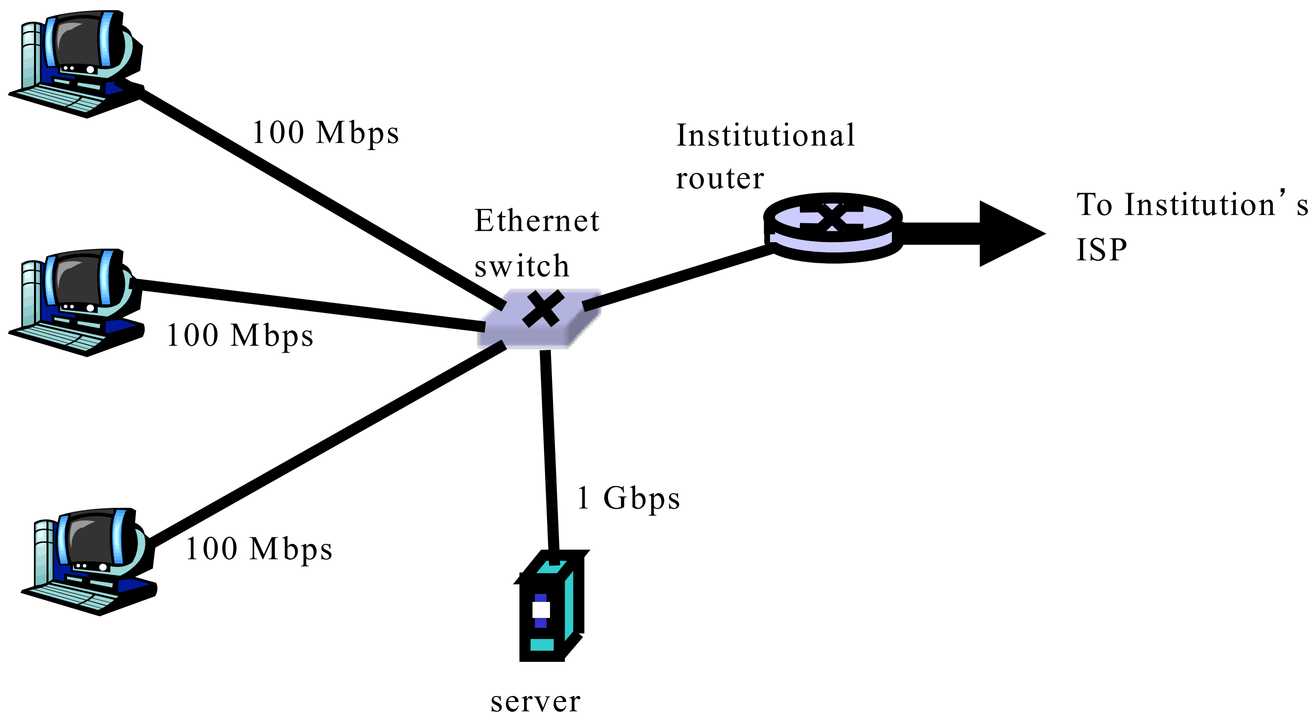
- An active optical system uses electrically powered switching equipment, such as a router or a switch aggregator, to manage signal distribution and direct signals to specific customers.
- In such a system, a customer may have a dedicated fiber running to his or her house.



# 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.

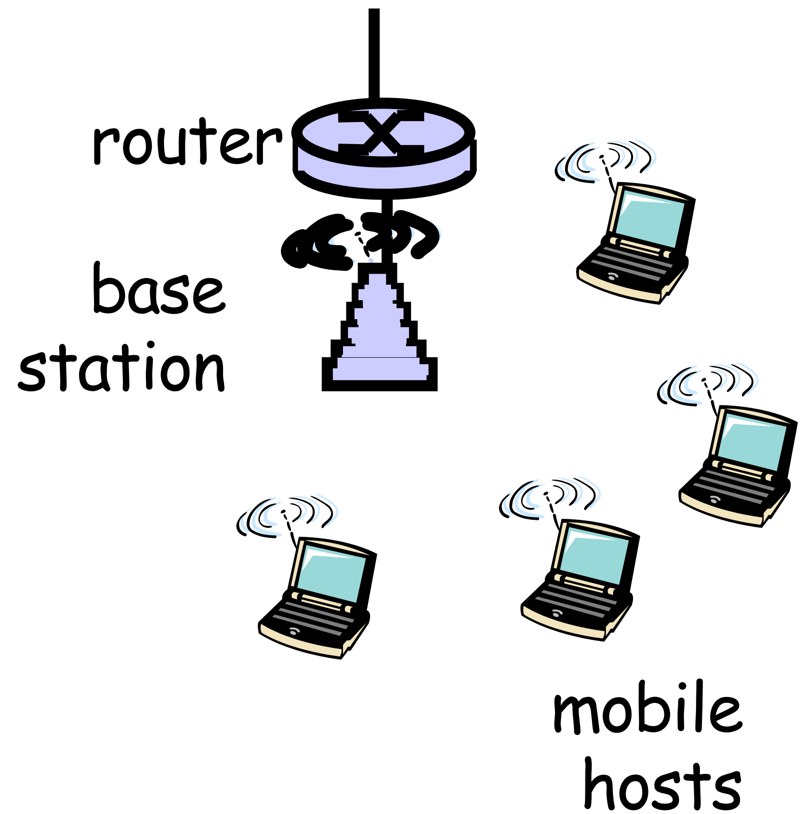
# Ethernet Internet access




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

# Wireless access networks

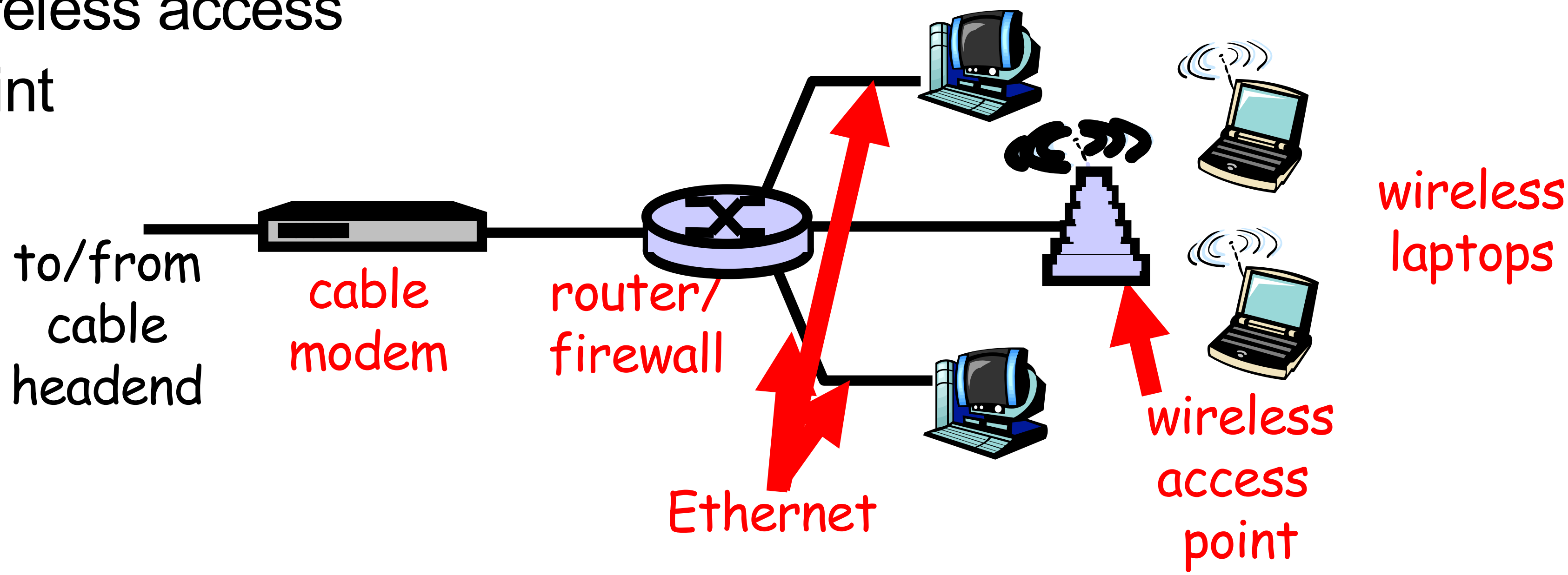
- shared *wireless* access network connects end system to router
  - via base station aka “access point”
- wireless LANs:
  - 802.11b/g (WiFi): 11 or 54 Mbps
- wider-area wireless access
  - provided by telco operator
  - ~1Mbps over cellular system (EVDO, HSDPA), LTE to come
  - next up (?): WiMAX (10’s Mbps) over wide area



# Home networks

Typical home network components:

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



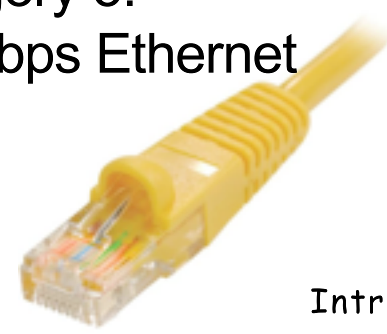
# Physical Media

- 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

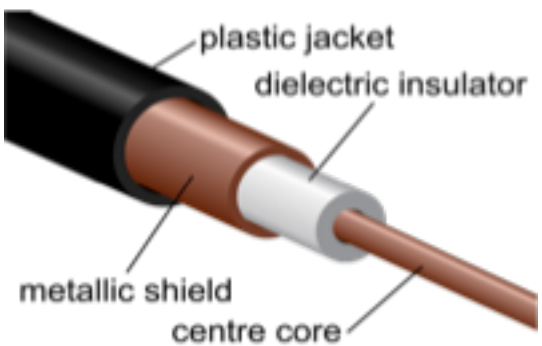
  - Category 5: 100Mbps Ethernet



# 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)
- 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

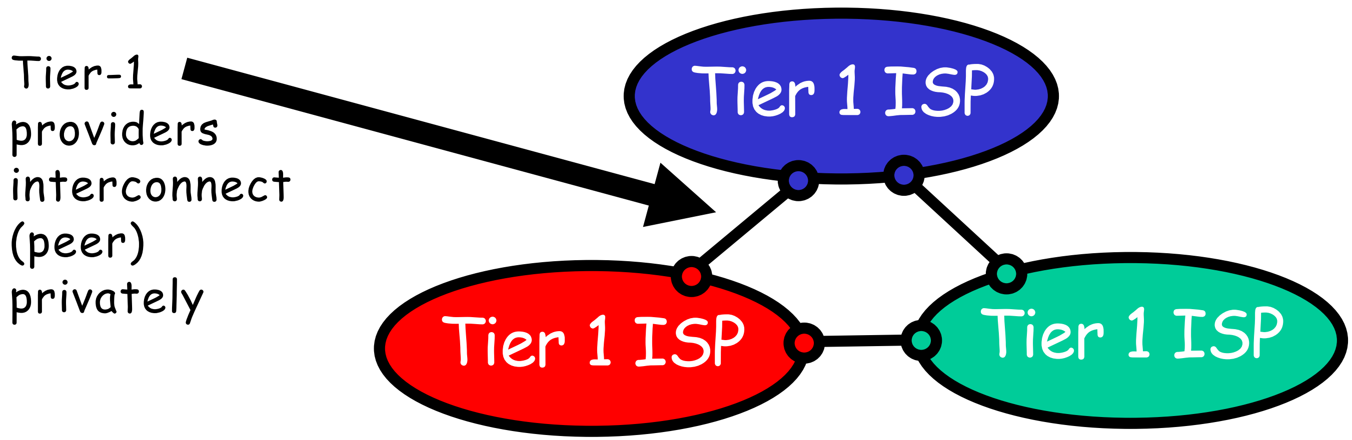
- signal carried in electromagnetic spectrum
- no physical "wire"
- bidirectional
- propagation environment effects:
  - reflection
  - obstruction by objects
  - interference

## Radio link types:

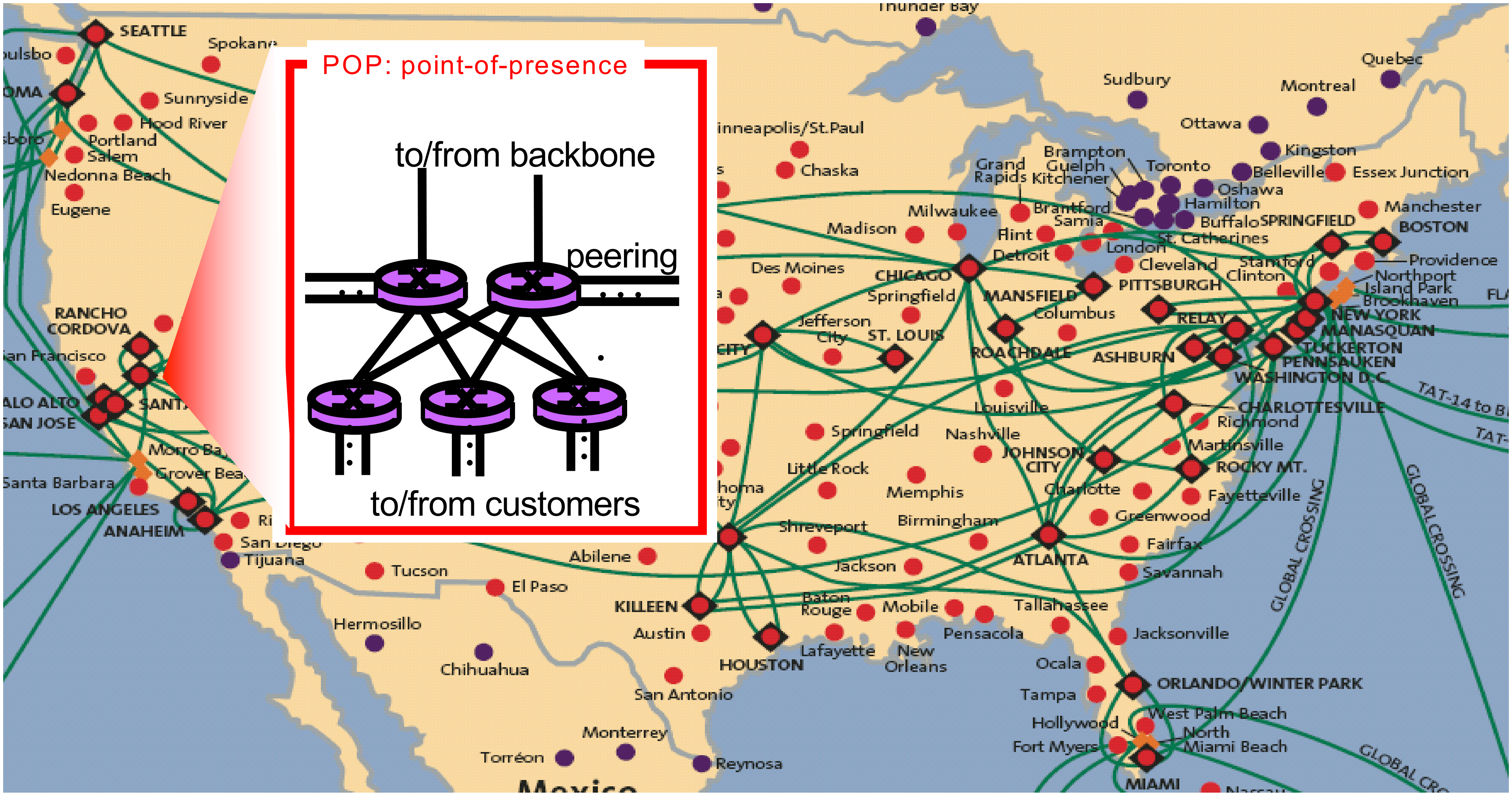
- terrestrial microwave
  - e.g. up to 45 Mbps channels
- LAN (e.g., Wifi)
  - 11Mbps, 54 Mbps
- wide-area (e.g., cellular)
  - 3G cellular: ~ 1 Mbps
- satellite
  - Kbps to 45Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus low altitude
    - (500 Km dalla superficie terrestre, servono costellazioni di satelliti)

# 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



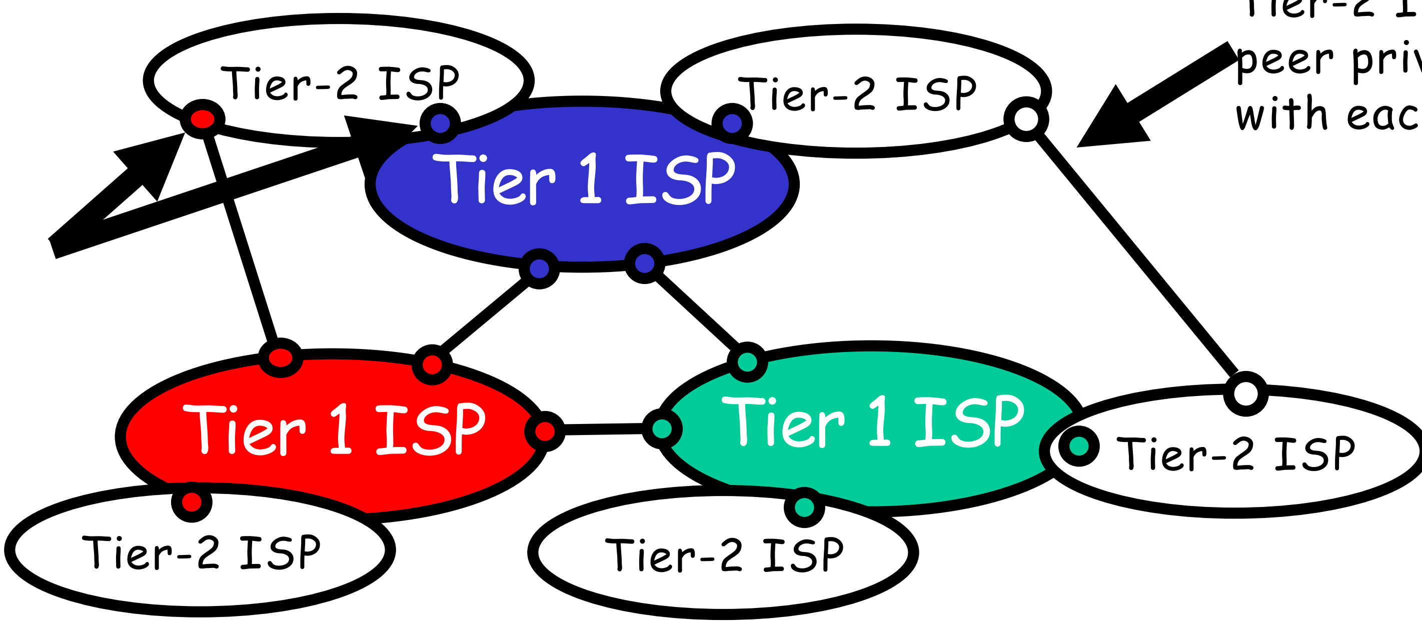
# Tier-1 ISP: e.g., Sprint



# 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

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

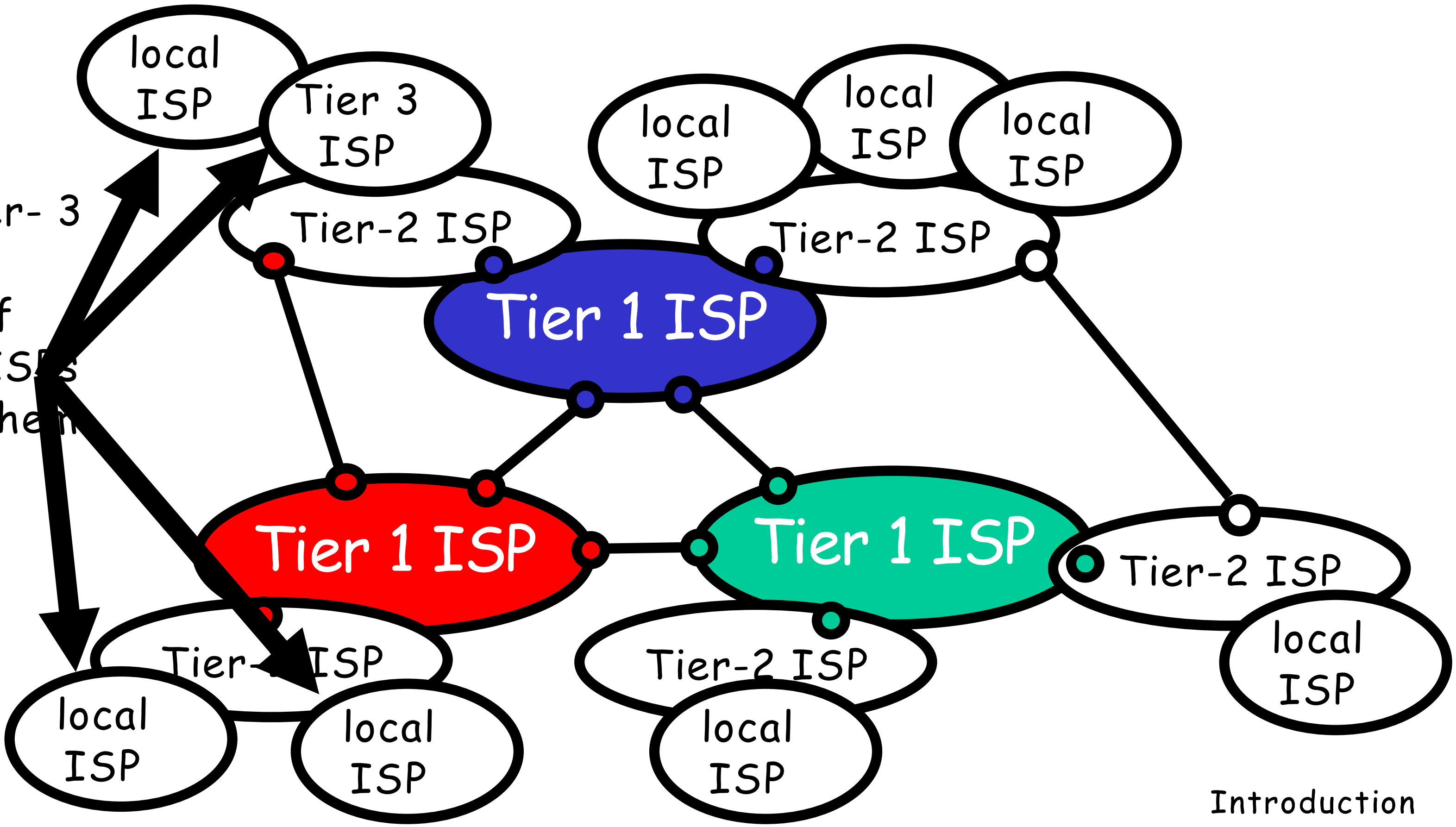



Tier-2 ISPs also peer privately with each other.

# Internet structure: network of networks

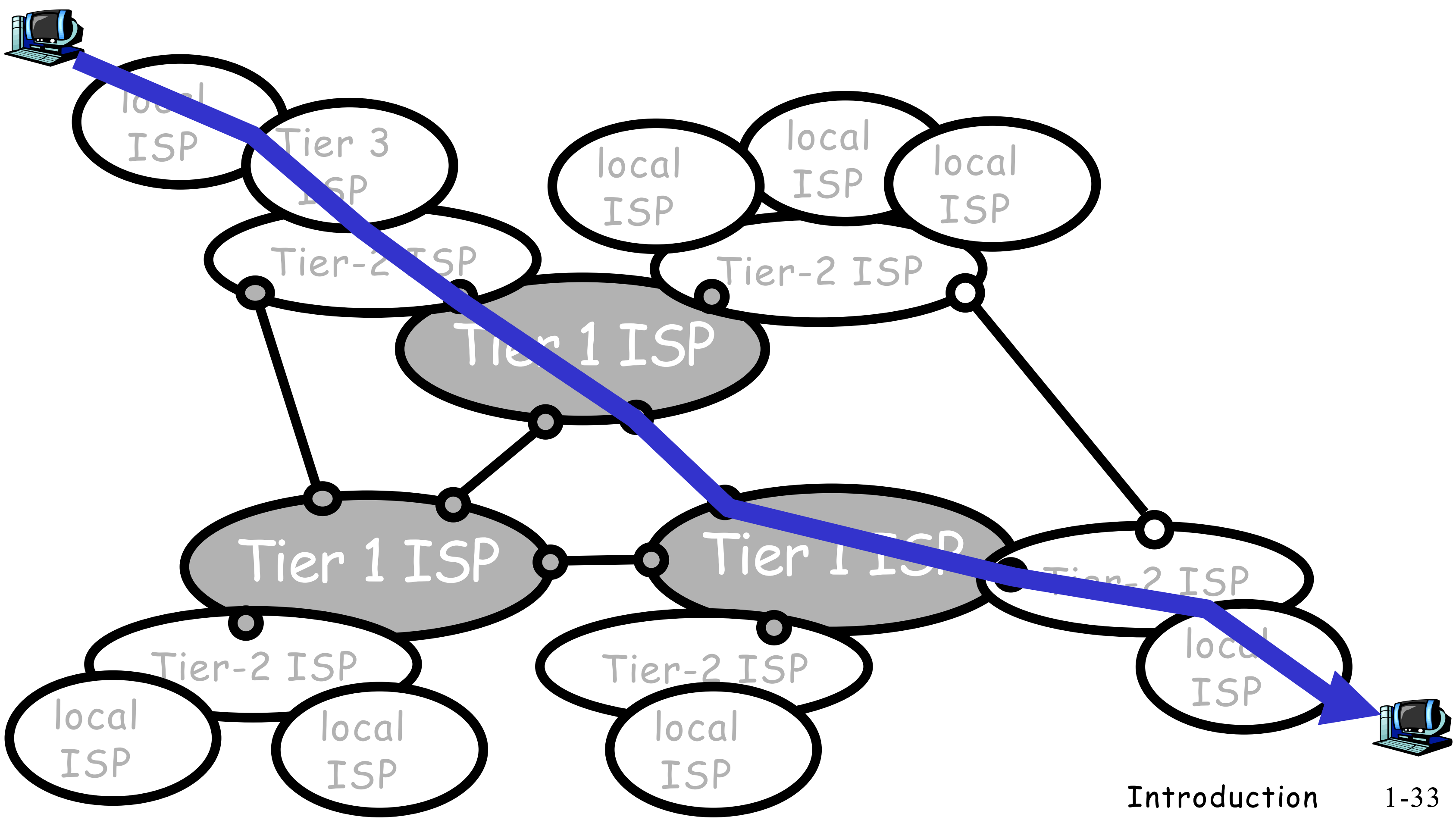
- "Tier-3" ISPs and local ISPs
  - last hop ("access") network (closest to end systems)

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



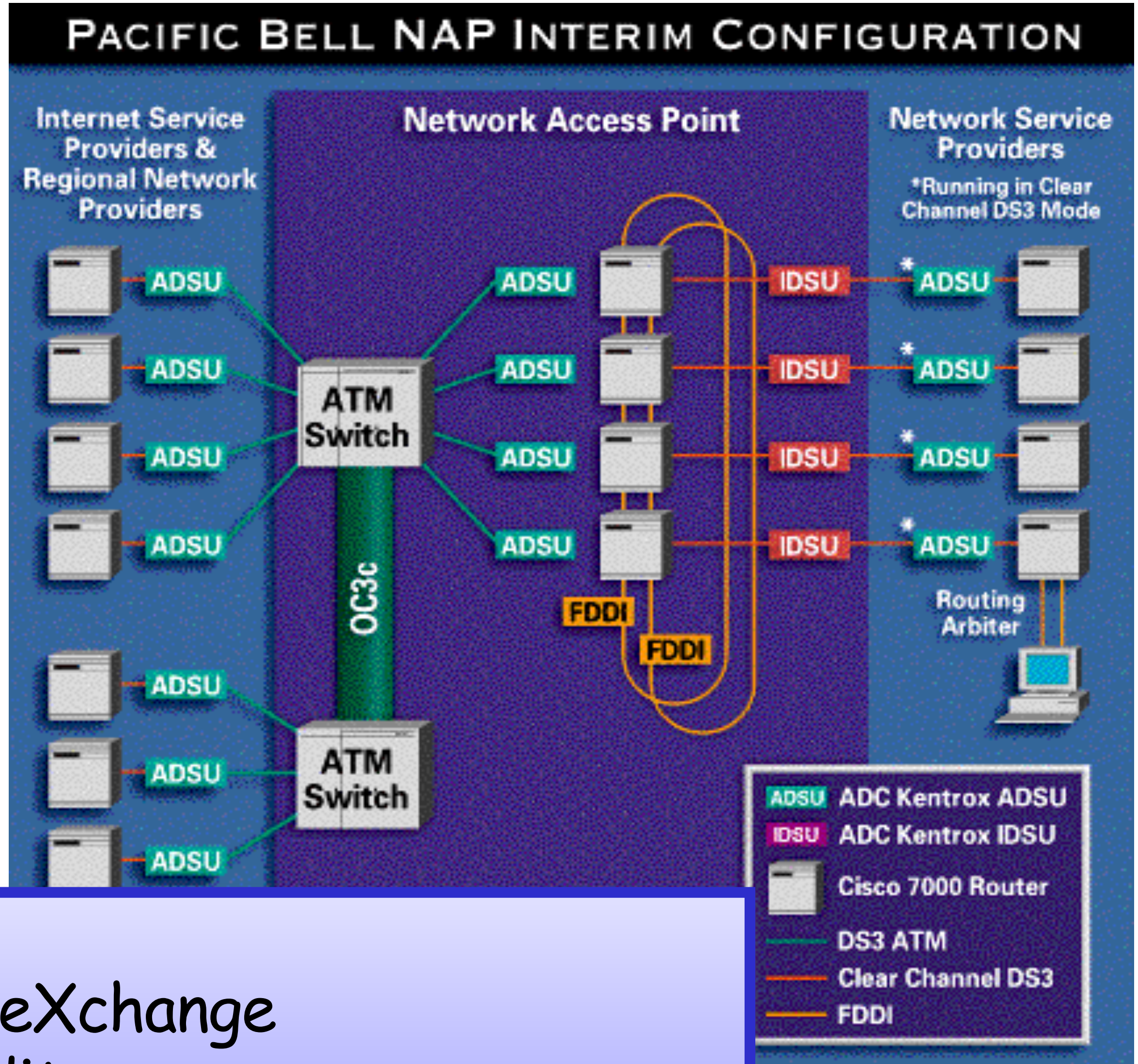
# Internet structure: network of networks

- a packet passes through many networks!



# A NAP: just another router...?

Pacific Bell S. Francisco NAP



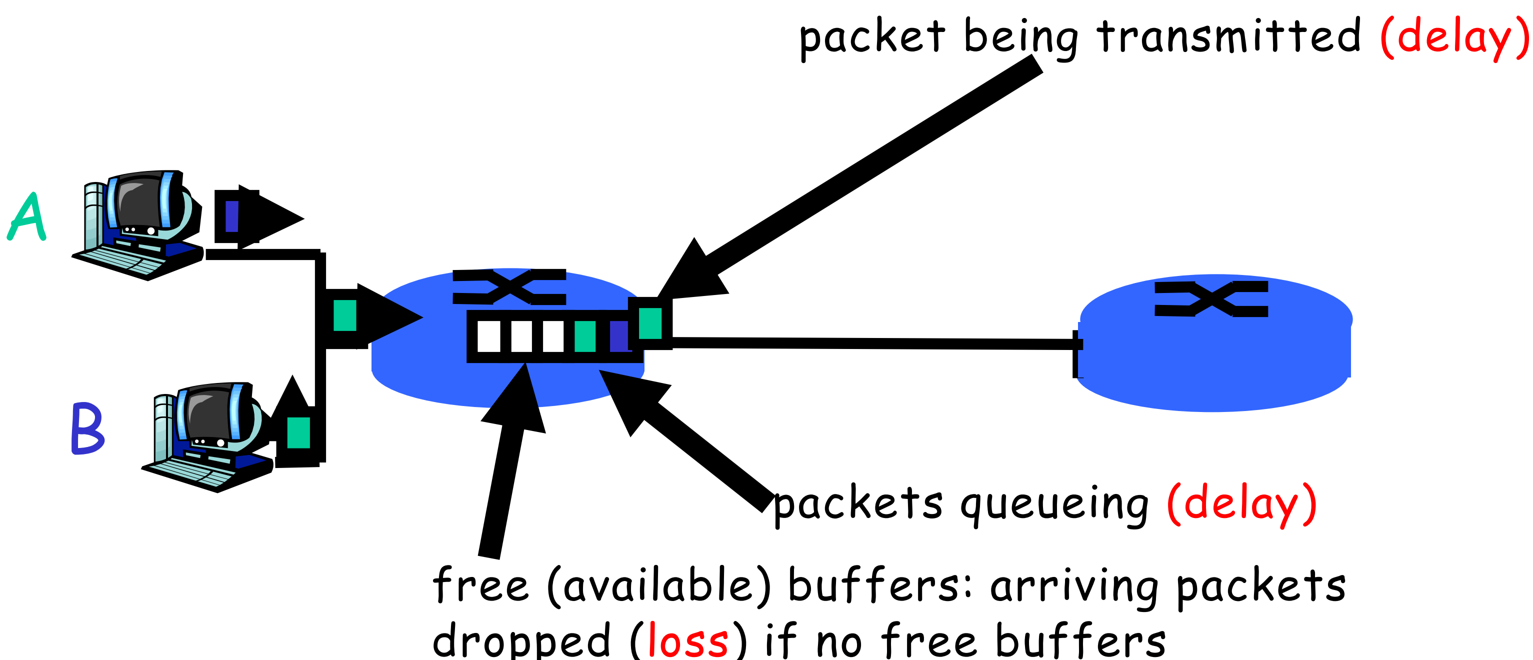

In Italia:
-MIX Milan Internet eXchange
-NaMeX Nautilus Mediterranean Exchange Point

# Chapter 1: roadmap

# How do loss and delay occur?

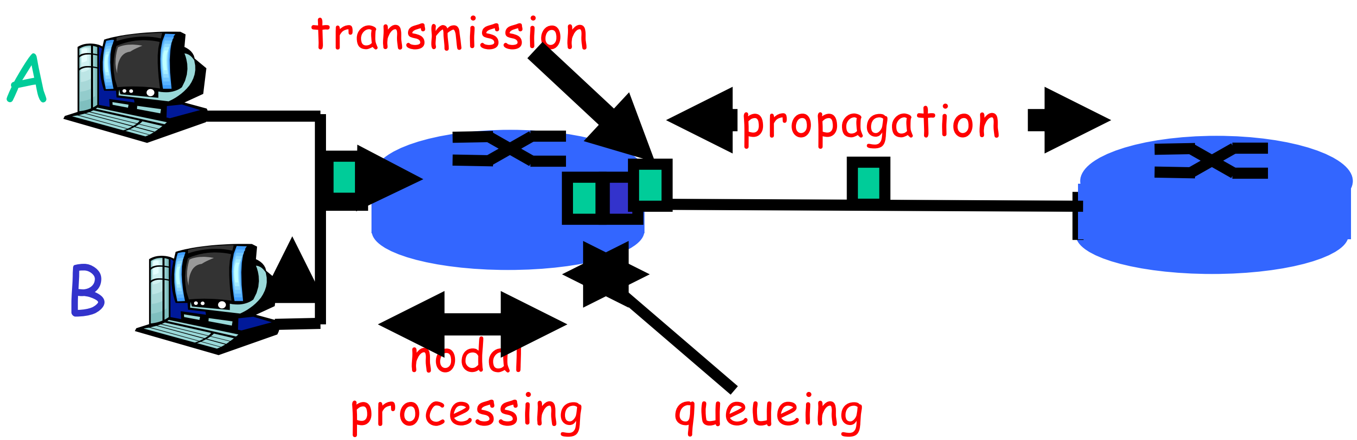
packets *queue* in router buffers

- 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

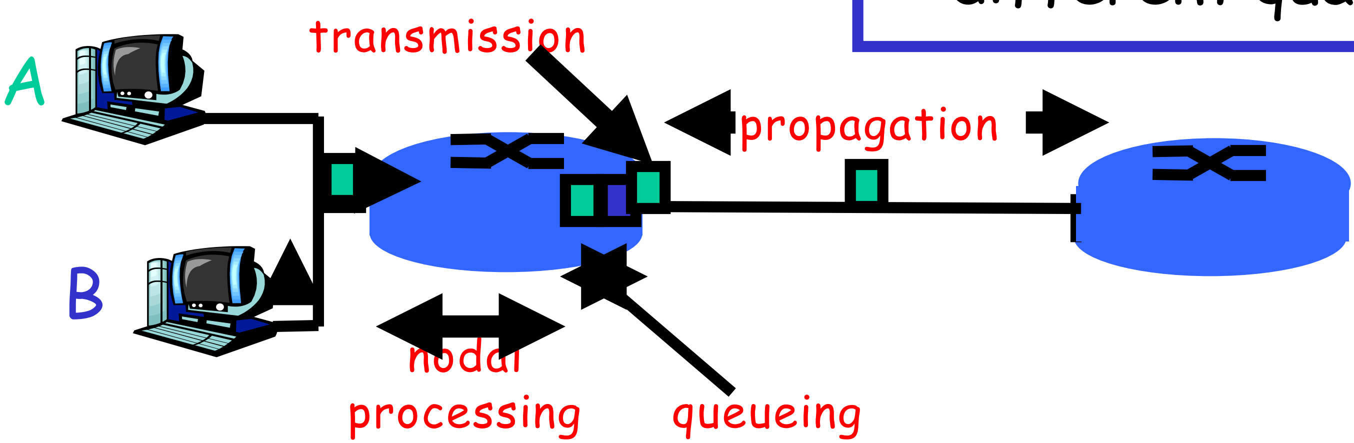
**3. Transmission delay:**

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

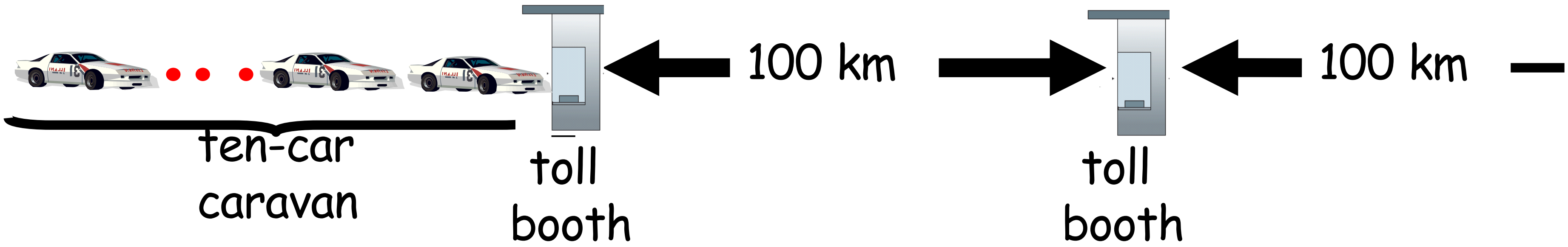
**4. Propagation delay:**

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

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

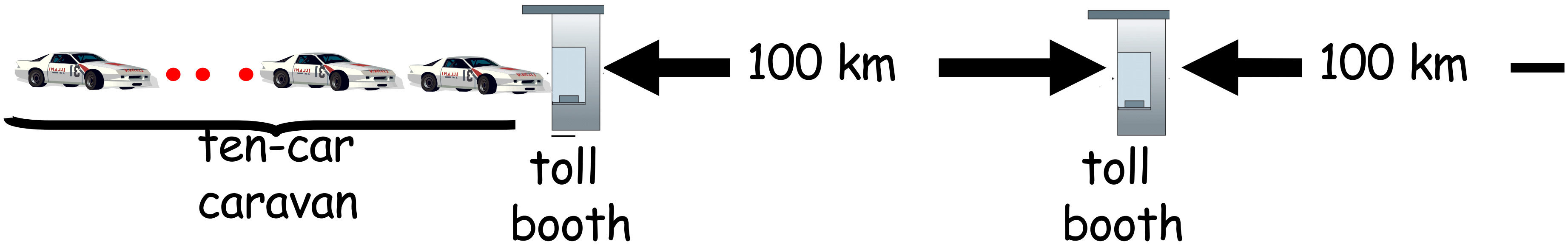


# Caravan analogy




- 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

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

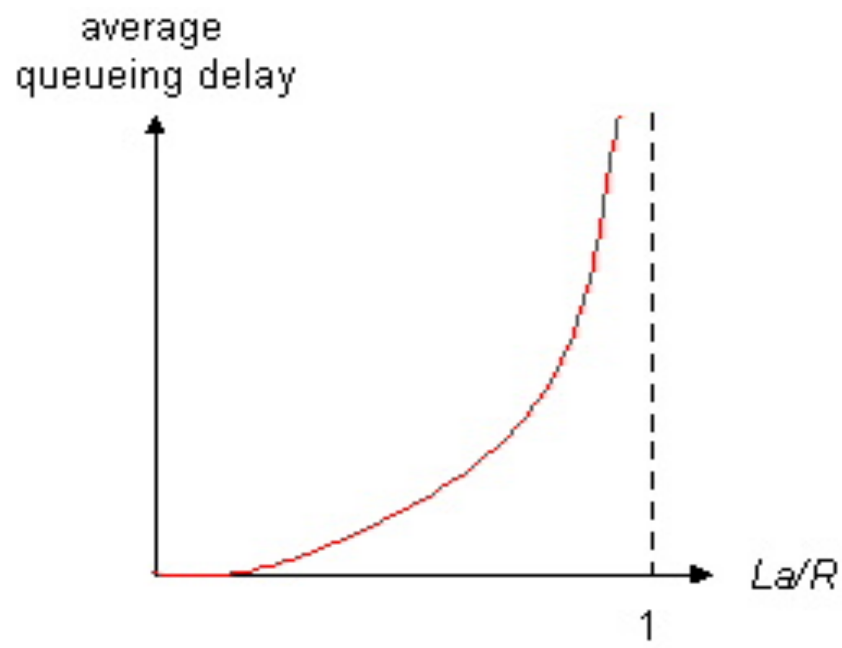
- $d_{proc}$ = processing delay
  - typically a few microsecs or less
- $d_{queue}$ = queuing delay
  - depends on congestion
- $d_{trans}$ = transmission delay
  - = L/R, significant for low-speed links
- $d_{prop}$ = propagation delay
  - a few microsecs to hundreds of msecs

Delay for each hop!!!

# Queueing delay (revisited)

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

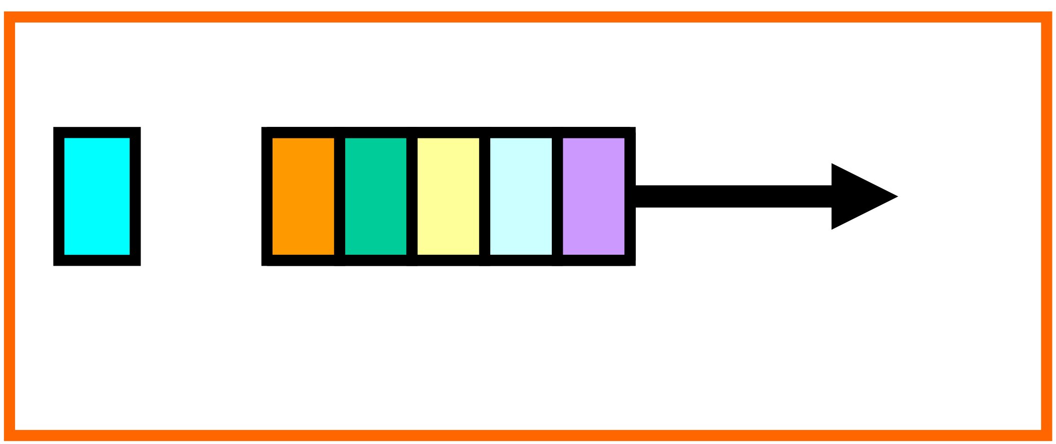
traffic intensity = La/R

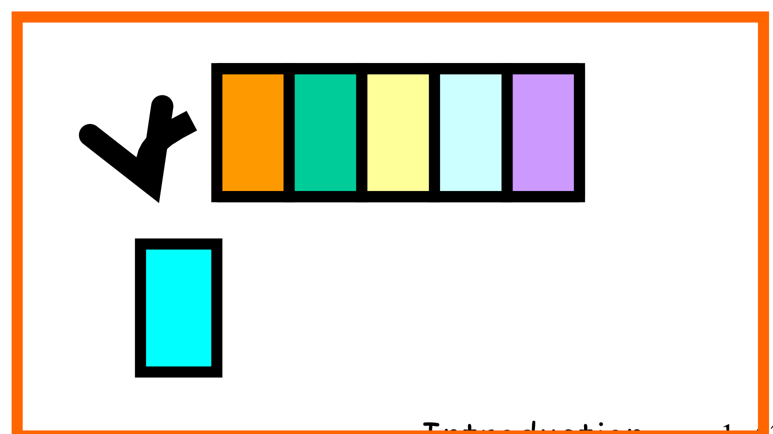



- La/R ~ 0: average queueing delay small
- La/R -> 1: delays become large
- La/R > 1: more "work" arriving than can be serviced, average delay infinite!

# Packet loss

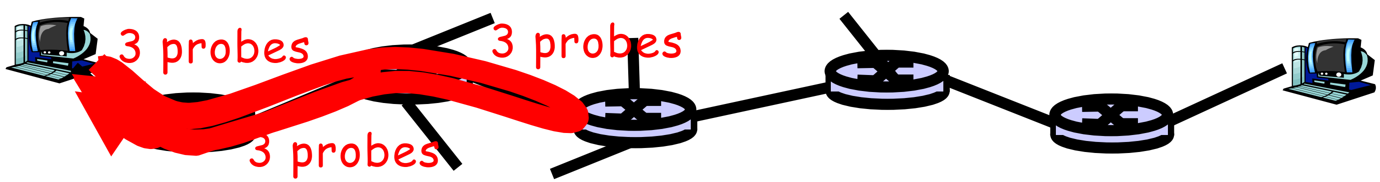
- queue (→buffer) preceding link in buffer has finite capacity
- when packet arrives to full queue, packet is dropped (→lost)
- lost packet may be retransmitted by previous node, by source end system, or not retransmitted at all





# "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

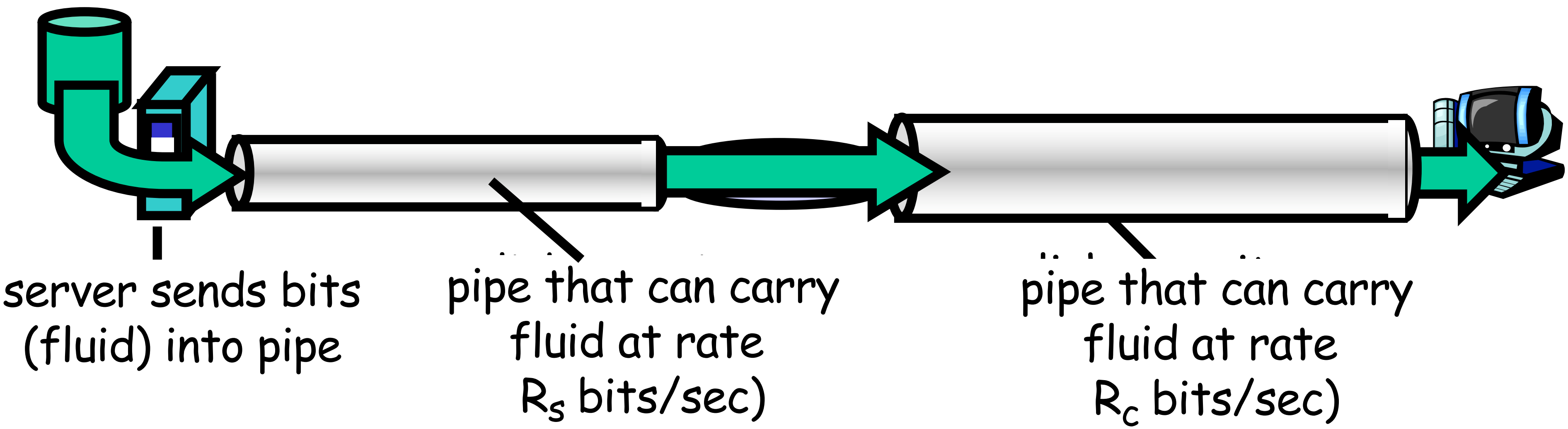
trans-oceanic link

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

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

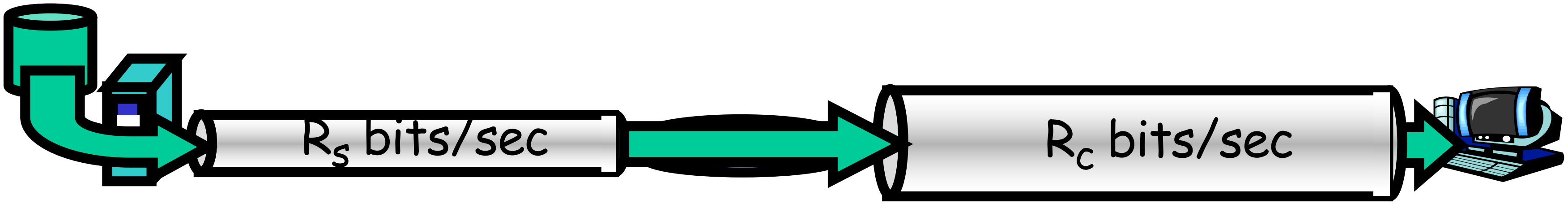
# Throughput

- *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

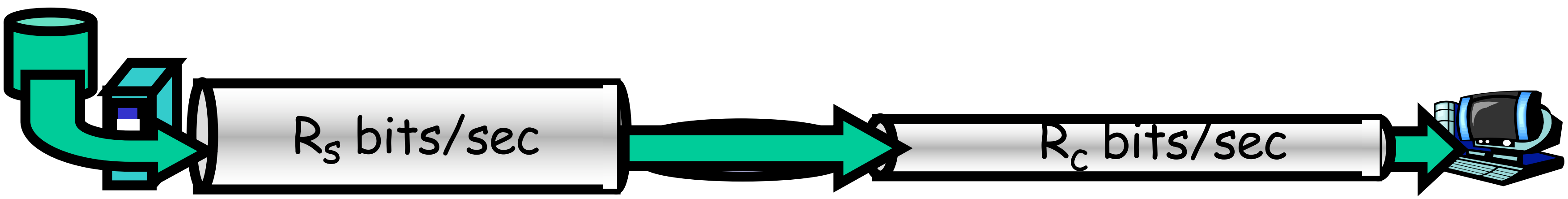


# Throughput (more)

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




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

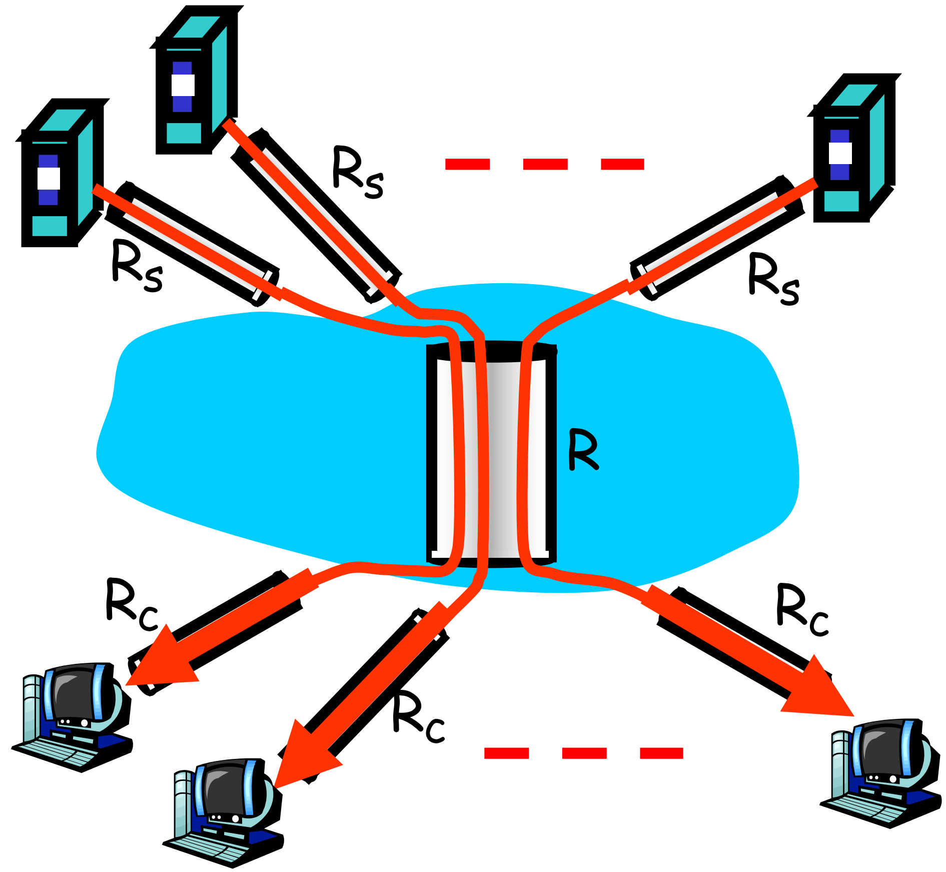



*bottleneck link*

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

# Chapter 1: roadmap

# Protocol "Layers"

**Networks are complex!**

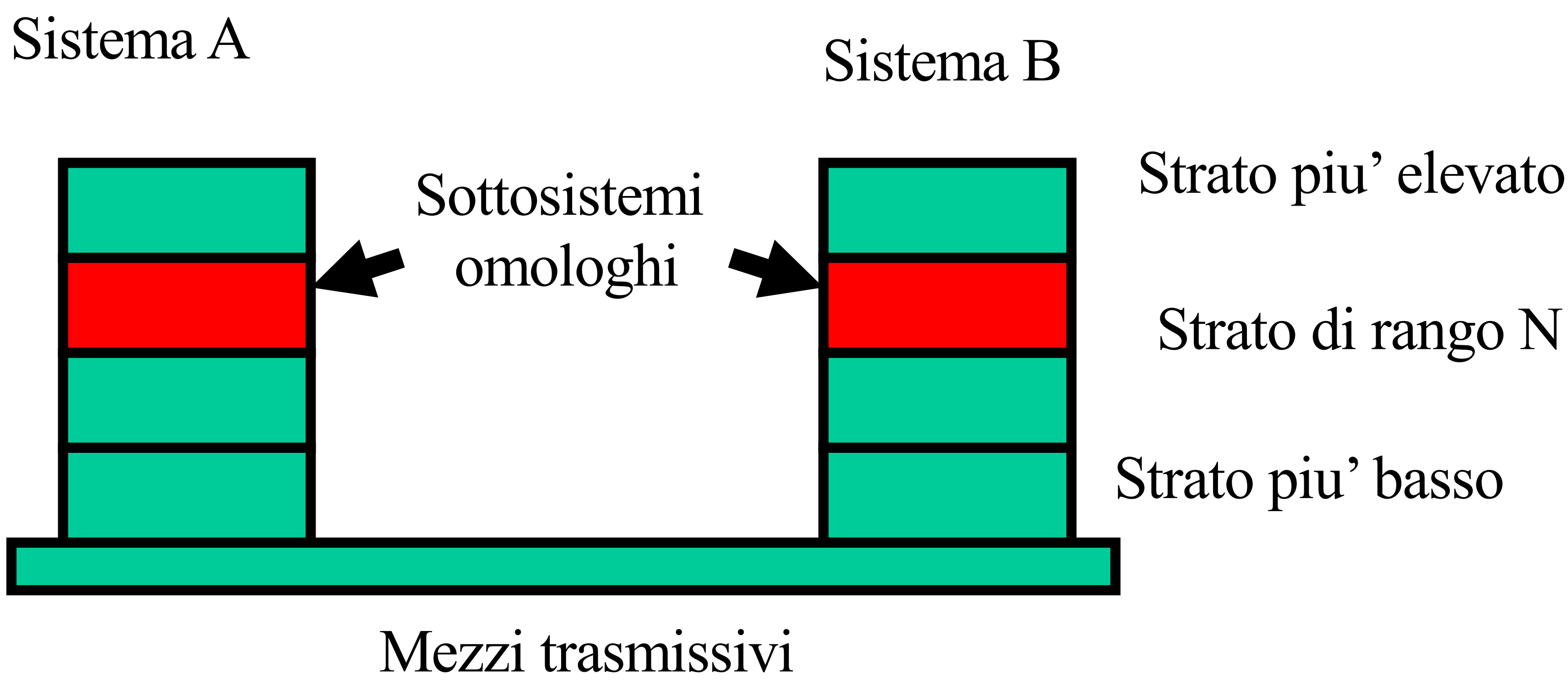
- many "pieces":
  - hosts
  - routers
  - links of various media
  - applications
  - protocols
  - hardware, software

**Question:**

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

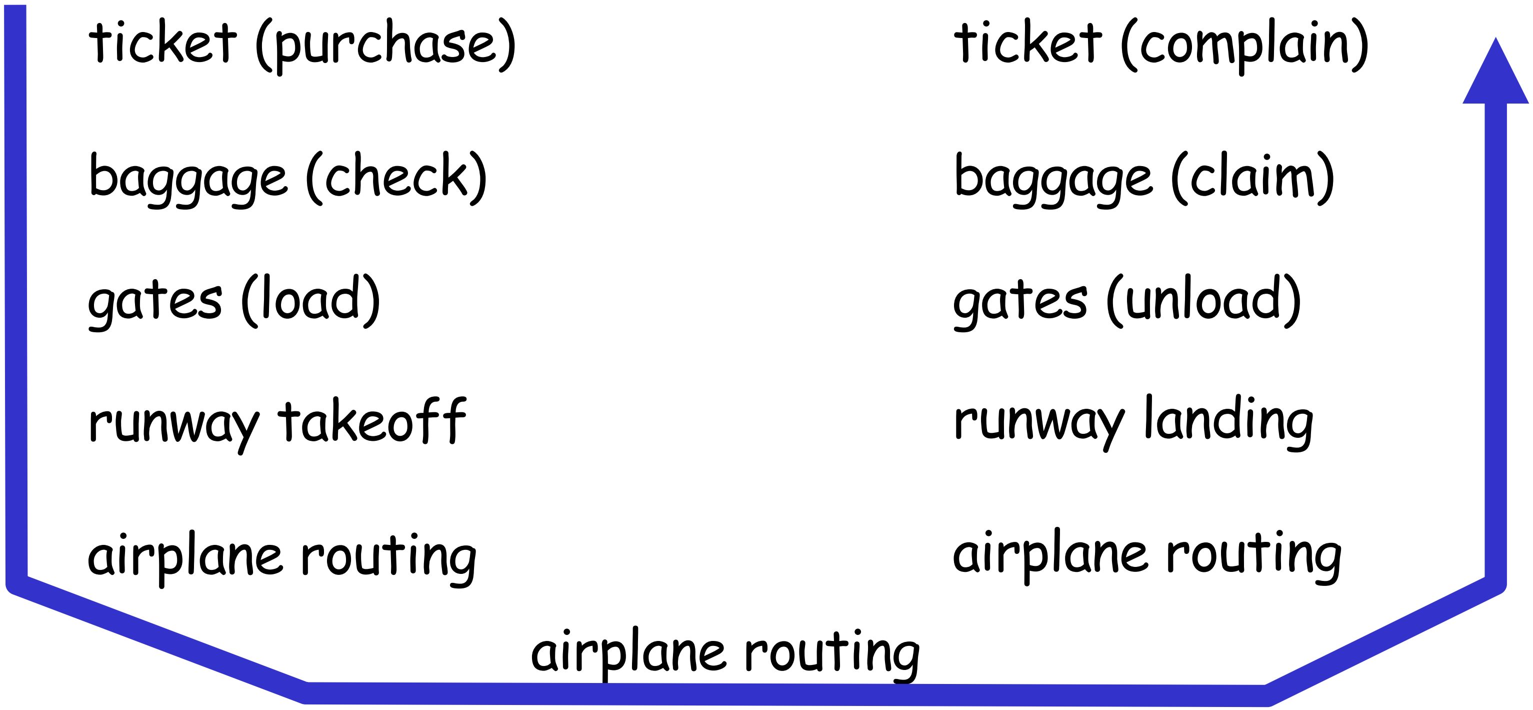
Or at least our discussion of networks?

# Layering



Sistema A
Sistema B
Sottosistemi omologhi
Strato piu' elevato
Strato di rango N
Strato piu' basso
Mezzi trasmissivi

# Organization of air travel




- a series of steps

# Organization of air travel: a different view

| | |
|---|---|
| ticket (purchase) | ticket (complain) |
| baggage (check) | baggage (claim) |
| gates (load) | gates (unload) |
| runway takeoff | runway landing |
| airplane routing | airplane routing |
| airplane routing | |

Layers: each layer implements a service

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

# Layered air travel: services

Counter-to-counter delivery of person+bags

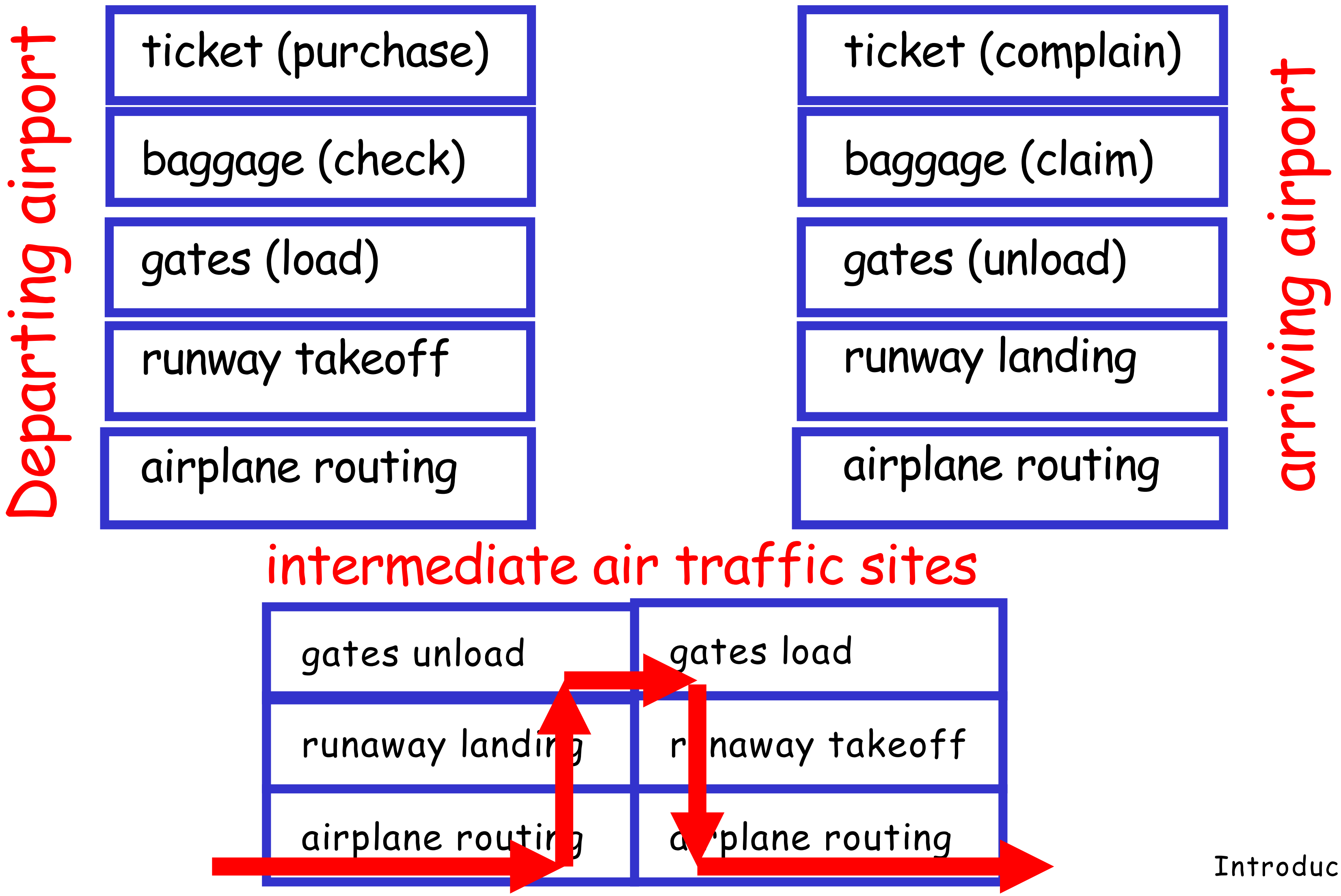
baggage-claim-to-baggage-claim delivery

people transfer: loading gate to arrival gate

runway-to-runway delivery of plane

airplane routing from source to destination

# Distributed implementation of layer functionality



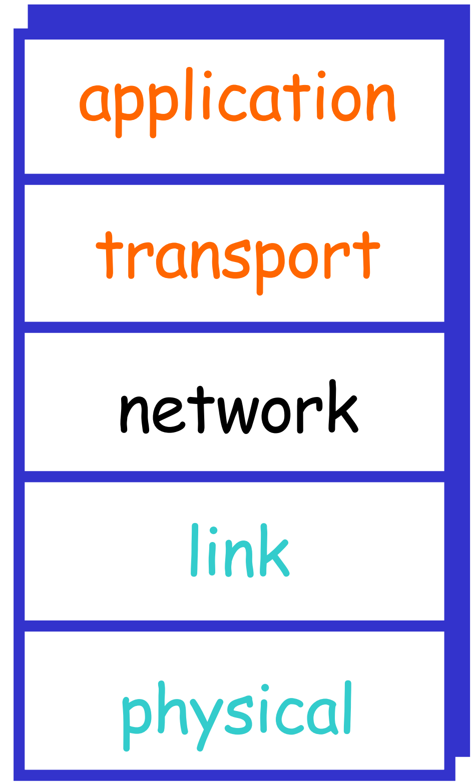
# Why layering?

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 (I.e. if baggage check and claim procedures changed due to Sept 11$^{th}$ or if the boarding rules change, boarding people by age)
- layering considered harmful?

# Internet protocol stack

- application: supporting network applications
  - FTP, SMTP, HTTP
- transport: host-host data transfer
  - TCP, UDP
- network: routing of datagrams from source to destination
  - IP, routing protocols
- link: data transfer between neighboring network elements
  - PPP, Ethernet
- physical: bits "on the wire"

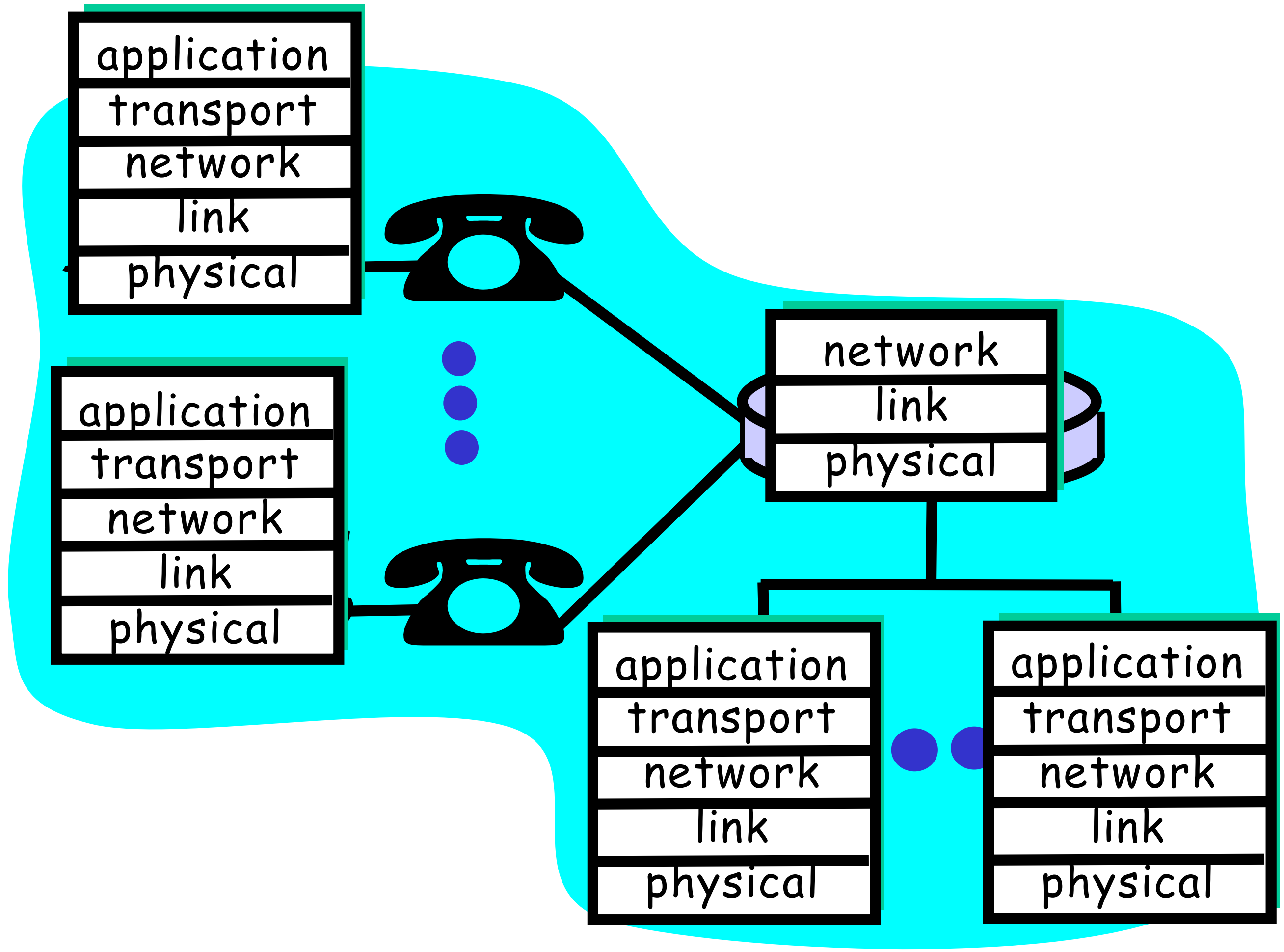



Typically in HW
Typically SW

# Layering: logical communication

Each layer:

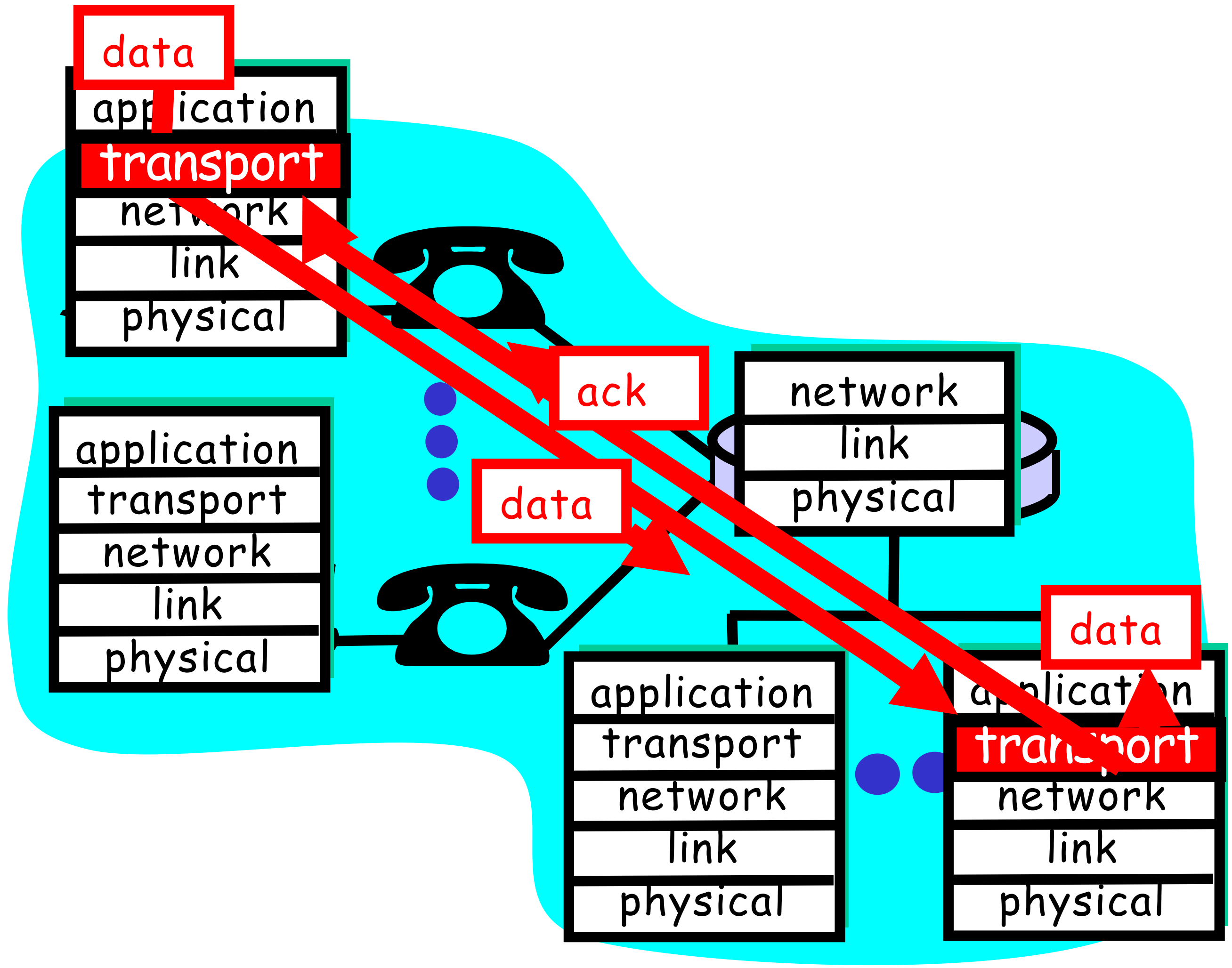
- distributed
- "entities" implement layer functions at each node
- entities perform actions, exchange messages with peers



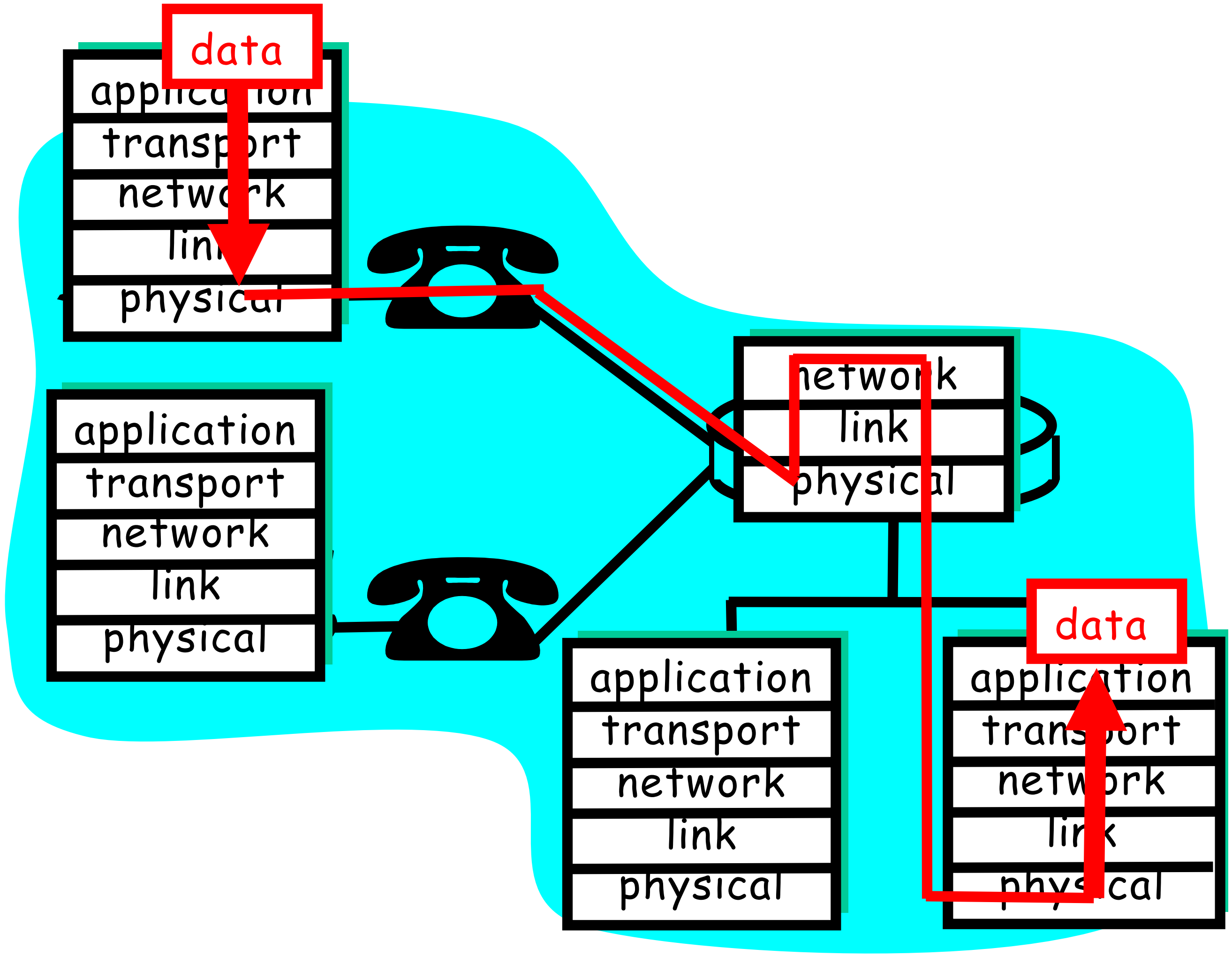
# Layering: *logical* communication

E.g.: transport

- take data from app
- add addressing, reliability check info to form "datagram"
- send datagram to peer
- wait for peer to ack receipt
- analogy: post office



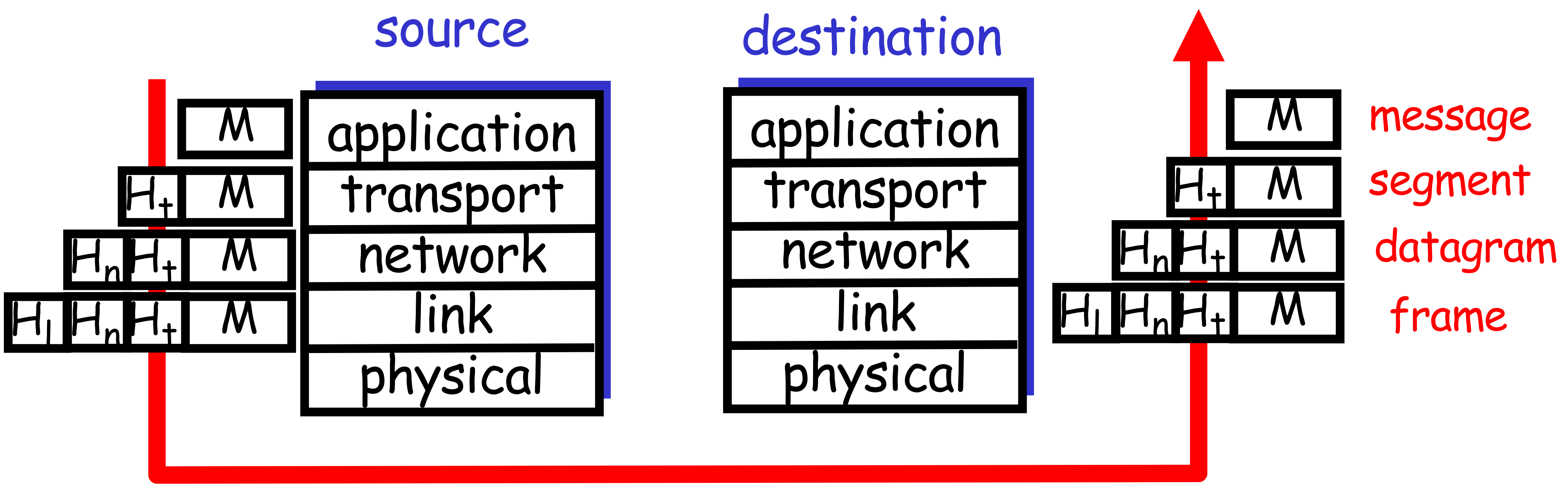
# Layering: physical communication



# Protocol layering and data

Each layer takes data from above

- adds header information to create new data unit
- passes new data unit to layer below



# Layering: pros

- Vantaggi della stratificazione
  - Modularita'
    - Semplicita' di design
    - Possibilita' di modificare un modulo in modo trasparente se le interfacce con gli altri livelli rimangono le stesse
    - Possibilita' per ciascun costruttore di adottare la propria implementazione di un livello purche' requisiti su interfacce soddisfatti
  - Gestione dell'eterogeneita'
    - Possibili moduli 'diversi' per realizzare lo stesso insieme di funzioni, che riflettano l'eterogeneita' dei sistemi coinvolti (e.g. diverse tecnologie trasmissive, LAN, collegamenti punto-punto, ATM etc.)
    - Moduli distinti possibili/necessari anche se le reti adottassero tutte la stessa tecnologia di rete perche' ad esempio le applicazioni possono avere requisiti diversi (es. UDP e TCP). All'inizio TCP ed IP erano integrati. Perche' adesso sono su due livelli distinti?

# Layering: cons

- Svantaggi della stratificazione
  - A volte modularita' inficia efficienza
  - A volte necessario scambio di informazioni tra livelli non adiacenti non rispettando principio della stratificazione

# Internet History

*1961-1972: Early packet-switching principles*

- 1961: Kleinrock - queueing theory shows effectiveness of packet-switching (MIT)
- 1964: Baran - packet-switching in military nets
- Davies at the National Physical Laboratory, UK was also developing ideas on packet switching
- 1967: ARPAnet conceived by Advanced Research Projects Agency
- 1969: first ARPAnet node operational

Packet switches dubbed Interface Message Processors (IMP)

- 1972:
  - ARPAnet demonstrated publicly by Robert Kahn
  - NCP (Network Control Protocol) first host-host protocol
  - first e-mail program
  - ARPAnet has 15 nodes

- Leonard Kleinrock with first IMP

Kleinrock's students:
Vinton Cerf
John Postel…

Network measurement center UCLA

# Internet History

*1972-1980: Internetworking, new and proprietary nets*

- 1970: ALOHAnet satellite network in Hawaii (Abramson)
- 1973: Metcalfe's PhD thesis proposes Ethernet
- 1974: Cerf and Kahn - architecture for interconnecting networks
- late70's: proprietary architectures, e.g. IBM SNA (Schwartz)
- 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, peer2peer file sharing (e.g., Naptser)
- network security to forefront
- est. 50 million host, 100 million+ users
- backbone links running at Gbps

Significant late developments: P2P,broadband access, wireless Internet

# Recent trends (2000-2016)

- Intense evolution
- Aggressive deployment of broadband Internet access to homes
  - enabler of distribution of user generated videos, on demand streaming videos, multi-person video conferencing services
- Ubiquitous deployment of high speed wireless access
  - number of wireless devices connected to Internet > wired devices from 2011
- Development of social networks
- Companies such as Google and Microsoft have developed extensive private networks
- Internet commerce companies and institutions run their applications on the cloud

A short digression:

# where is Internet standardized? Who controls the Internet?

- No single administrative organization
- IETF - Internet Engineering Task Force (since 86)
  - Developement of current protocols and specifications for standardization.
    - International community, open to everyone
    - Most of the work via mailing lists
    - Meets three times/year
  - organized in areas and working groups
    - Dynamically activated & deactivated on need
    - group coordination: IESG (Internet Engineering Steering Group). Area directors are members of the IESG. Responsible for the actions associated with entry into and movement along the Internet "standards track," including final approval of specifications as Internet Standards.
- Industry also preemptively determine standards