Reti di Elaboratori

Corso di Laurea in Informatica

Università degli Studi di Roma "La Sapienza"

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Chapter 1: roadmap

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

Tier 1 ISP

Tier 1 ISP

Tier-1 ISP: e.g., Sprint

POP: point-of-presence

to/from backbone

peering

to/from customers
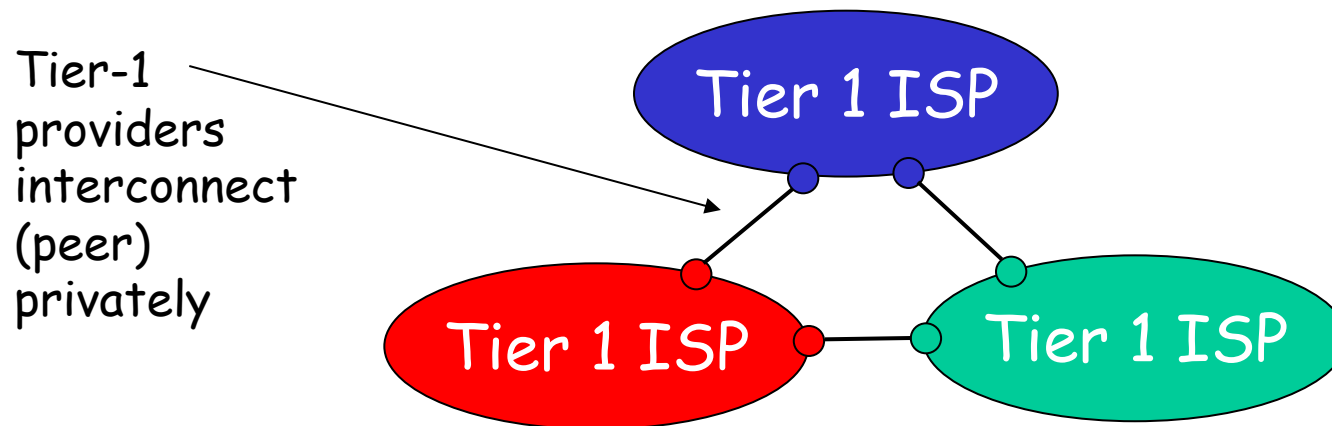
Internet structure: network of networks
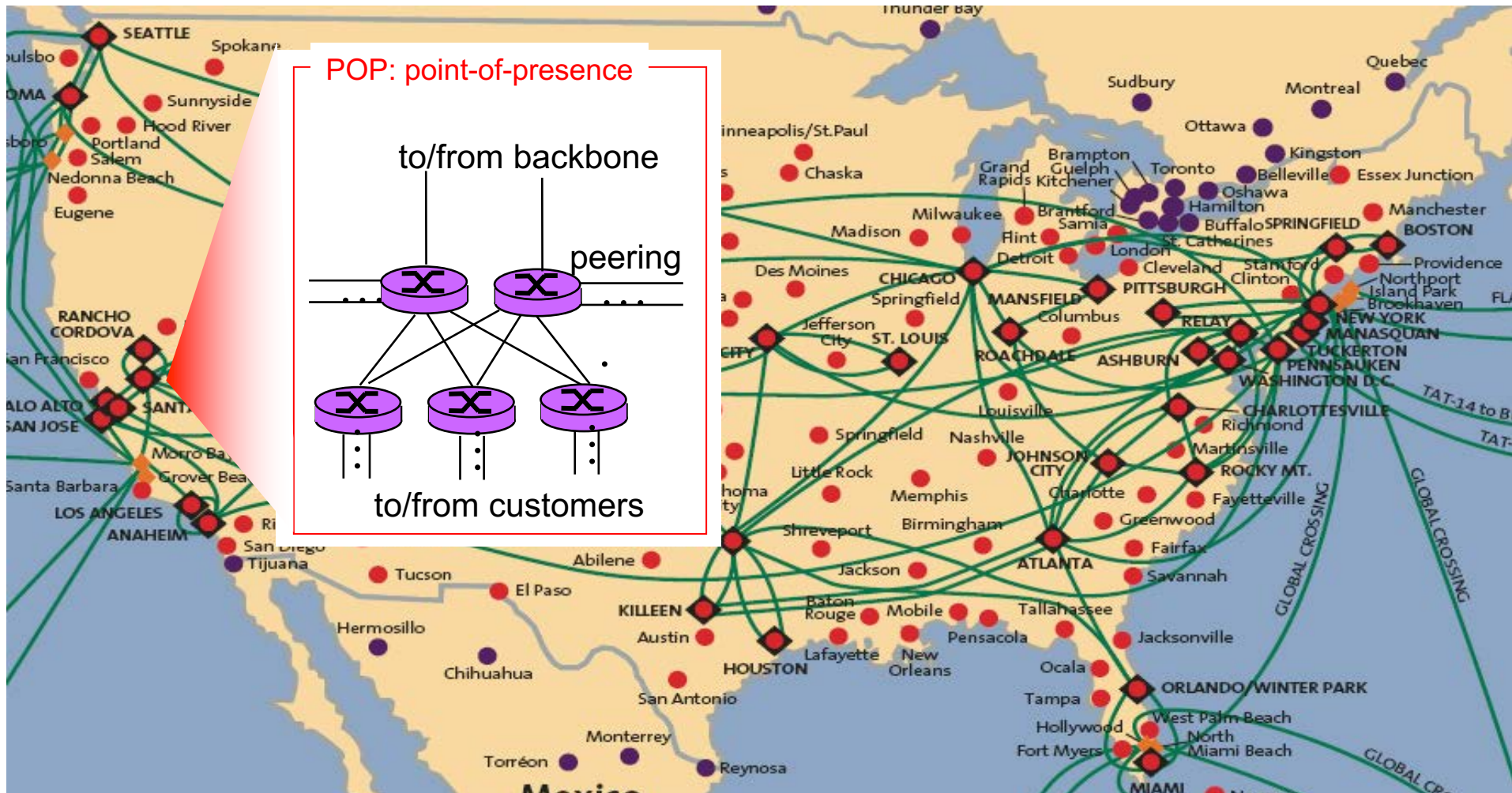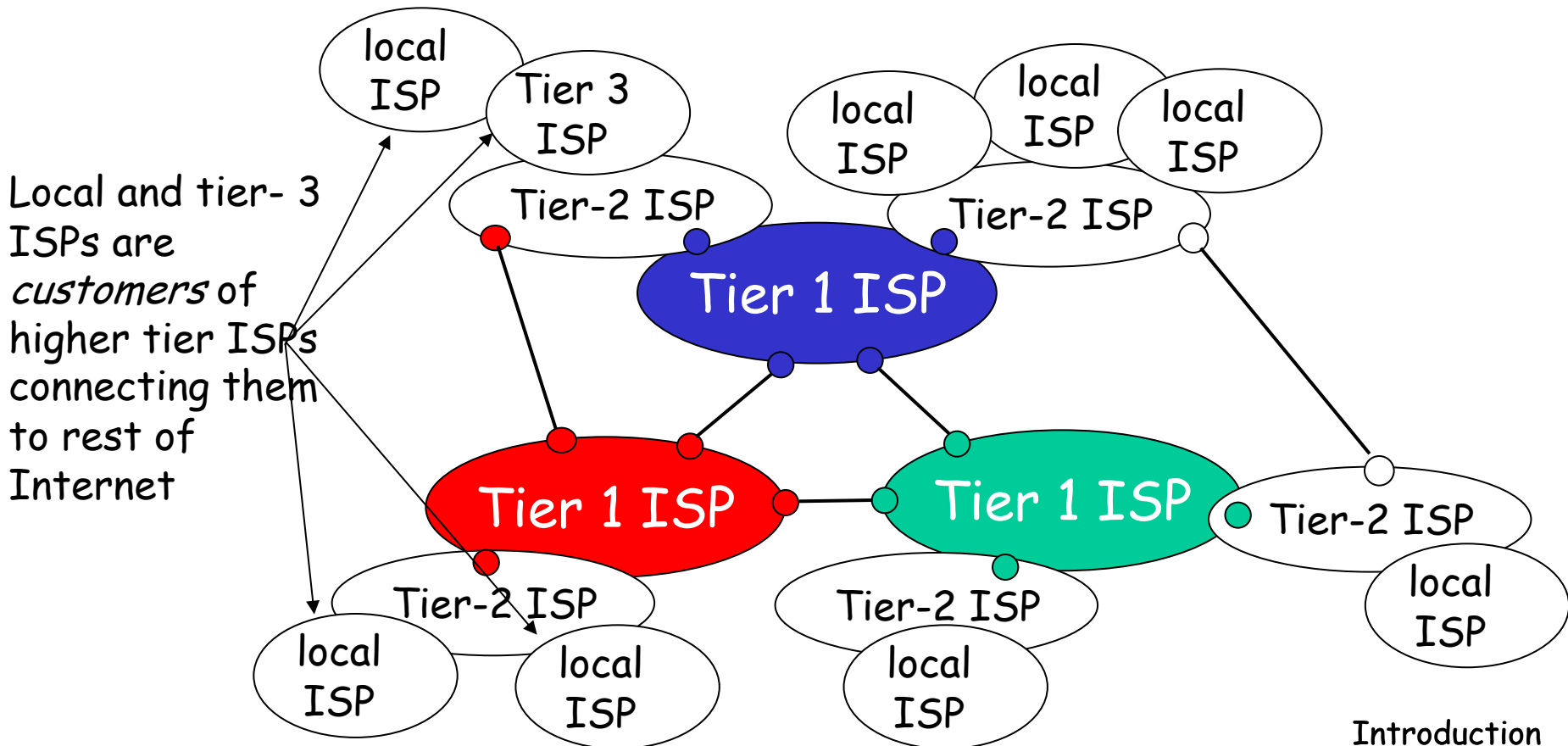
- ❑ "Tier-2" ISPs: smaller (often regional) ISPs
  - ❍ Connect to one or more tier-1 ISPs, possibly other tier-2 ISPs

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.

Tier-2 ISP

Tier-2 ISP

Tier 1 ISP

Tier 1 ISP

Tier 1 ISP

Tier-2 ISP

Tier-2 ISP

Tier-2 ISP

Tier-2 ISP
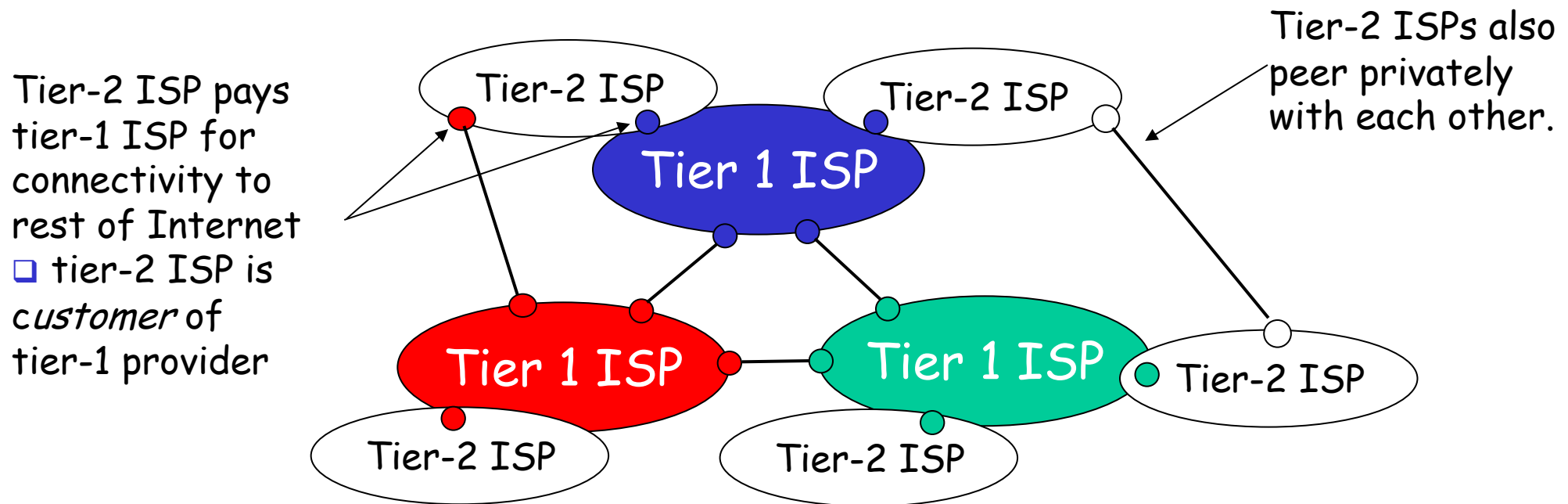
Internet structure: network of networks

❑ **"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

local ISP

Tier 3 ISP

Tier-2 ISP

local ISP

local ISP

local ISP

Tier-2 ISP

Tier 1 ISP

Tier 1 ISP

Tier 1 ISP

Tier-2 ISP

Tier-2 ISP

local ISP

Tier-2 ISP

local ISP

local ISP

local ISP

local ISP

Internet structure: network of networks

❑ **a packet passes through many networks!**
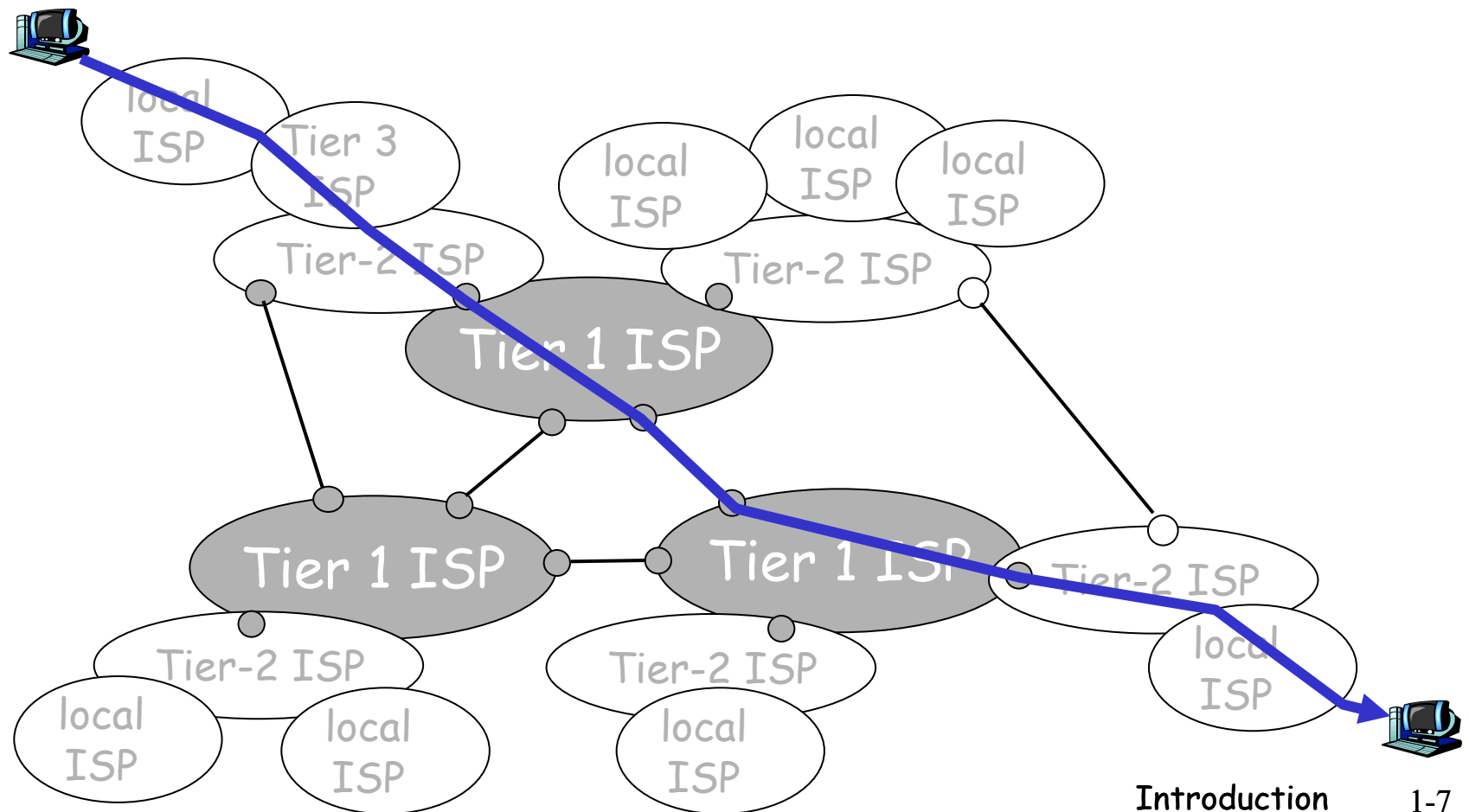
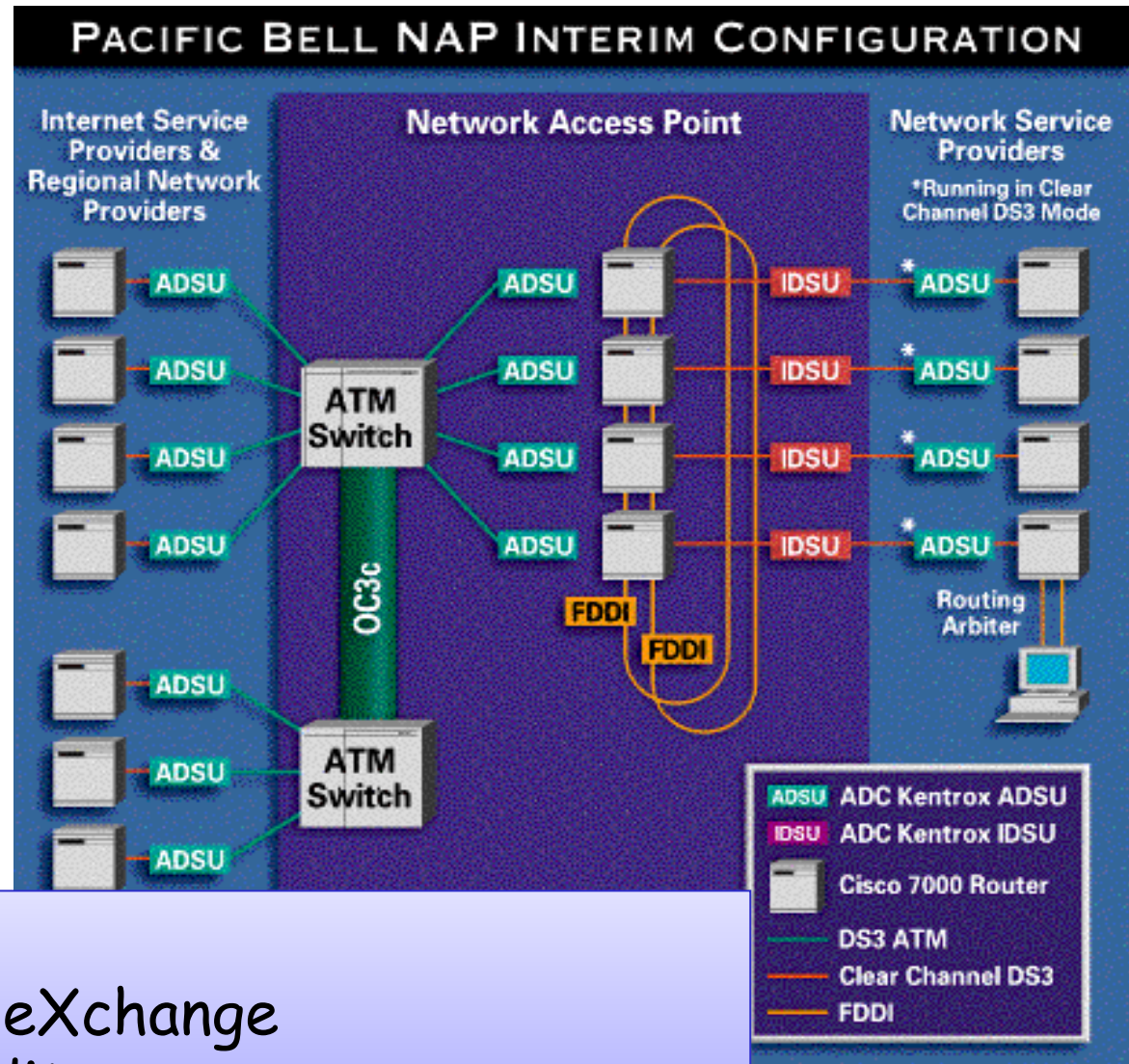# A NAP: just another router…?

Pacific Bell S. Francisco NAP

PACIFIC BELL NAP INTERIM CONFIGURATION

Internet Service Providers & Regional Network Providers

Network Access Point

Network Service Providers
*Running in Clear Channel DS3 Mode

ATM Switch

OC3c

ATM Switch

ADSU

IDSU

FDDI
FDDI

Routing Arbiter

ADSU	ADC Kentrox ADSU
IDSU	ADC Kentrox IDSU
	Cisco 7000 Router
	DS3 ATM
	Clear Channel DS3
	FDDI

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

packet being transmitted (delay)

A

B

packets queueing (delay)

free (available) buffers: arriving packets
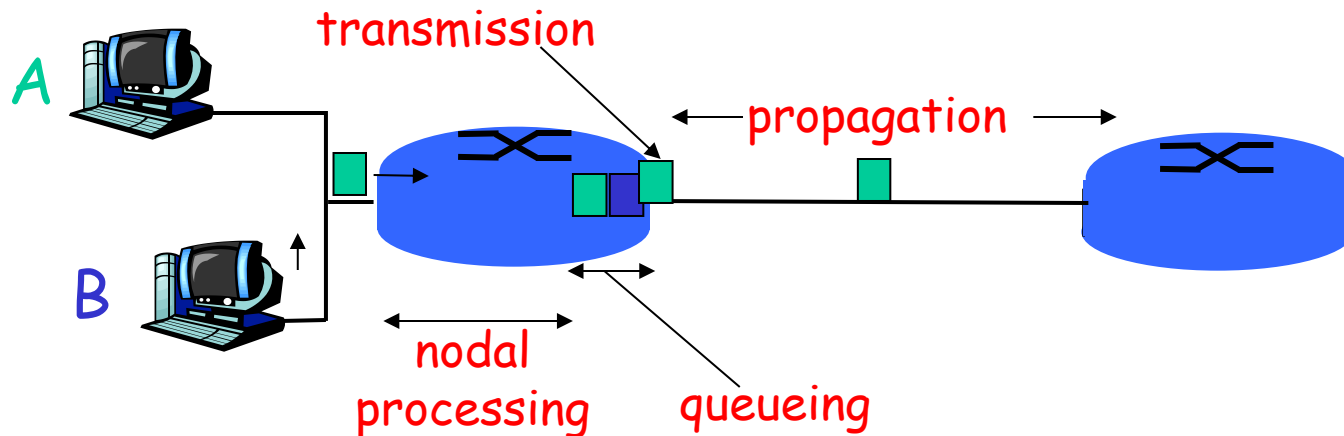dropped (loss) if no free buffers
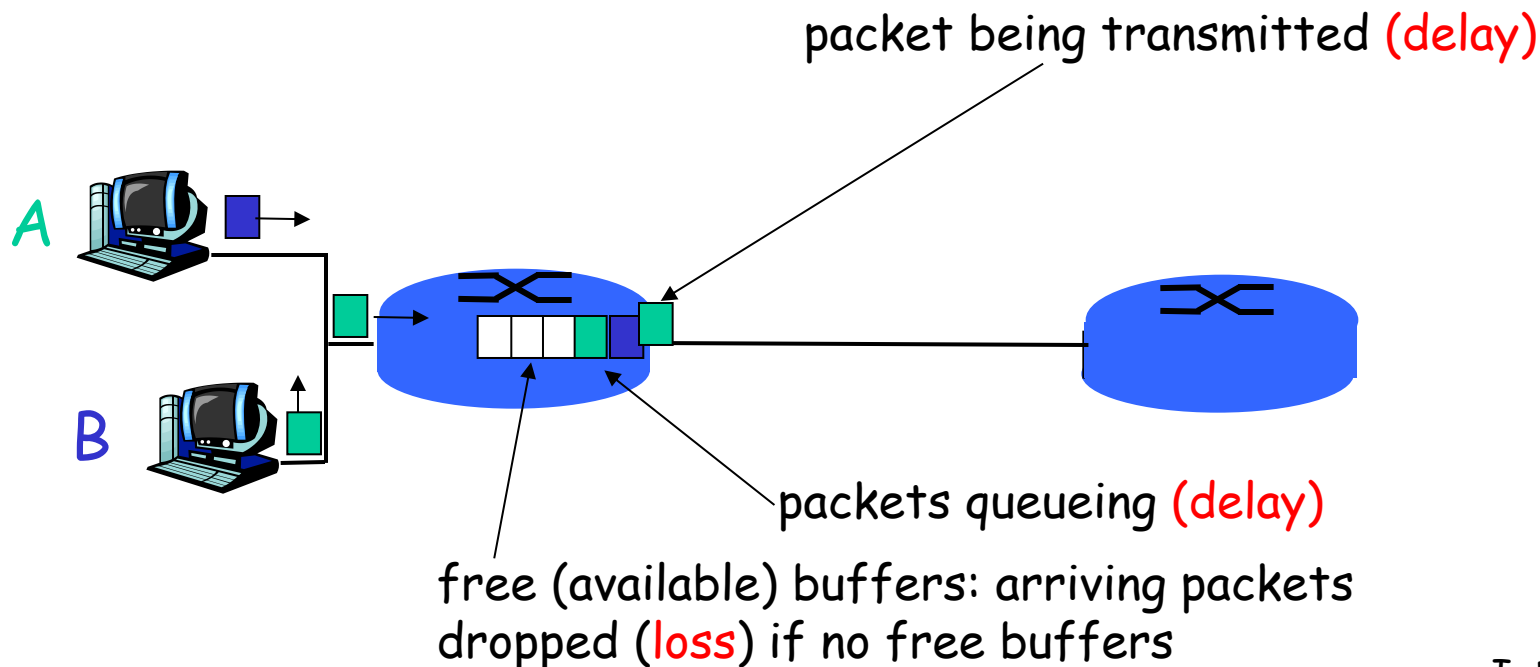
Four sources of packet delay

❑ 1. nodal processing:
- check bit errors
- determine output link

❑ 2. queueing
- time waiting at output link for transmission
- depends on congestion level of router
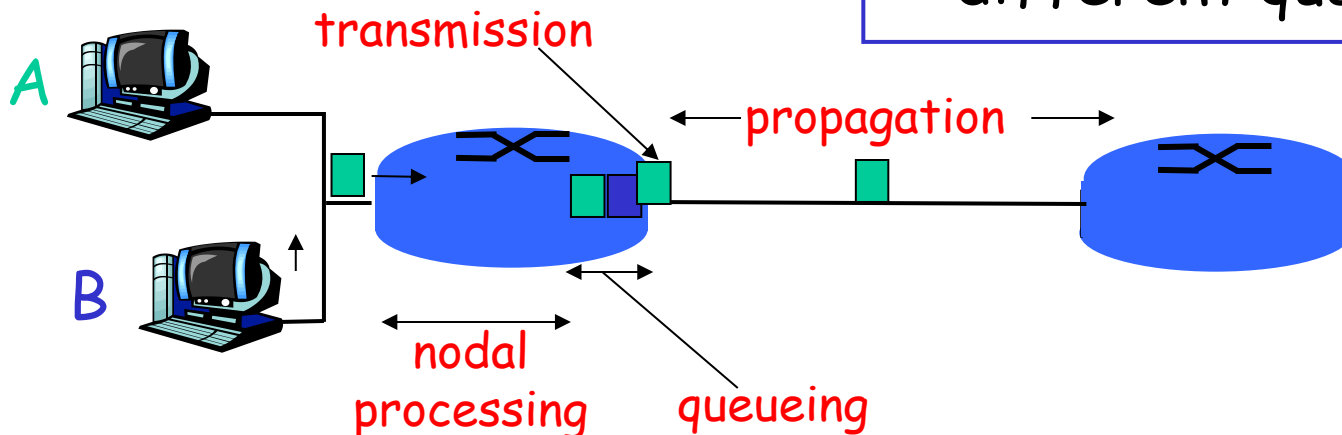
Delay in packet-switched networks

3. Transmission delay:

- R=link bandwidth (bps)
- L=packet length (bits)
- time to send bits into link = L/R
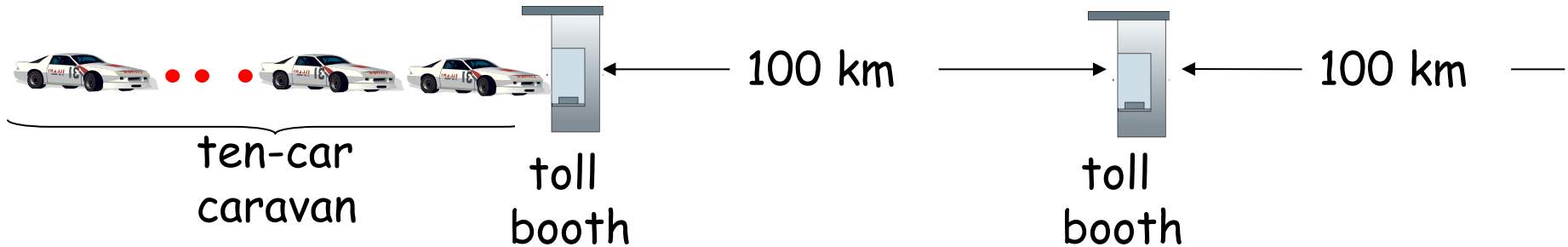
4. Propagation delay:

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

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

A

B

transmission

propagation

nodal processing

queueing

Caravan analogy

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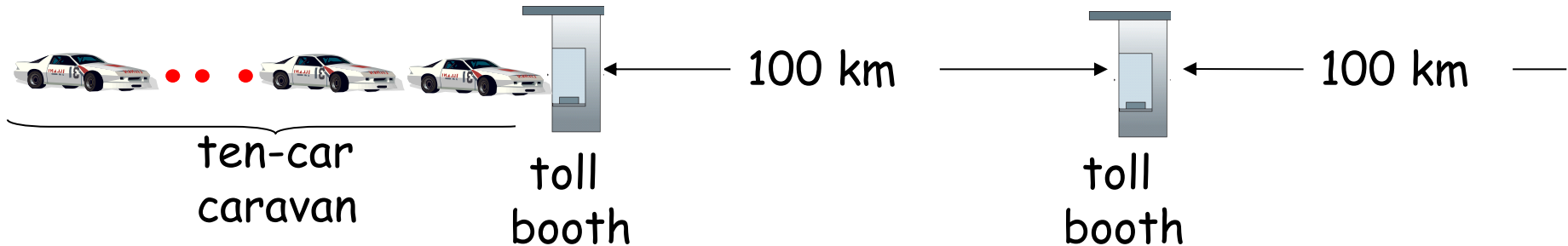
- cars "propagate" at 100 km/hr
- toll booth takes 12 sec to service car (transmission time)
- car~bit; caravan ~ packet
- Q: How long until caravan is lined up before 2nd toll booth?

- 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)

ten-car caravan

toll booth

100 km

toll booth

100 km

- ❑ 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
    - m   typically a few microsecs or less
- ❑ d_{queue} = queuing delay
    - m   depends on congestion
- ❑ d_{trans} = transmission delay
    - m   = L/R, significant for low-speed links
- ❑ d_{prop} = propagation delay
    - m   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
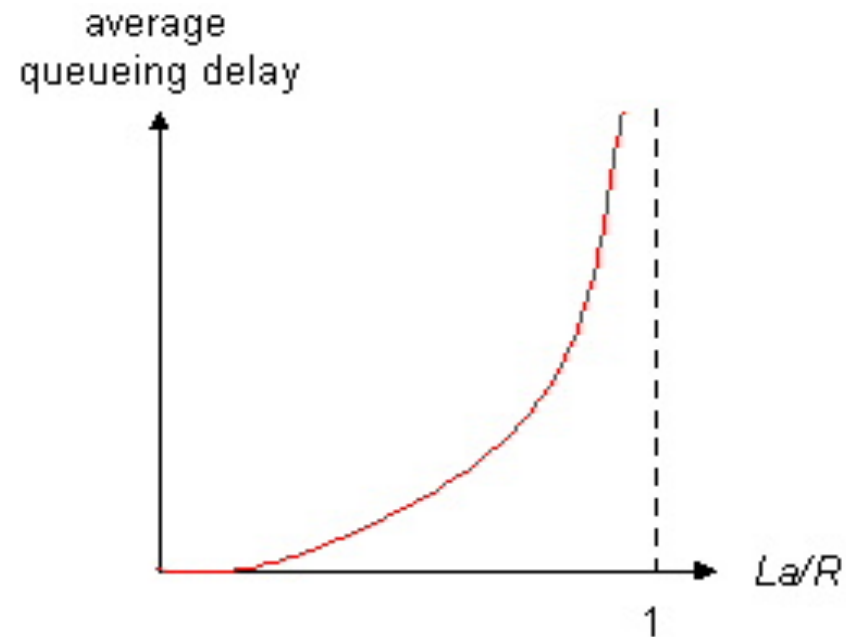
- La/R ~ 0: average queueing delay small
- La/R -> 1: delays become large
- La/R > 1: more "work" arriving than can be serviced, average delay infinite!

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
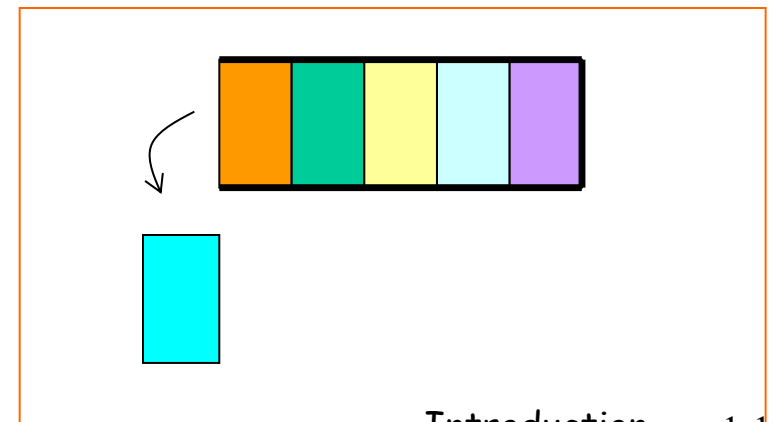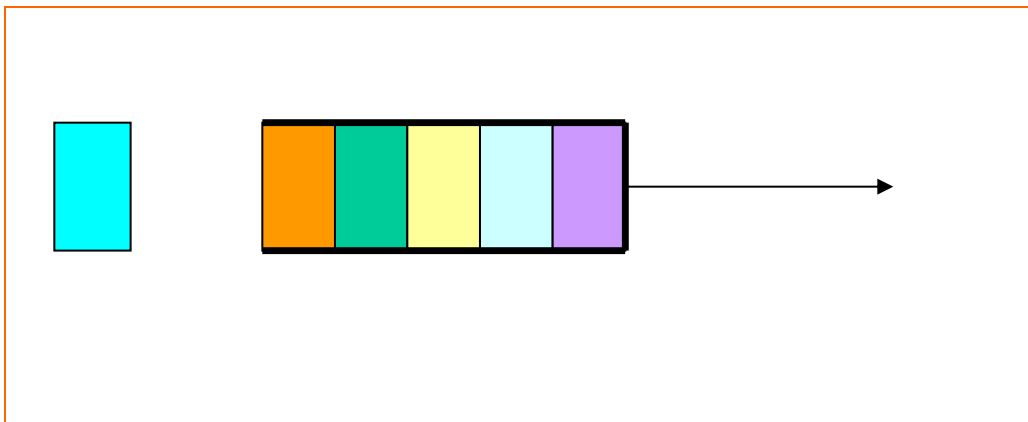
"Real" Internet delays and routes

❑ What do "real" Internet delay & loss look like?
❑ <u>Trace route program:</u> 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.

3 probes   3 probes

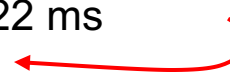3 probes
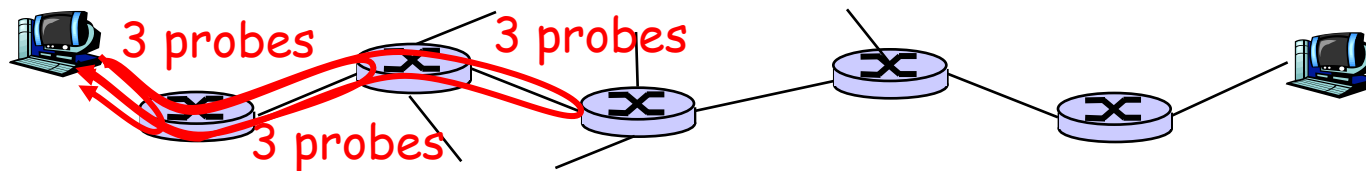
"Real" Internet delays and routes

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

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)
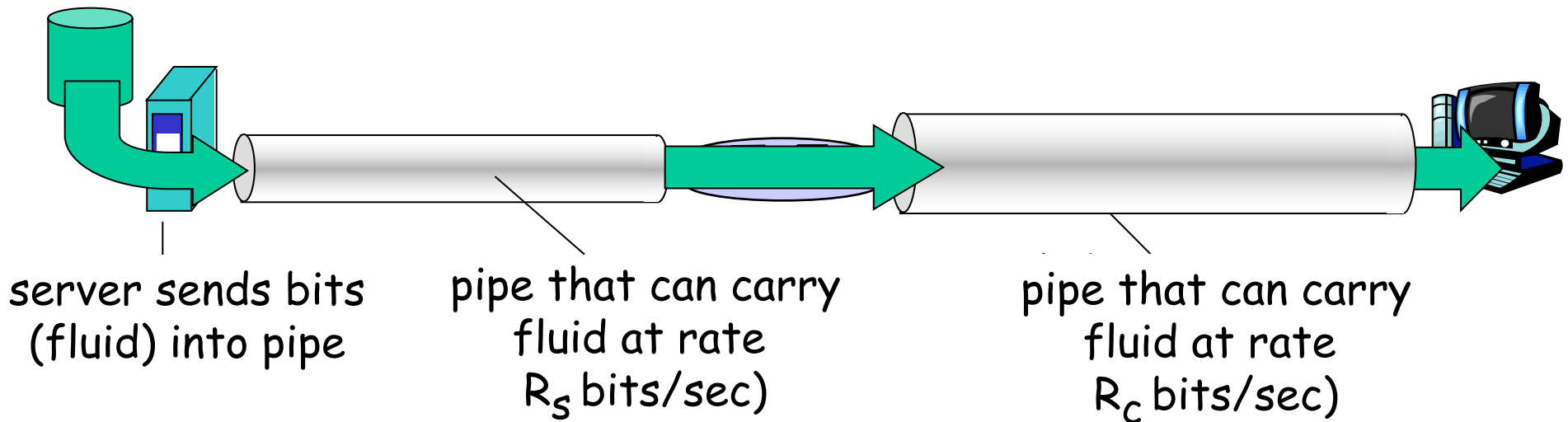
Throughput (more)

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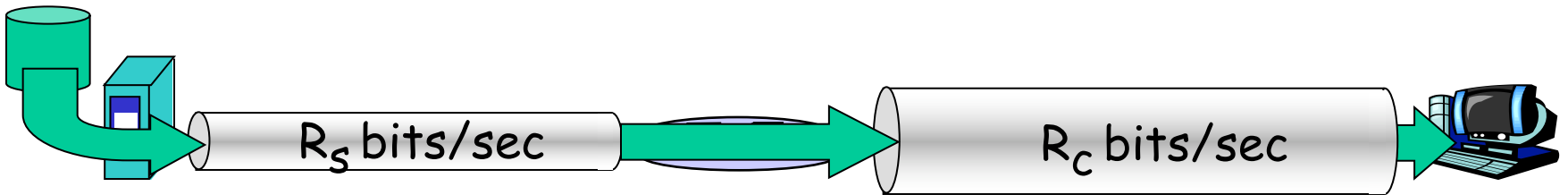
- $R_s > R_c$ What is average end-end throughput?

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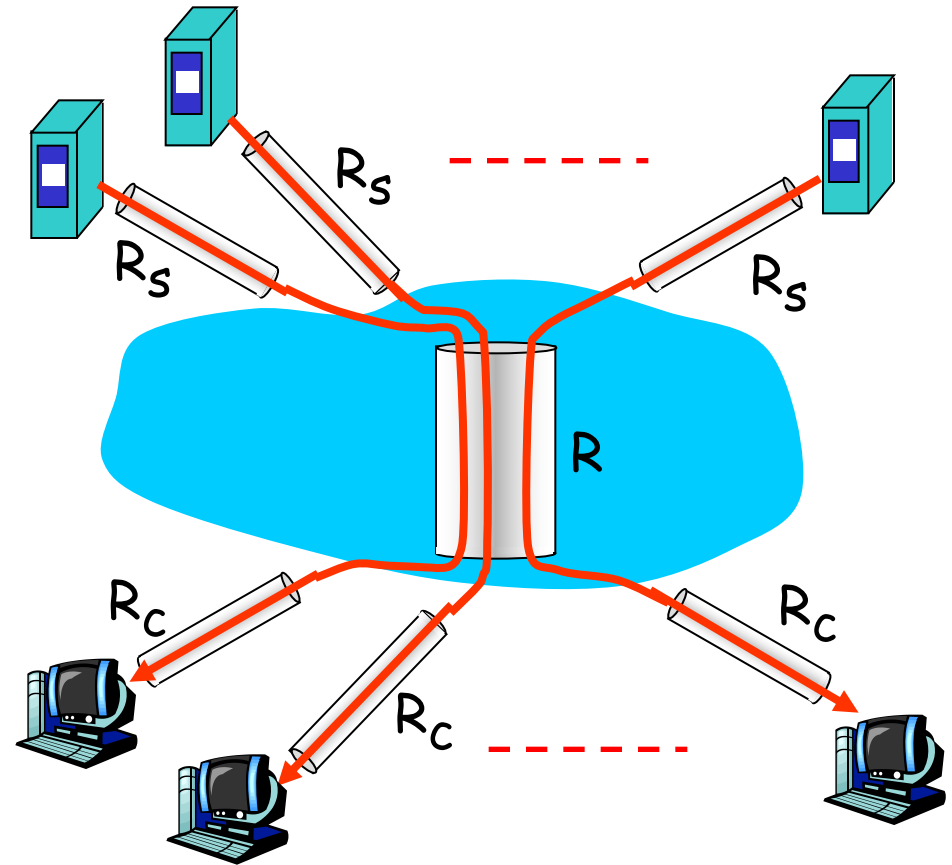
10 connections (fairly) share backbone
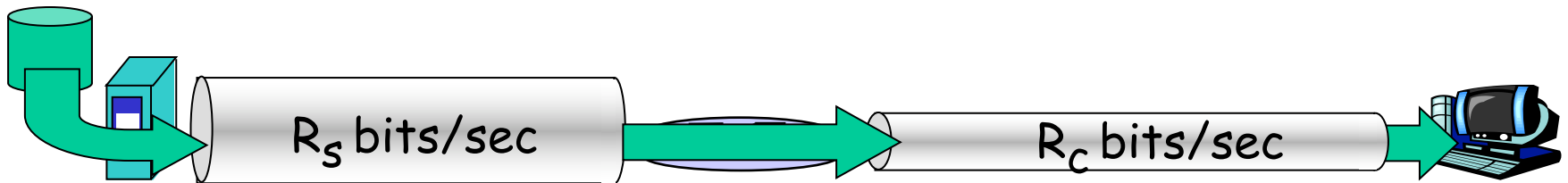bottleneck link R bits/sec

Chapter 1: roadmap

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

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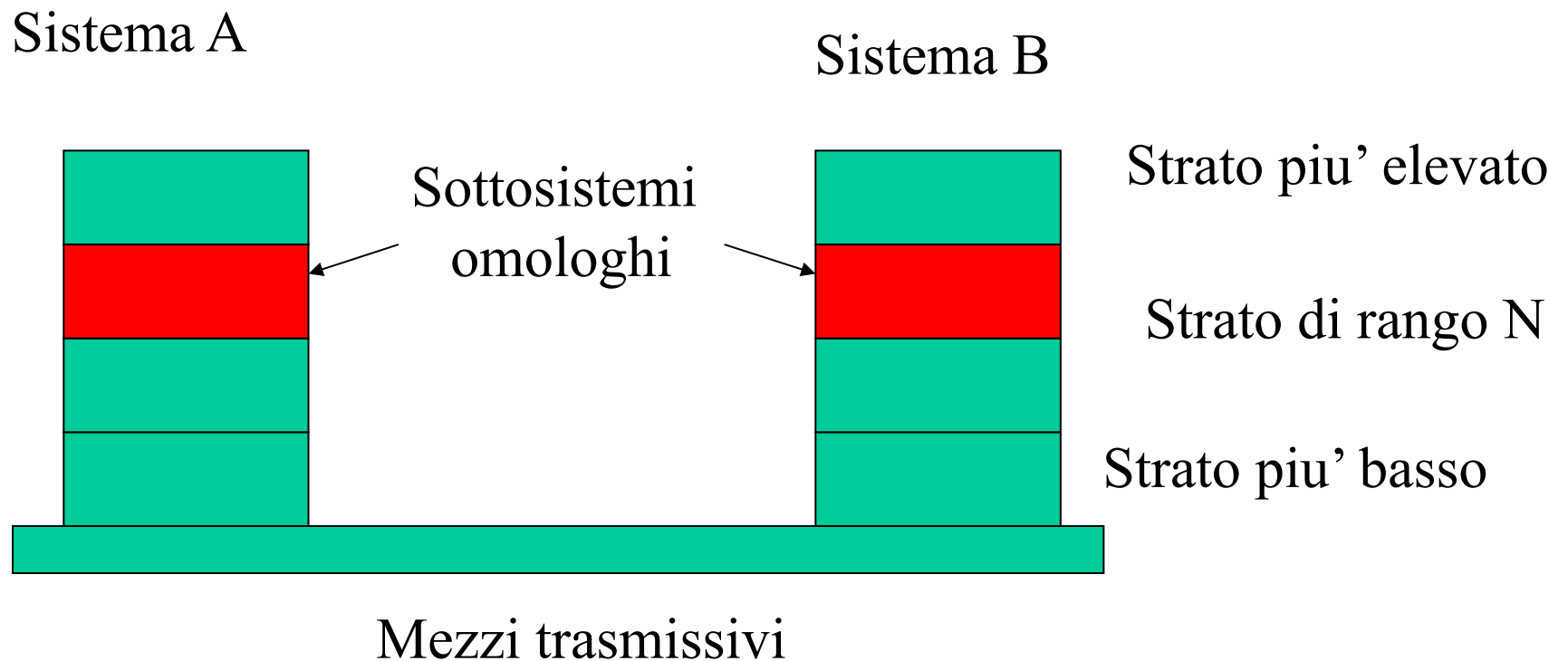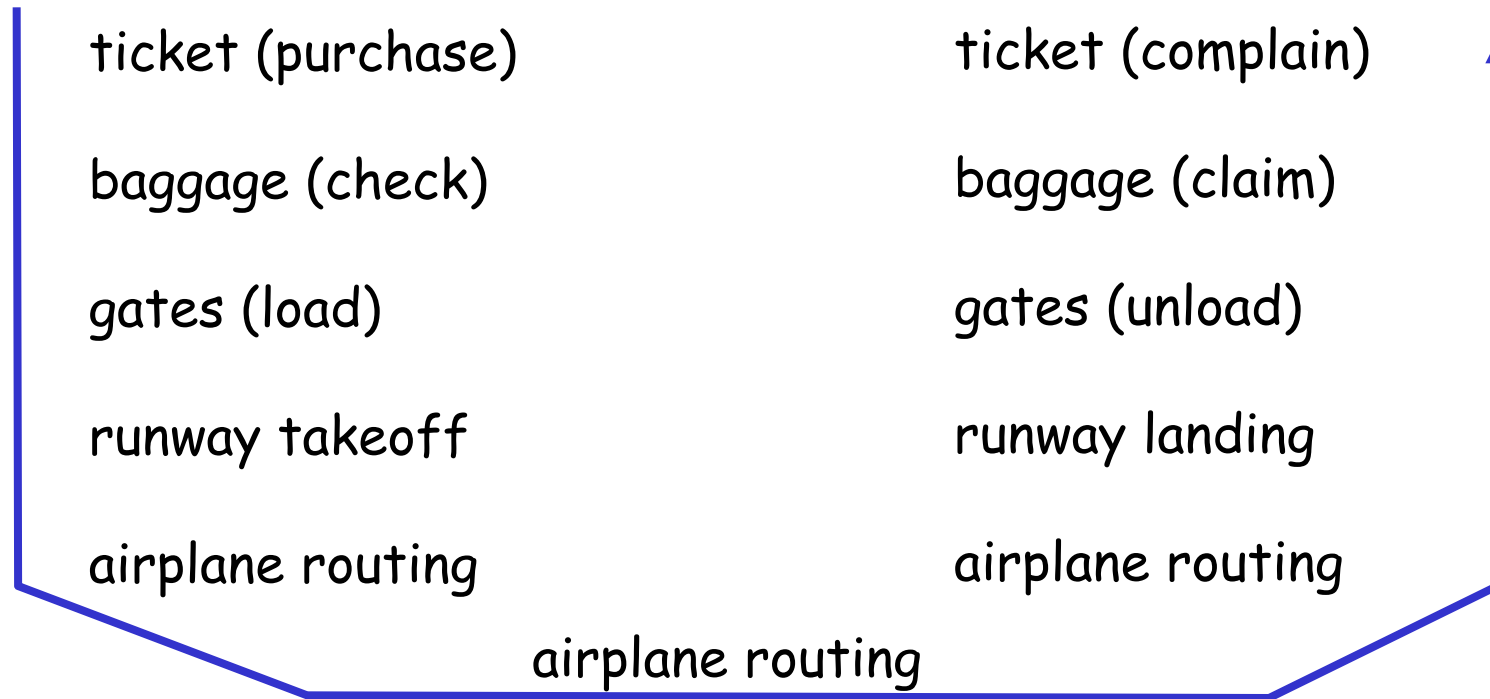
airplane routing

❑ 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
   o via its own internal-layer actions
   o 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

Departing airport

ticket (purchase)
baggage (check)
gates (load)
runway takeoff
airplane routing

arriving airport

ticket (complain)
baggage (claim)
gates (unload)
runway landing
airplane routing

intermediate air traffic sites

gates unload	gates load
runaway landing	runaway takeoff
airplane routing	airplane routing
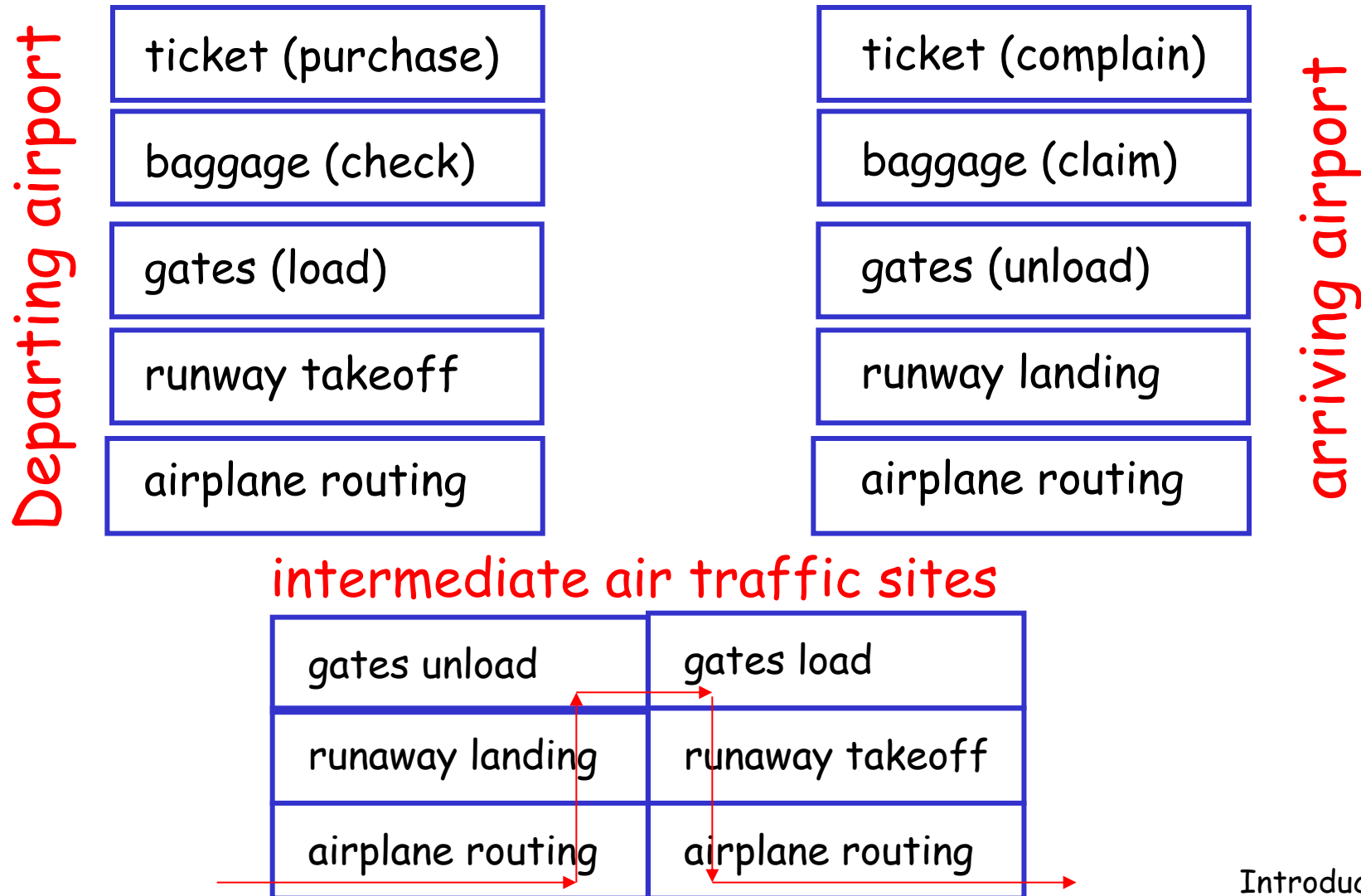
Why layering?

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 11th 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
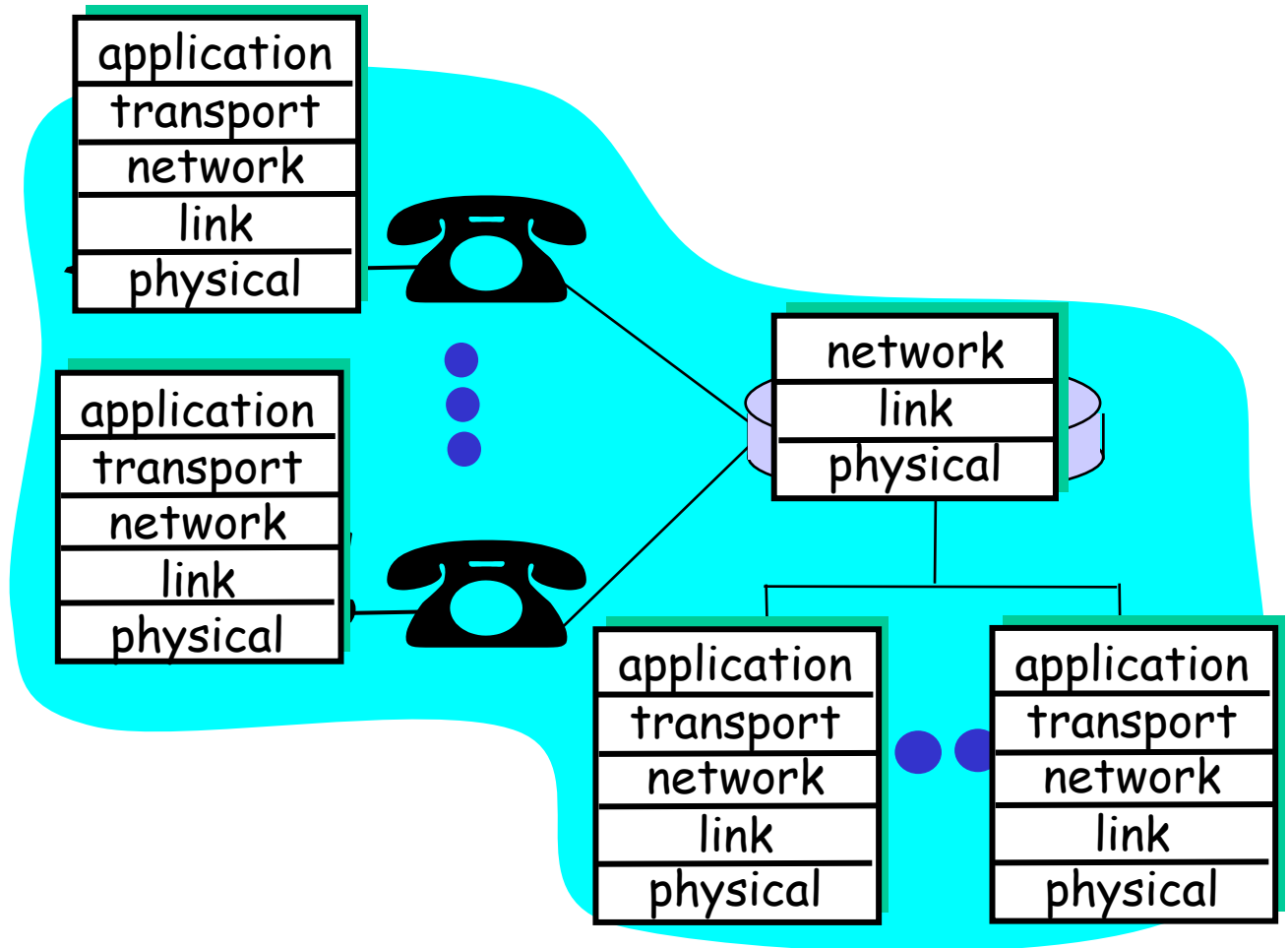 - PPP, Ethernet
- **physical:** bits "on the wire"

application
transport
network
link
physical
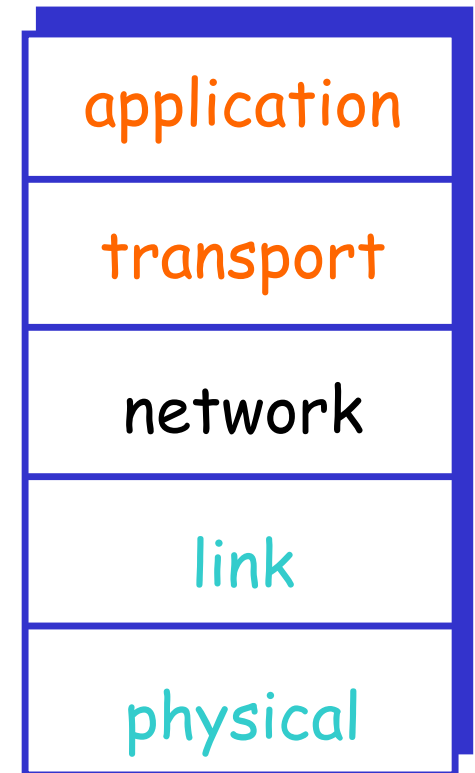
____ Typically in HW
____ Typically SW

Layering: logical communication

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

application
transport
network
link
physical

application
transport
network
link
physical

network
link
physical

application
transport
network
link
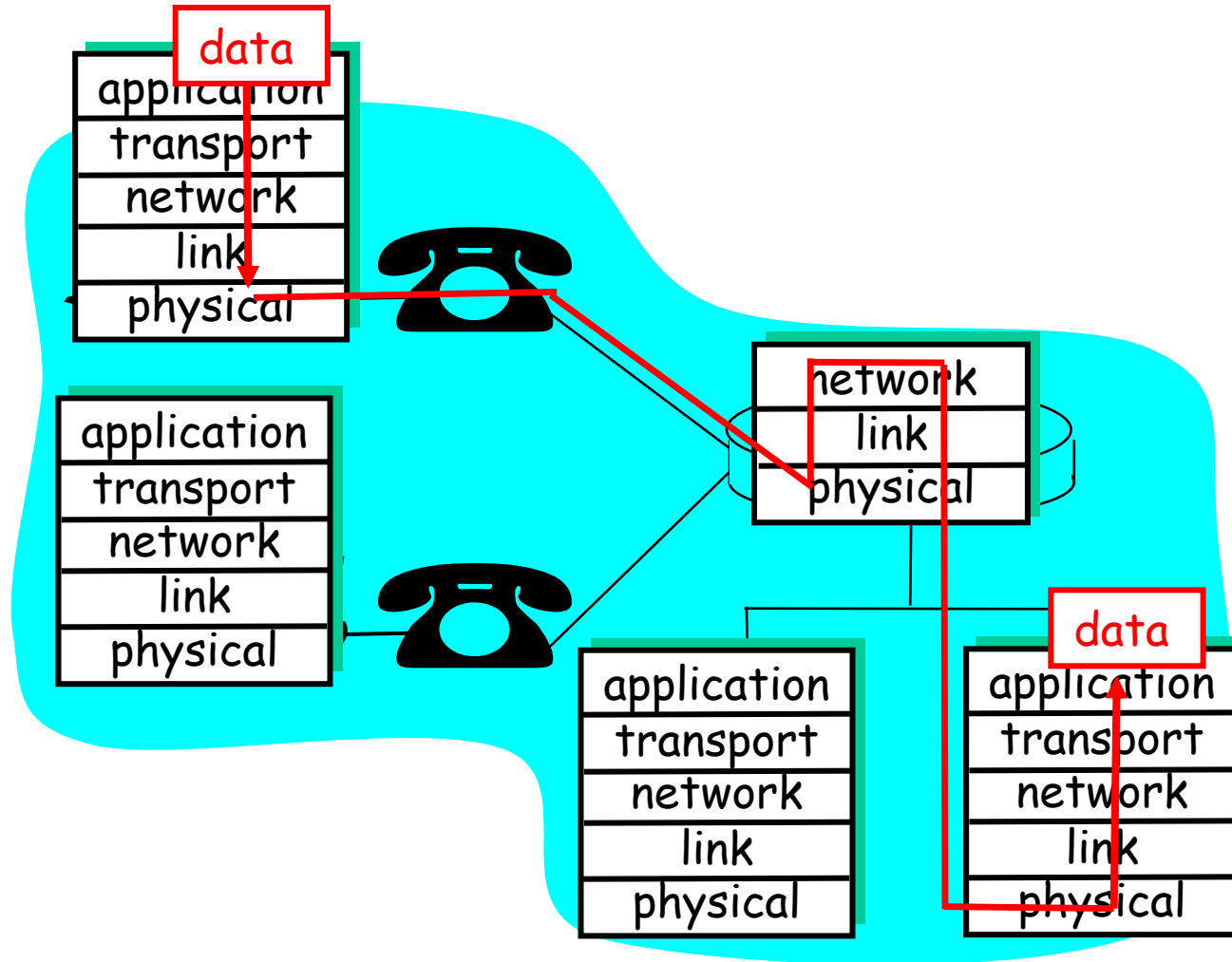physical

application
transport
network
link
physical

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
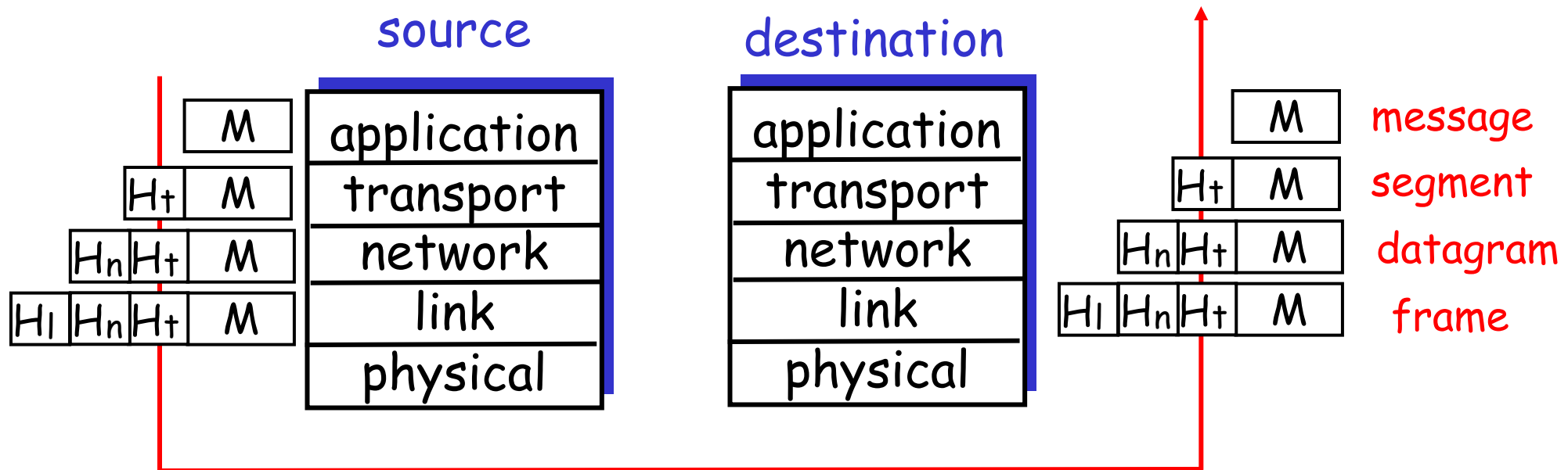- analogy: post office
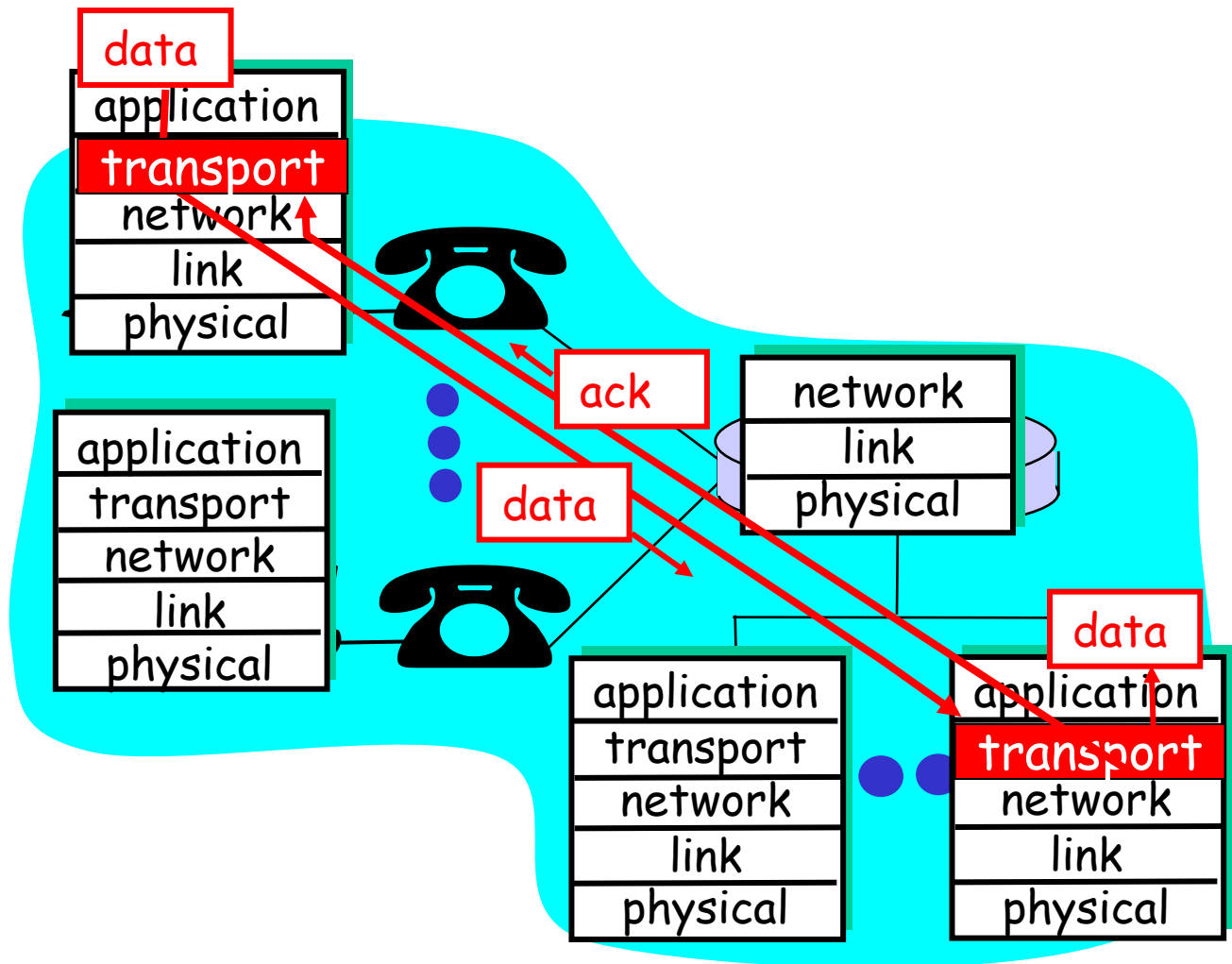
Layering: physical communication

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

source			destination	message

(diagram)

source

M	
H_t	M
H_n	H_t	M
H_l	H_n	H_t	M

application
transport
network
link
physical

destination

application
transport
network
link
physical

M	message
H_t	M	segment
H_n	H_t	M	datagram
H_l	H_n	H_t	M	frame

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