Reti Internet Multimediali

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Professore

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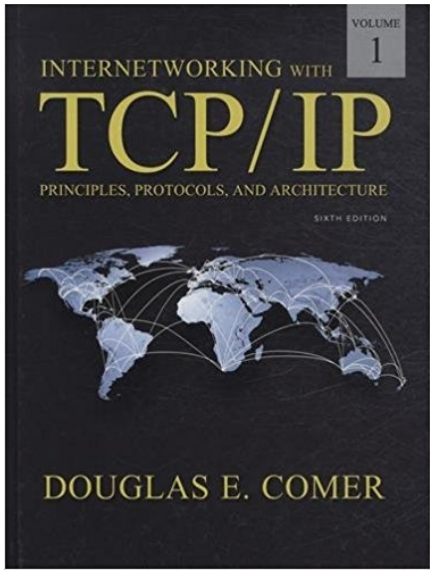
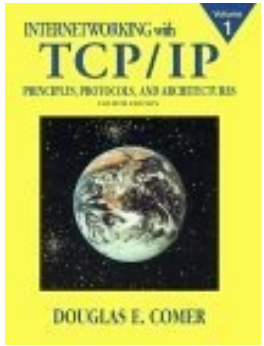
- Orario di ricevimento
  (previo appuntamento via mail):
  - Lunedi 13:30-15:30

Teaching material

- **Book :**
- **Douglas E. Comer, *Internetworking with TCP/IP*, volume 1, Prentice Hall.**





☑ **6th edition**

☑ **… but previous editions work as well (for example the 5th)**

Teaching material

- Slides on the website
- Other documents signaled during the course on the course Web page
- Internet (RFCs …)

- Web page:

http://cs.unibg.it/martignon/indexRIM.html

http://193.204.253.55/martignon/indexRIM.html

Course Agenda

- Recap on the topics studied in FRT
- Access Technologies
  - LAN protocols and devices
  - Multiplexing/Multiple Access techniques
    - ✓ Focus on: Cellular (Mobile) Networks
    - ✓ STP protocol
- The Network Layer (Internet Protocol, IP)
  - Routing in IP networks
  - Algorithms and protocols for routing (DV, Link State, RIP, OSPF, BGP)
- Internet Evolution and Organization

..Course Agenda..

- **The Transport Layer**
  - **Unreliable Transport, UDP**
  - **Reliable Transport, TCP**

- **Application Layer**
  - **Domain Name System (DNS)**
  - **File Transfer (FTP)**
  - **Web Browsing (HTTP)**
  - **E-mail (SMTP)**
  - **Peer to Peer Systems**

...Course Agenda

- Wireless networks
- Internet of Things (IoT)

- Quality of Service
- Content Delivery Networks/Information Centric Networks (CDN/ICN)
- Voice Over IP

Target

- To give you the basics of the

INTERNET

Any ICT Engineer MUST know the INTERNET

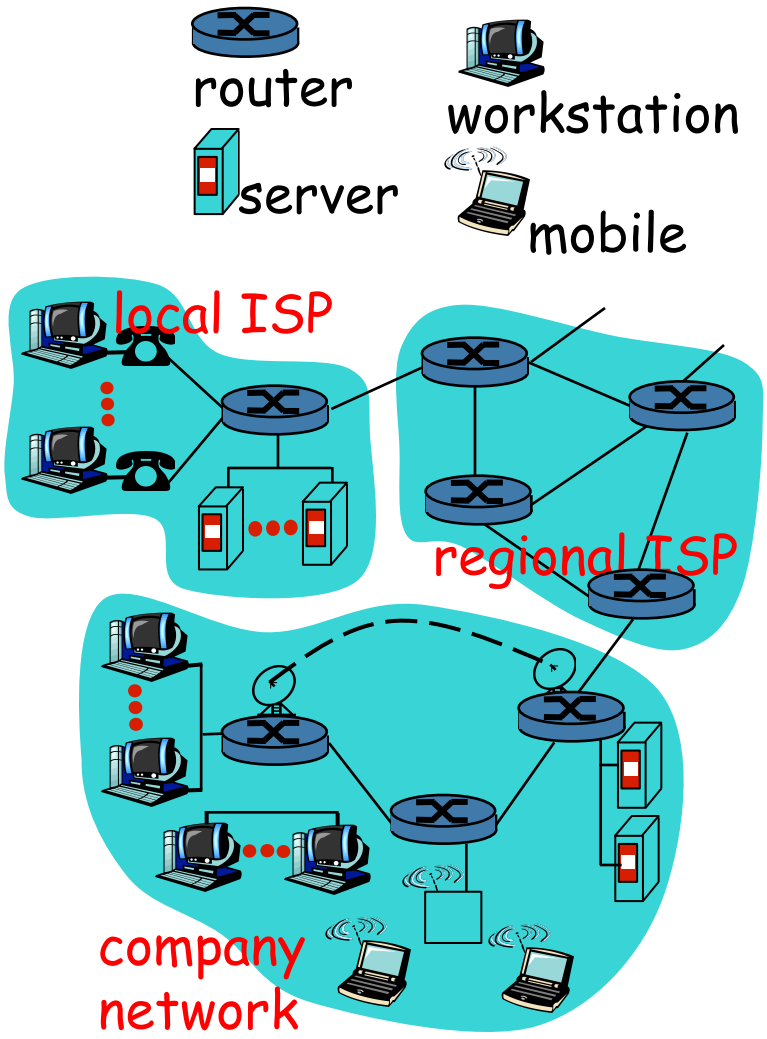
Background

- We'll discuss on:
  - Communication Protocols
  - Internet Network infrastructures and devices

What is The Net?

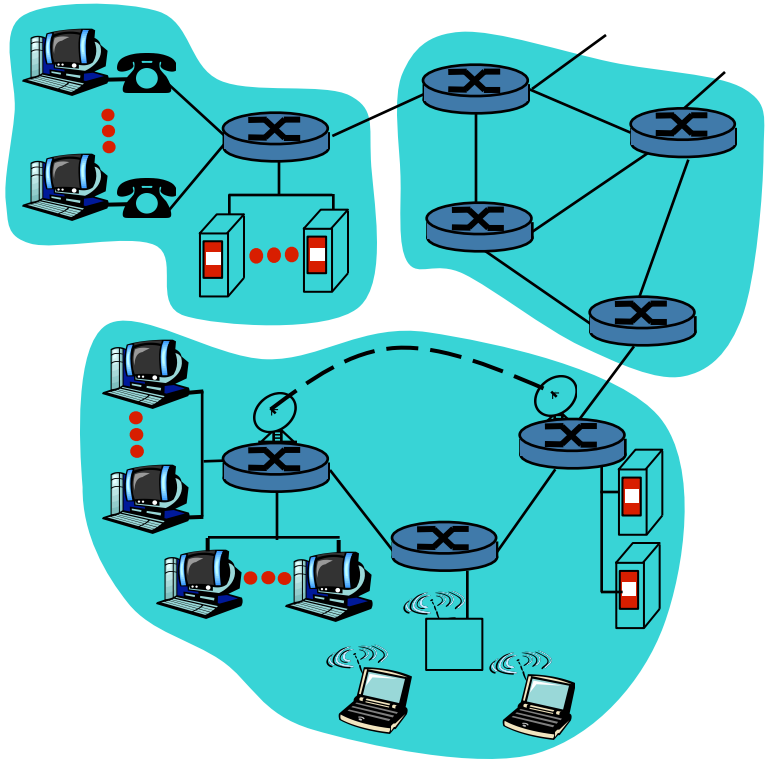
What's Internet?

- Millions of computers connected named *hosts* = terminals
- Applications running on hosts
- Links (fibers, cables, wireless, satellite)
- Network devices, named routers



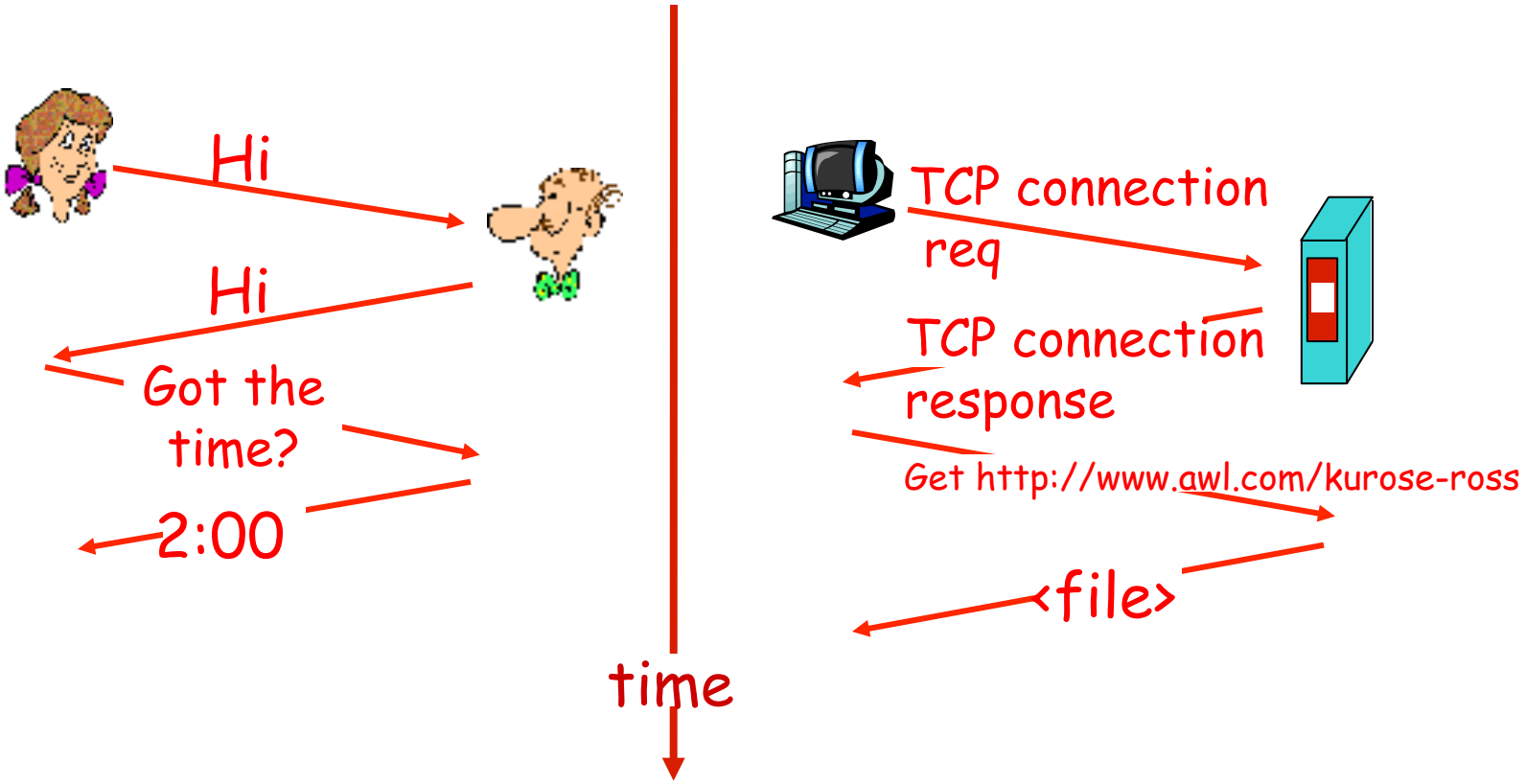
What's Internet?

- Communication Infrastructure to let applications talk
  - Web, email, games, e-commerce, file sharing
- Communication protocols to send/ receive messages



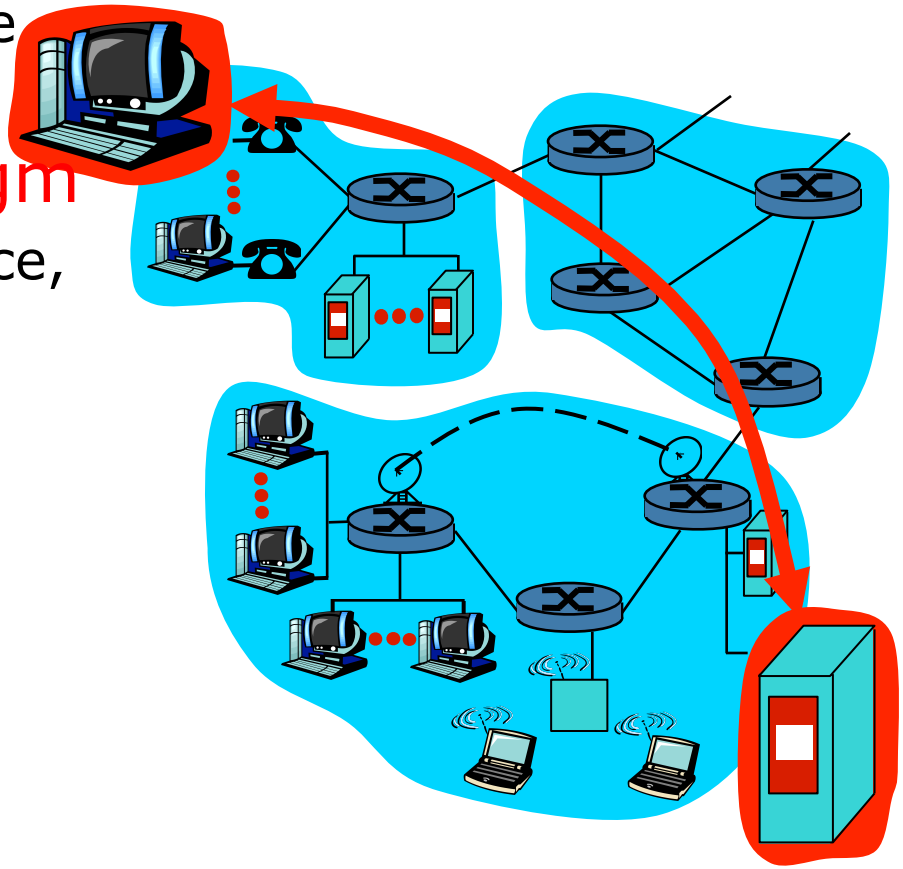
What's a protocol?

a human protocol and a computer network protocol:



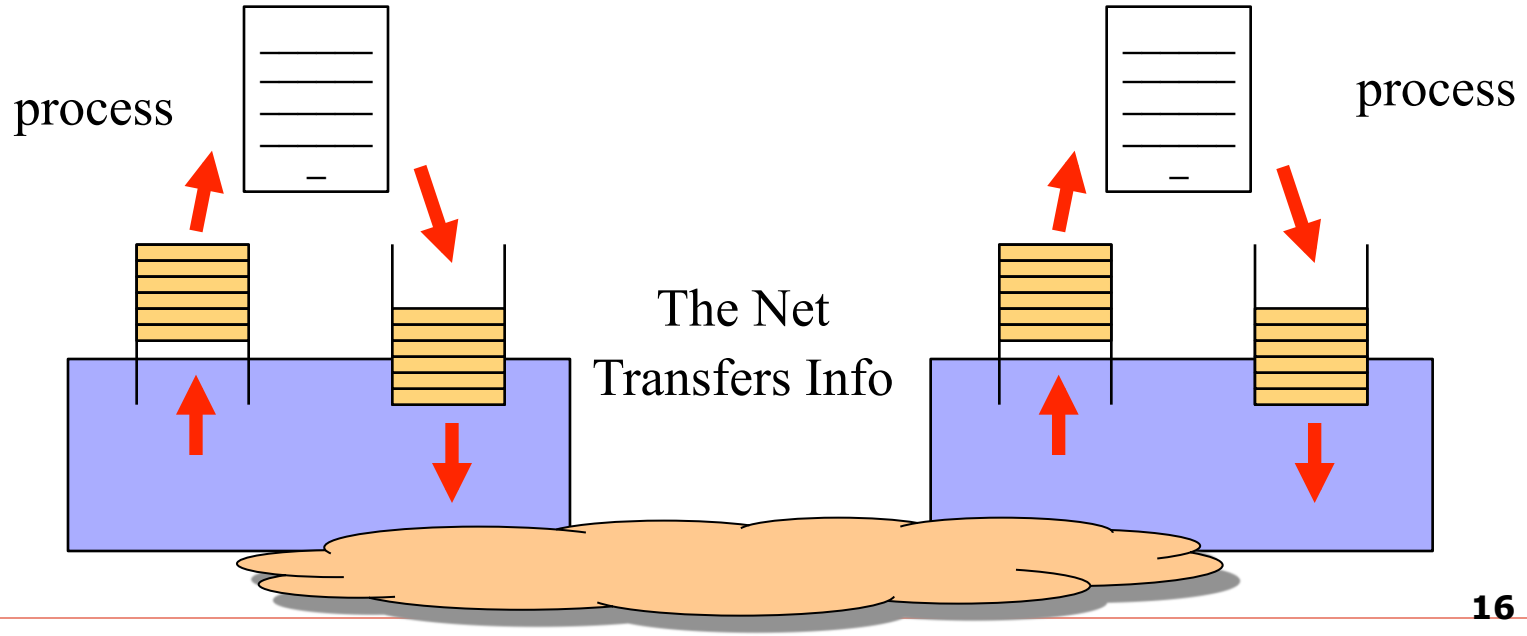
At the Edges of The Internet

- Terminals (hosts):
  - Run application software (Web, email, ecc.).
- Client/server Paradigm
  - clients request for service, servers provide it
  - Clients issue requests, servers issue responses
- Peer-to-peer:
  - No strict distinctions
  - Flat architecture



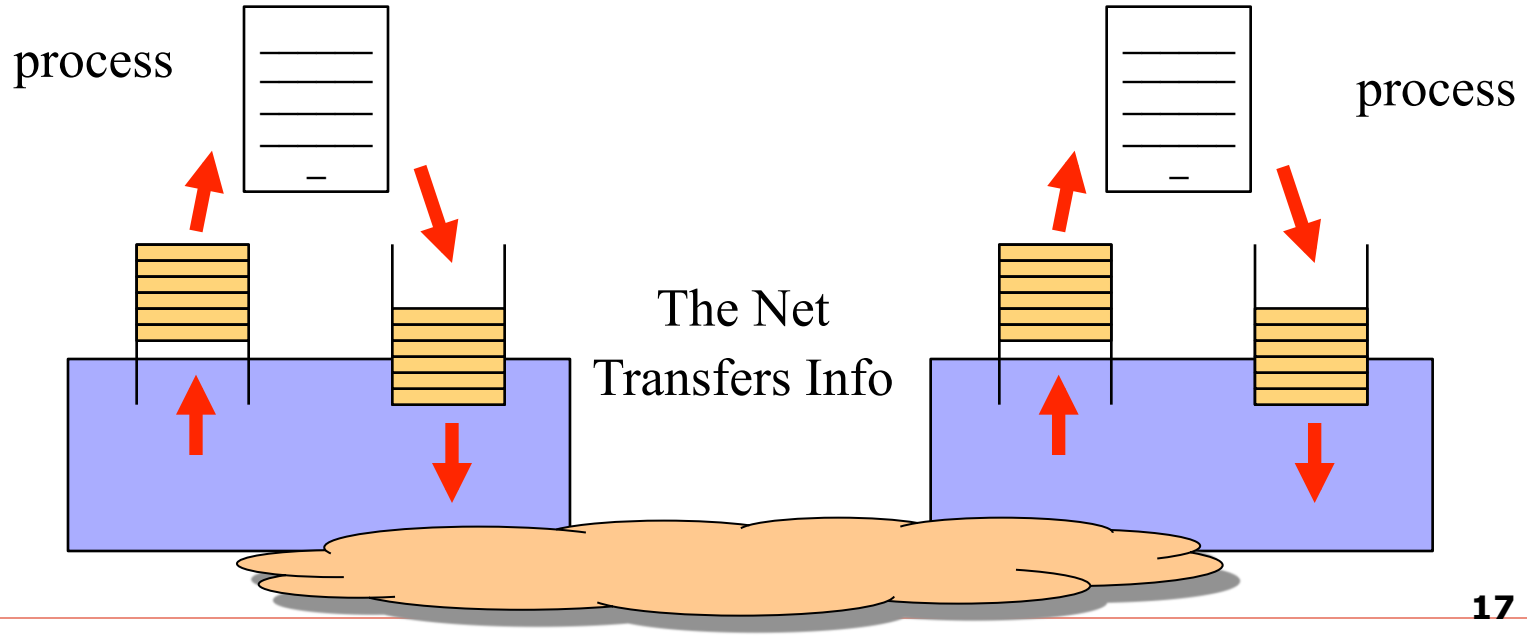
Applications over The Net

- The Net provides a *communication service* to *transport* information among remote processes
- The type of transfer provided by The Net may be of various kinds



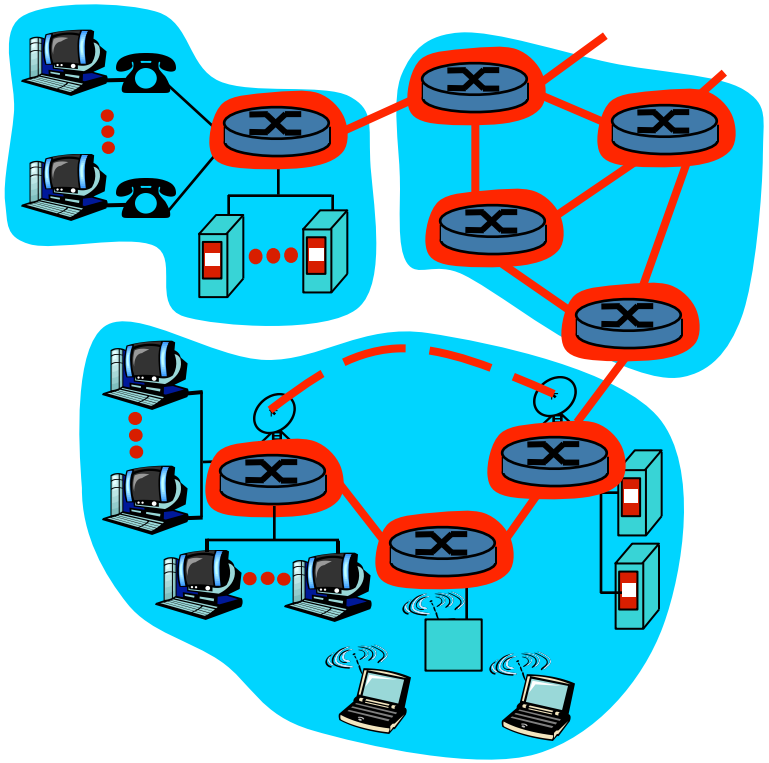
Types of Transport

- Short messages, unreliable (e.g. DNS, signaling, etc.)
- Reliable byte streaming (web, email, file transfer, etc.)



Network Core

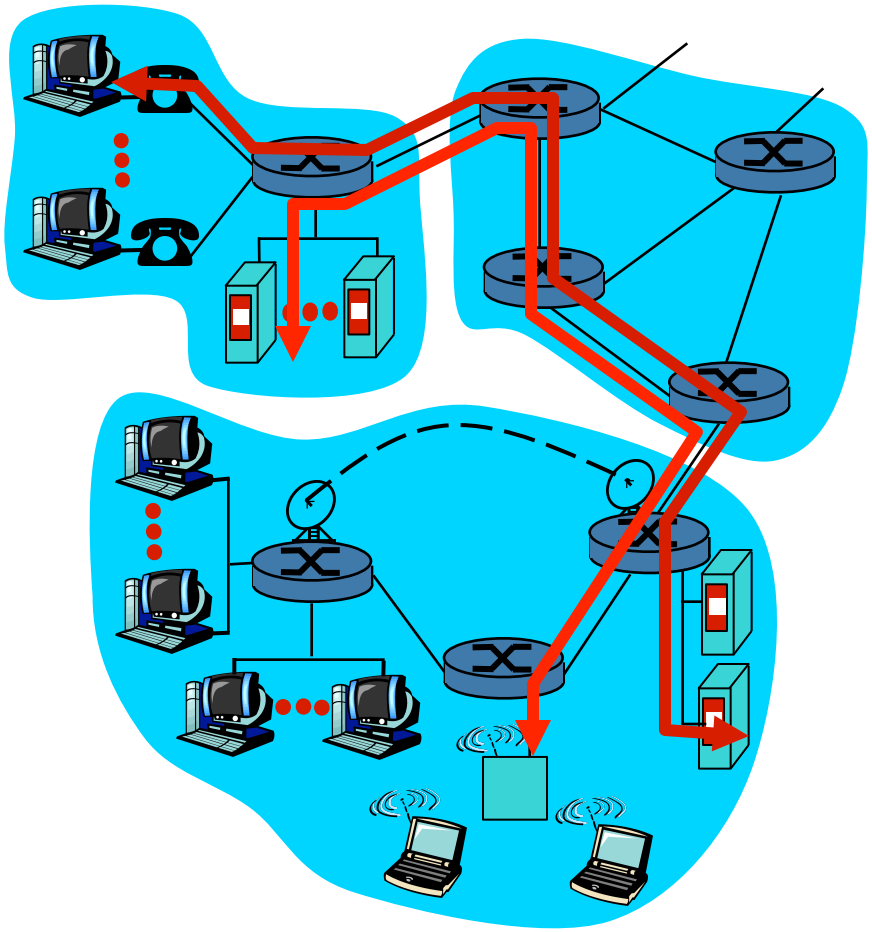
- Bunch of Interconnected routers
- How to transfer information?
  - Circuit Switched communication: each call is assigned a circuit
  - Packet Switched communication: info divided into messages



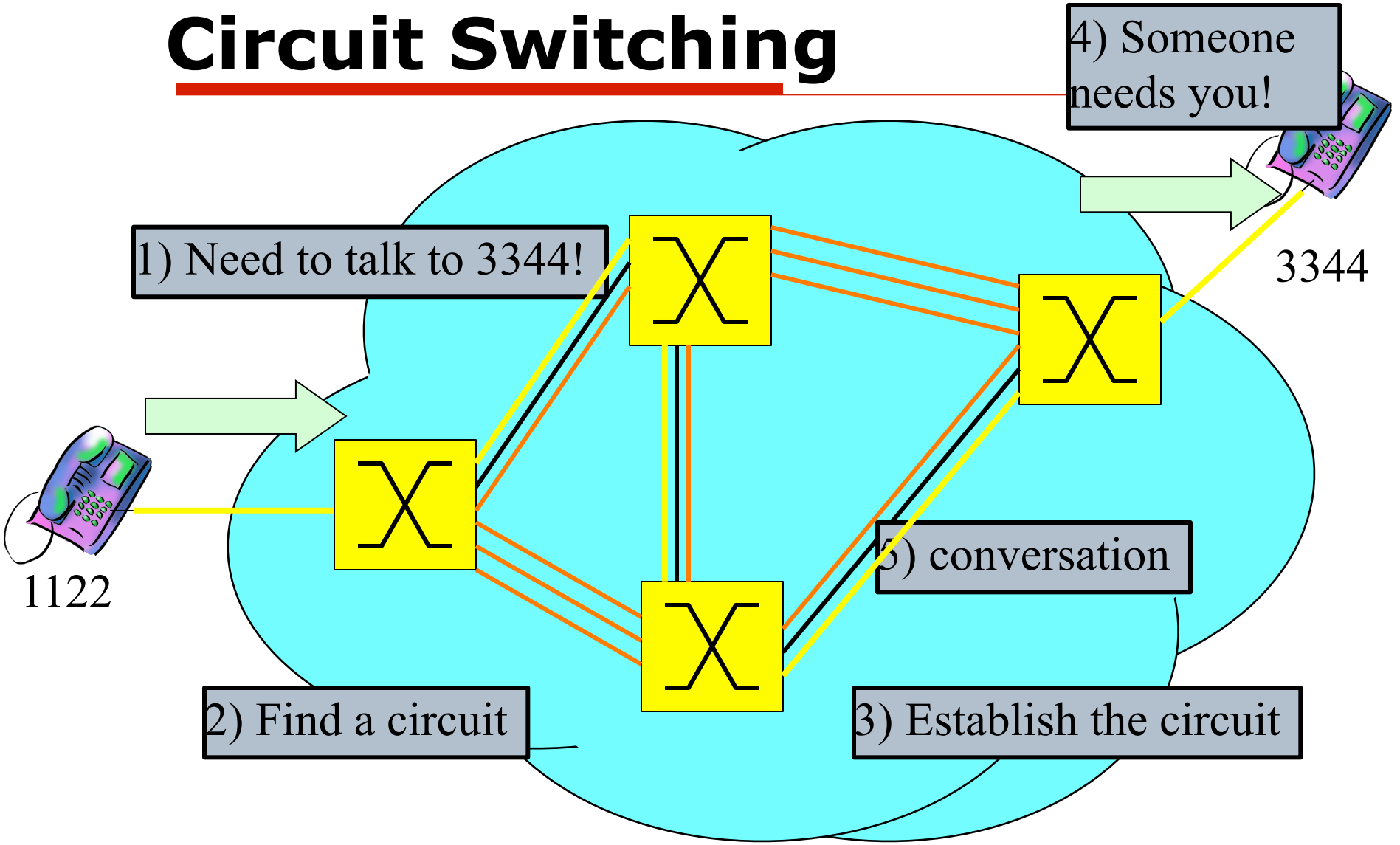
Circuit Switching

Communication resources are reserved on call basis

- E.g. PSTN



Circuit Switching

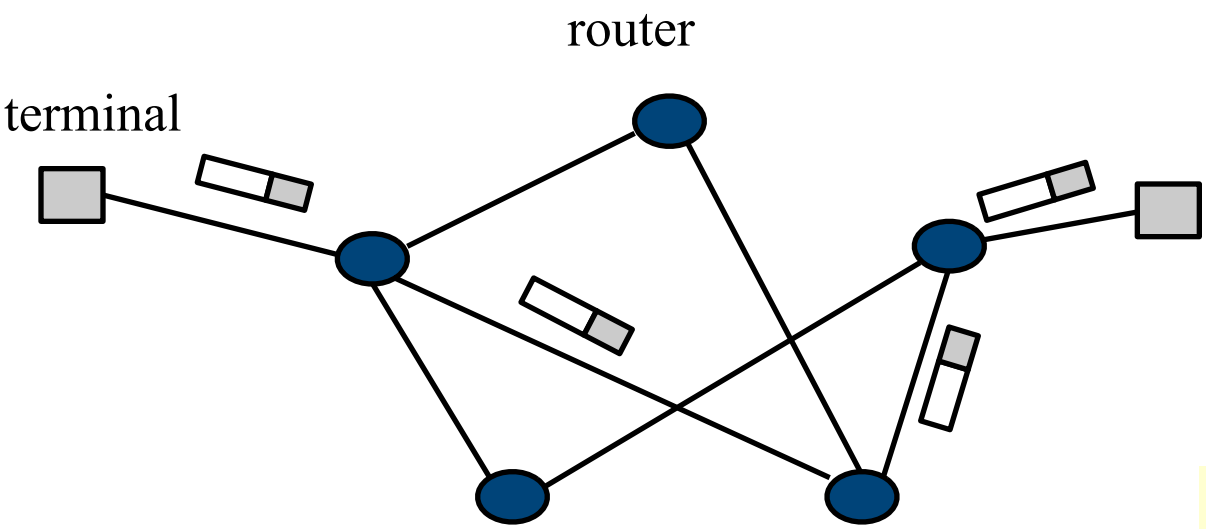


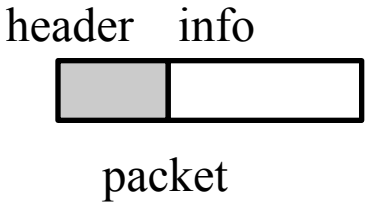
Circuit Switching

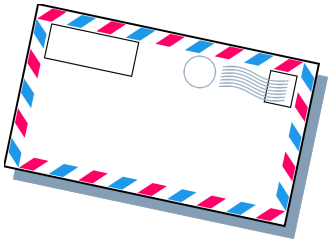
- Network resources divided into "circuits"
- each circuit is statically assigned to communications
- Assigned circuit stays idle if not used *(lack of sharing)*

- Circuits can be built through:
  - Time division
  - Frequency division
  - Code division

Packet Switching

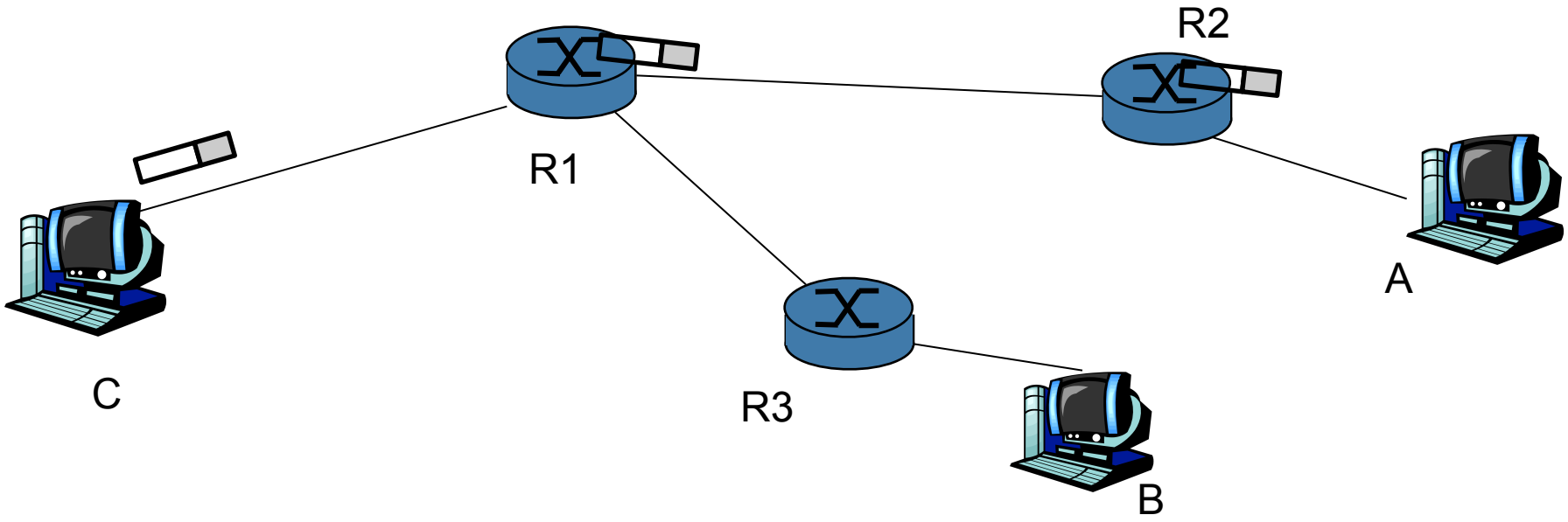






Packet Switching

Routing Table	
dest.	Next router
A	R2
B	R3



Packet Switching

Data Flow split up in packets

- Packets from different flows share the network resources
- Each packet fully utilizes the channel
- Network resources are used according to current needs

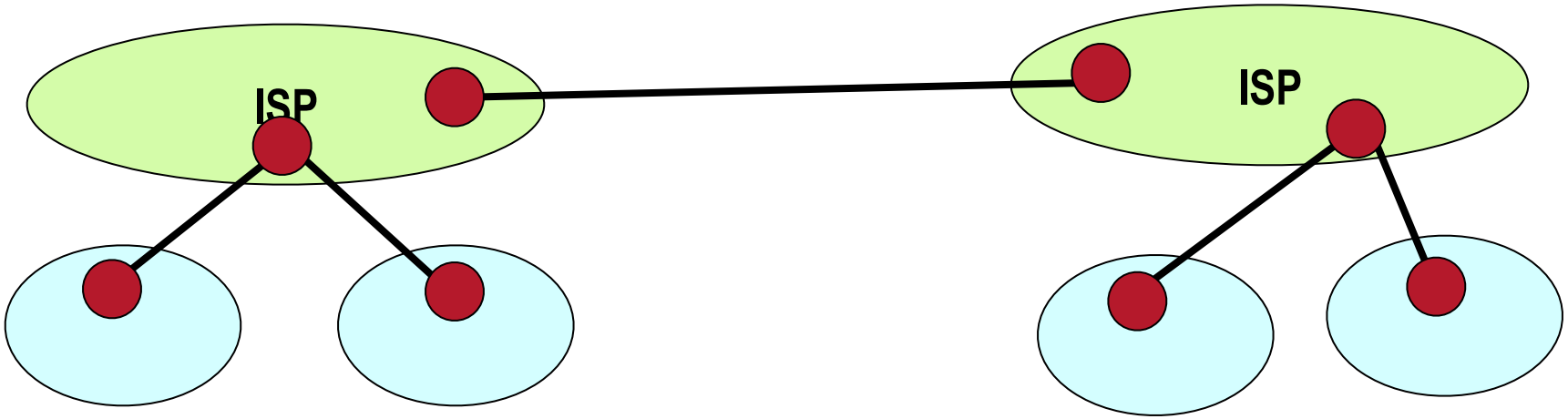
Resource Contention

- **store and forward**: each packet must be completely received before starting the transmission on the outgoing link
- **Statistical Multiplexing**: packet queuing, waiting time to use the link

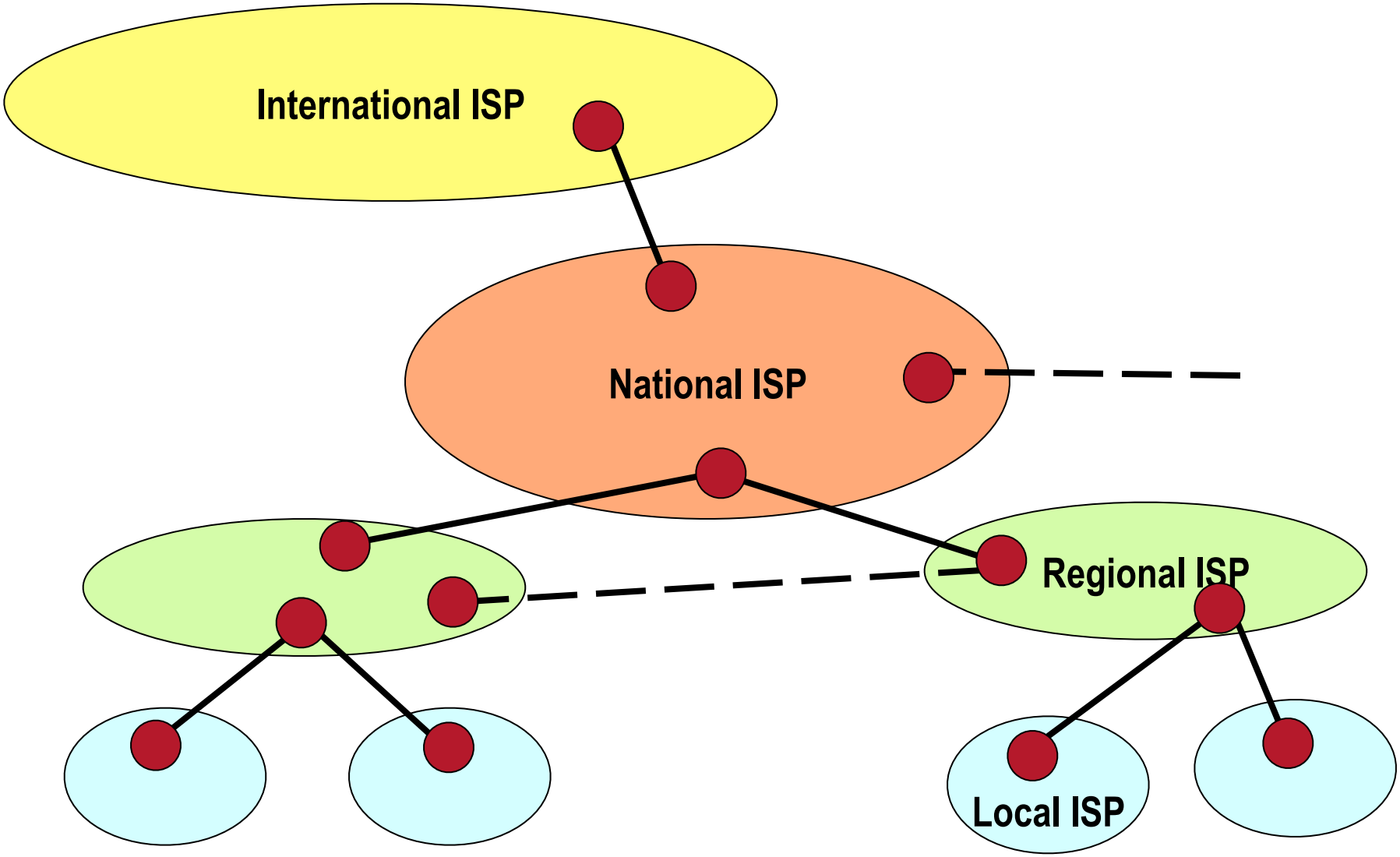
Internet Architecture and Access Technologies

General Architecture

- *Internet Service Providers* (ISP) provide connectivity (AOL, Orange, Free, etc.)
- ISPs share a common backbone

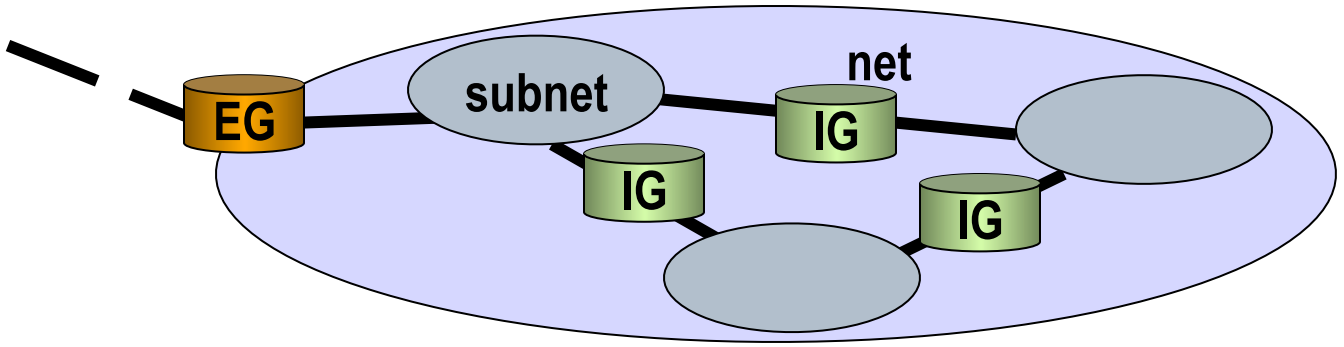


Internet Hierarchy



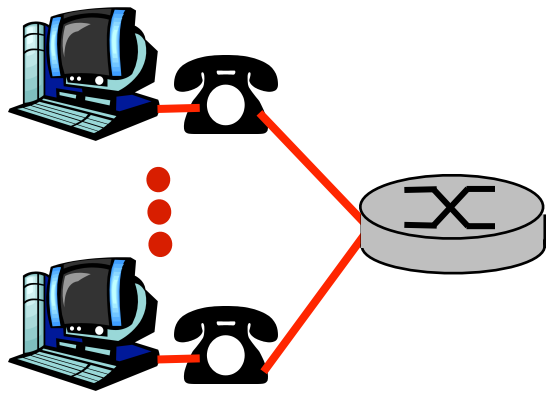
Internet Taxonomy

- The IP Network managed by a single organization is called *Autonomous System (AS)*
- TCP/IP are often used even in private networks (companies, campus nets, etc.) called *Intranets*
- The routers belonging to a given AS are *Interior Gateway (IG),* whereas the routers connecting differet ASs are *Exterior Gateway (EG)*



Access to the Internet

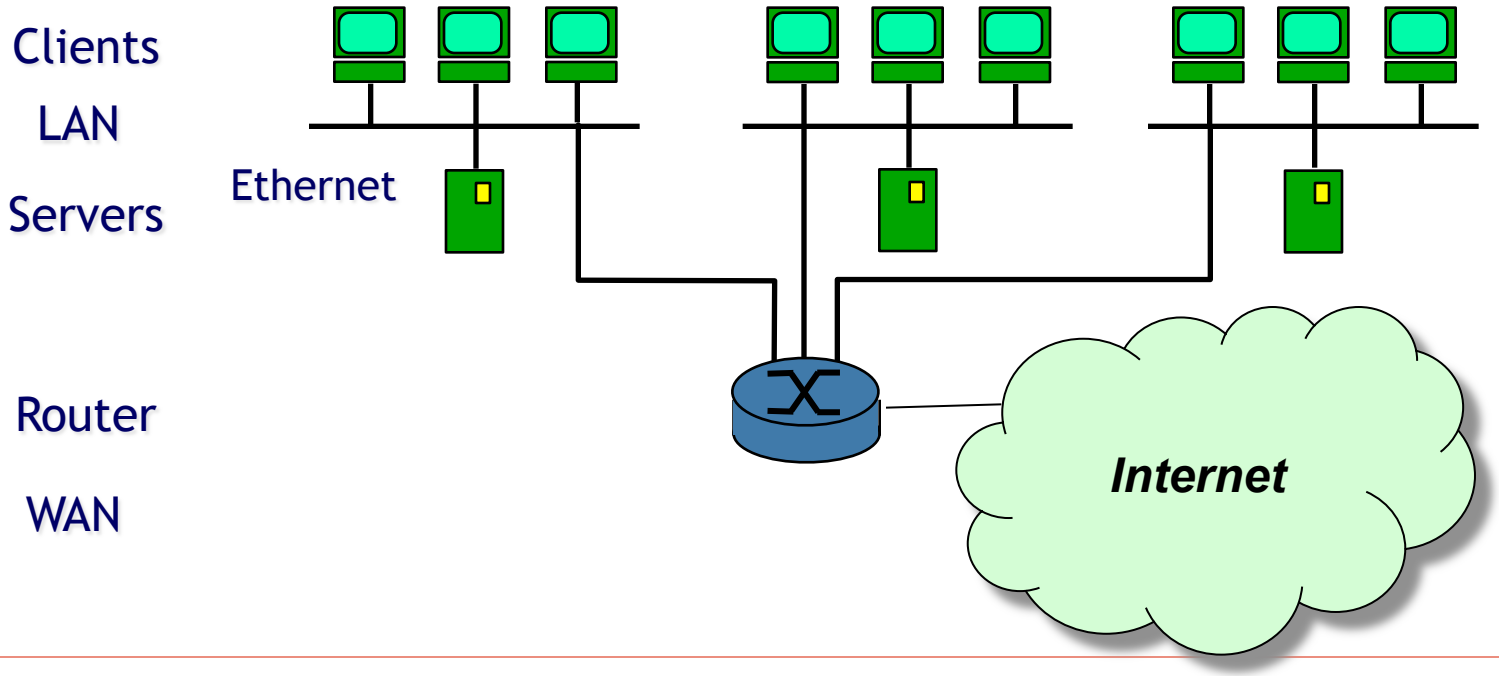
- Dialup
  - Direct access to ISP router through PSTN



- ADSL: asymmetric digital subscriber line
  - UTP shared with PSTN till the first Switching Point (frequency division)
  - Access to ISP router through fast data network

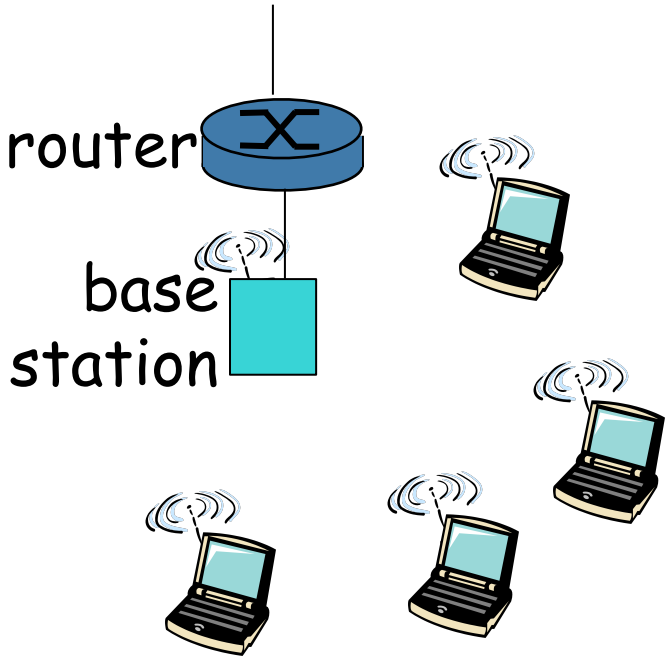
Access to the Internet

- Local Networks
  - Local Area Network (LAN) link between terminals and routers
  - Ethernet: 10 Mbs, 100Mbps, Gigabit Ethernet



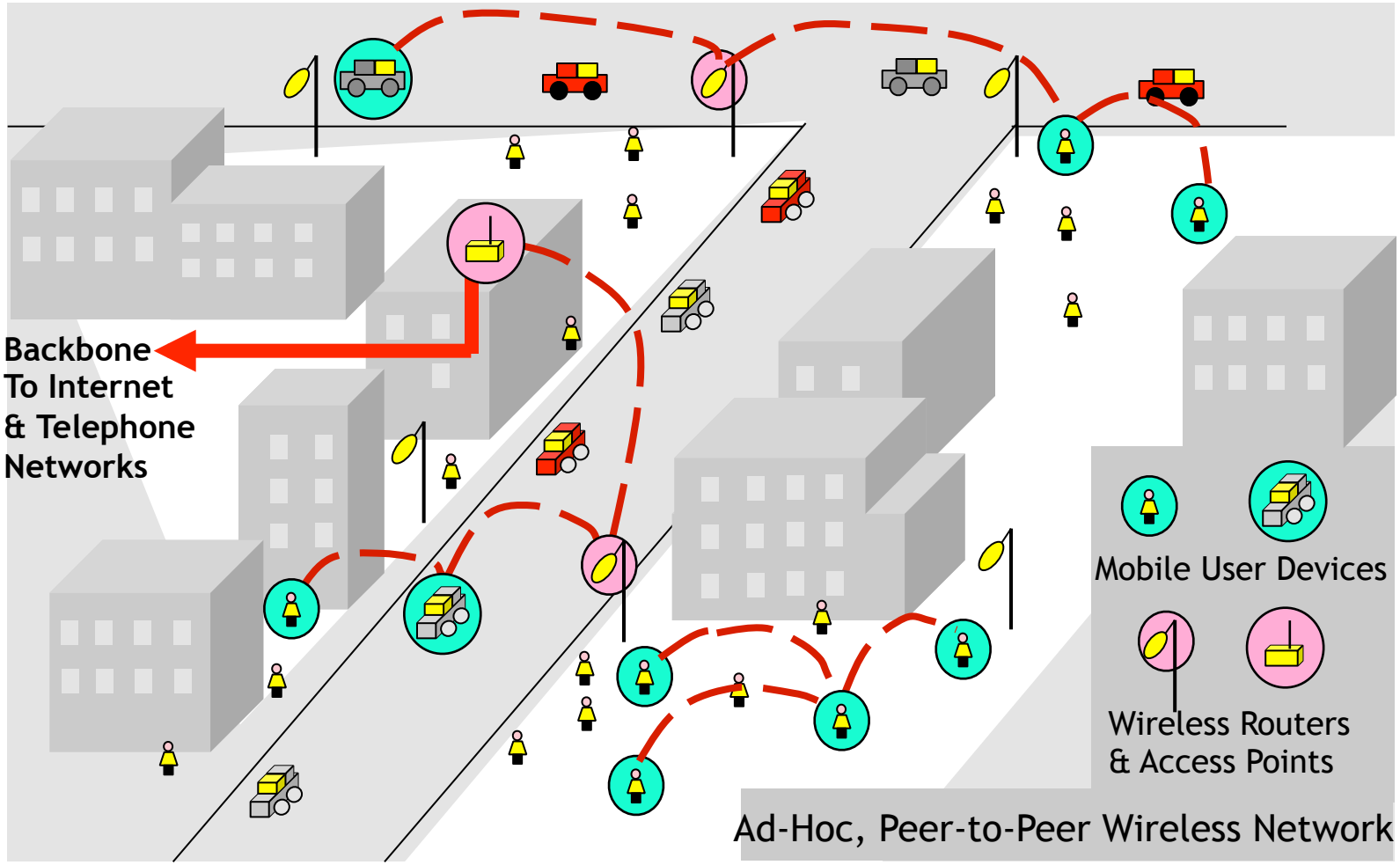
Access to the Internet

- Wireless Access
  - Wireless LAN:
  - Cellular Systems
    - GSM
    - GPRS
    - EDGE
    - UMTS
    - WiMAX
    - LTE …



Access through a base station or access point

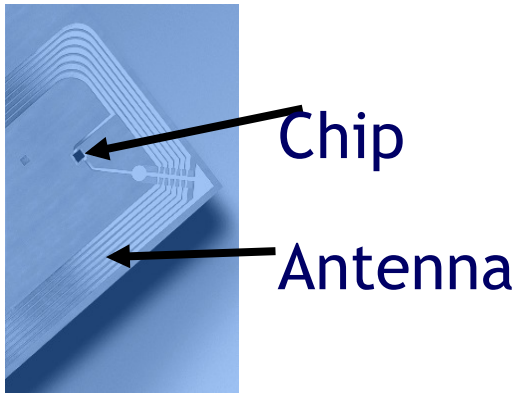
Pervasive Internet
Mesh & Ad hoc Networks



Distributed Networking

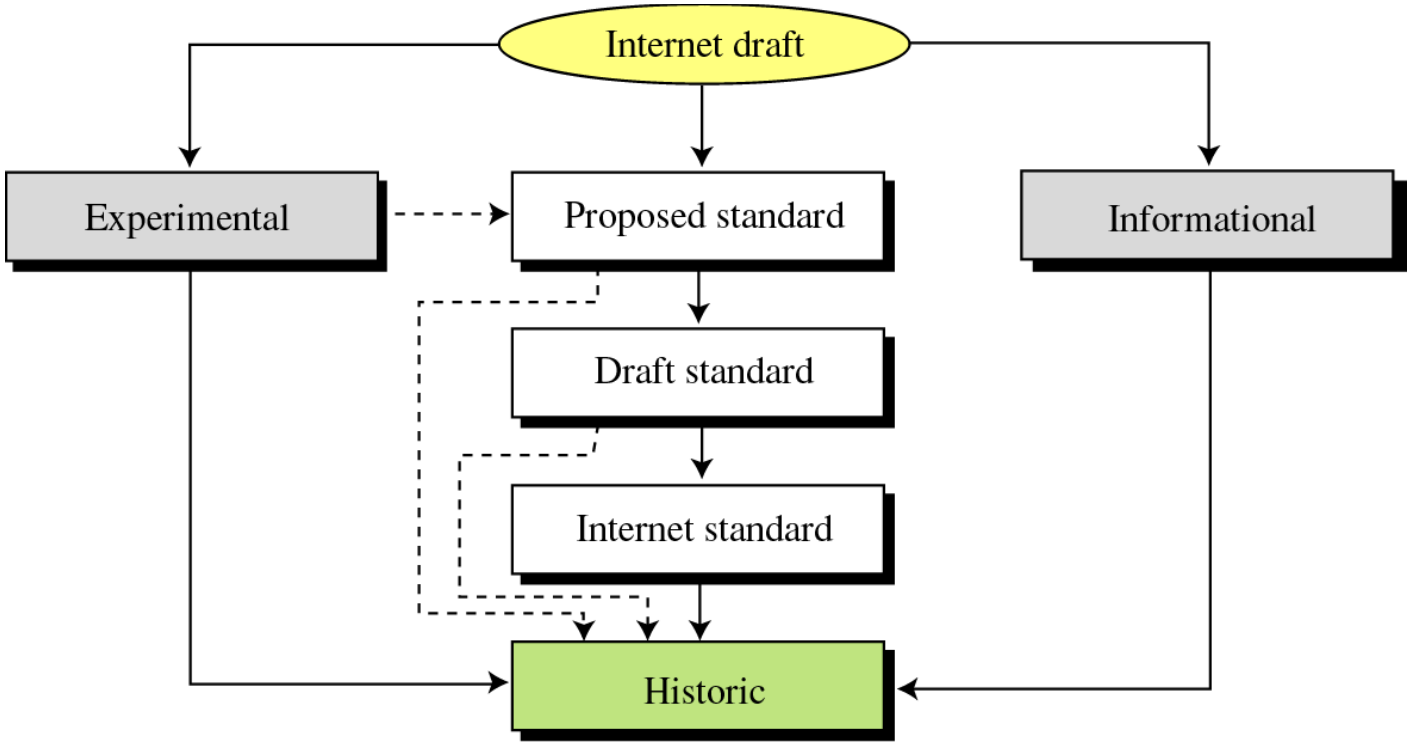
Pervasive Internet
Wireless Sensor Networks

- Small, ligth, cheap network nodes able to:
  - Measure
  - Communicate
  - Act
- Applications
  - Embedded computing: e.g. home appliances
  - wearable computing: e.g. mp3 players, PDAs
  - Ambient intelligence: e.g. sensors/actuators



Internet Standardization

- Internet Standards are public documents called RFC (*Request For Comments*)
- The *Internet Engineering Task Force* (IETF) coordinates the RFC pubblication

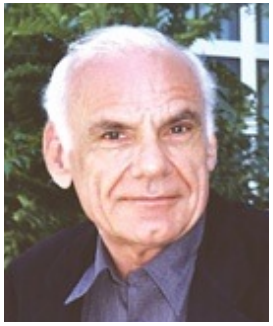


How to Get a Standard

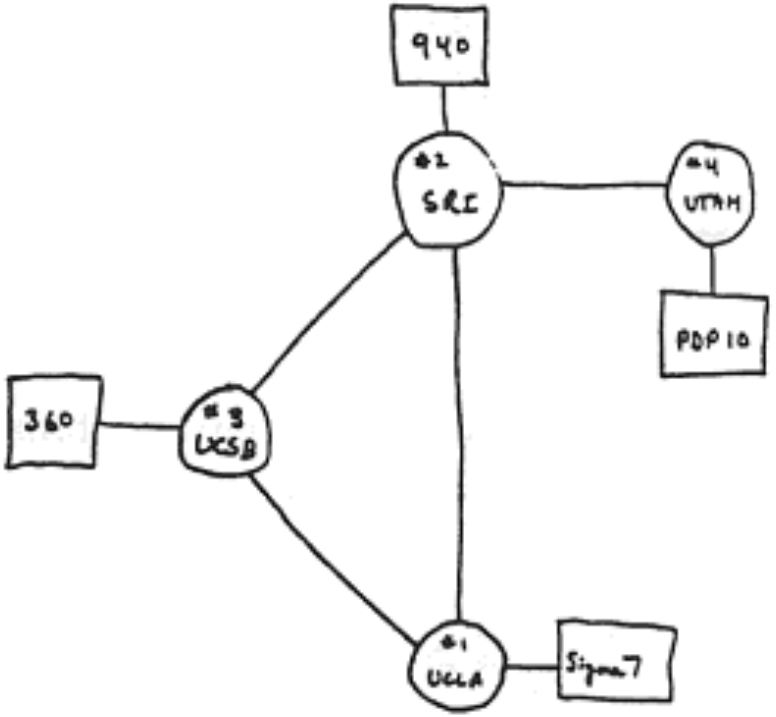
Internet Evolution

Internet Birth Days: The ’60s

- **1961**: Kleinrock – applies queuing theory to packet switched networks proving its efficiency
- **1967**: Lawrence Roberts designs ARPAnet (Advanced Research Projects Agency)
- **1969**: first ARPAnet node IMP (Interface Message Processor) deployed at UCLA



A Bit of History

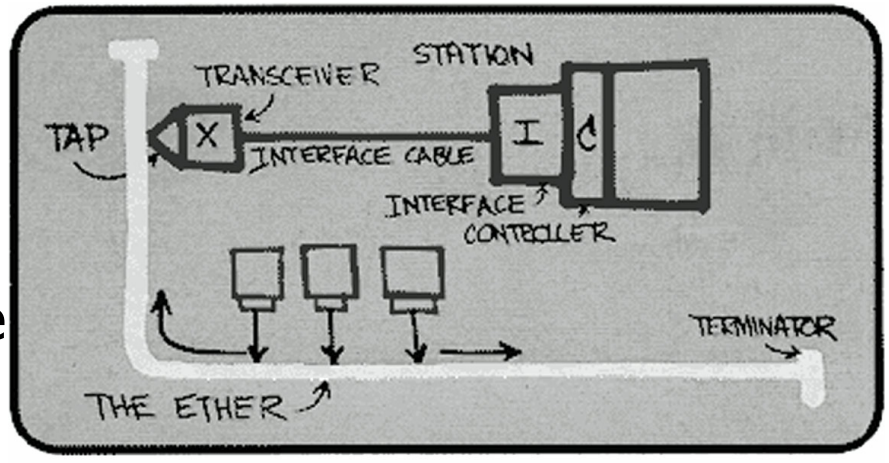


THE ARPA NETWORK

DEC 1969

Internet Birth Days: The ’70s

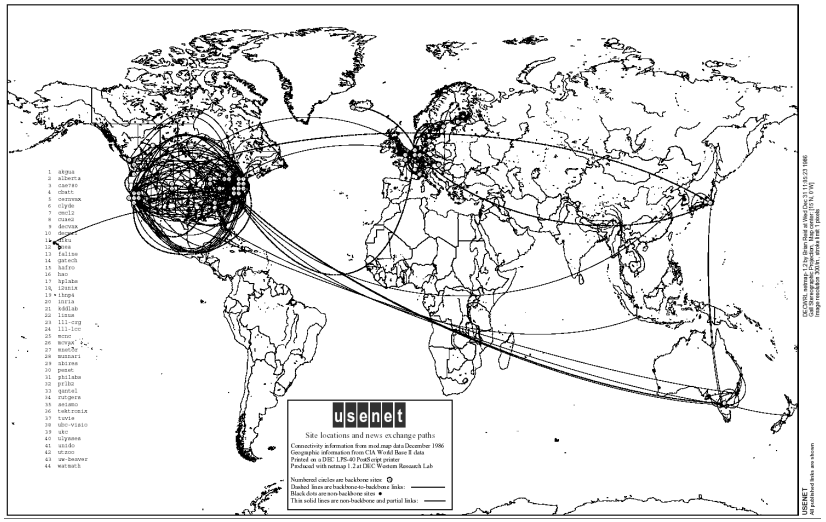
- **1972:**
  - NCP (Network Control Protocol) first internet protocol
  - First email application
  - ARPAnet has 15 nodes
- **1970:**
  - ALOHAnet packet switched network at Univ. of Hawaii
- **1974:**
  - Cerf and Kahn –study the internetworking principles (Network of Networks)
- **1976:**
  - Ethernet birth at Xerox
- **1979:**
  - ARPAnet has 200 nodes



Internet Birth Days: The ’80s

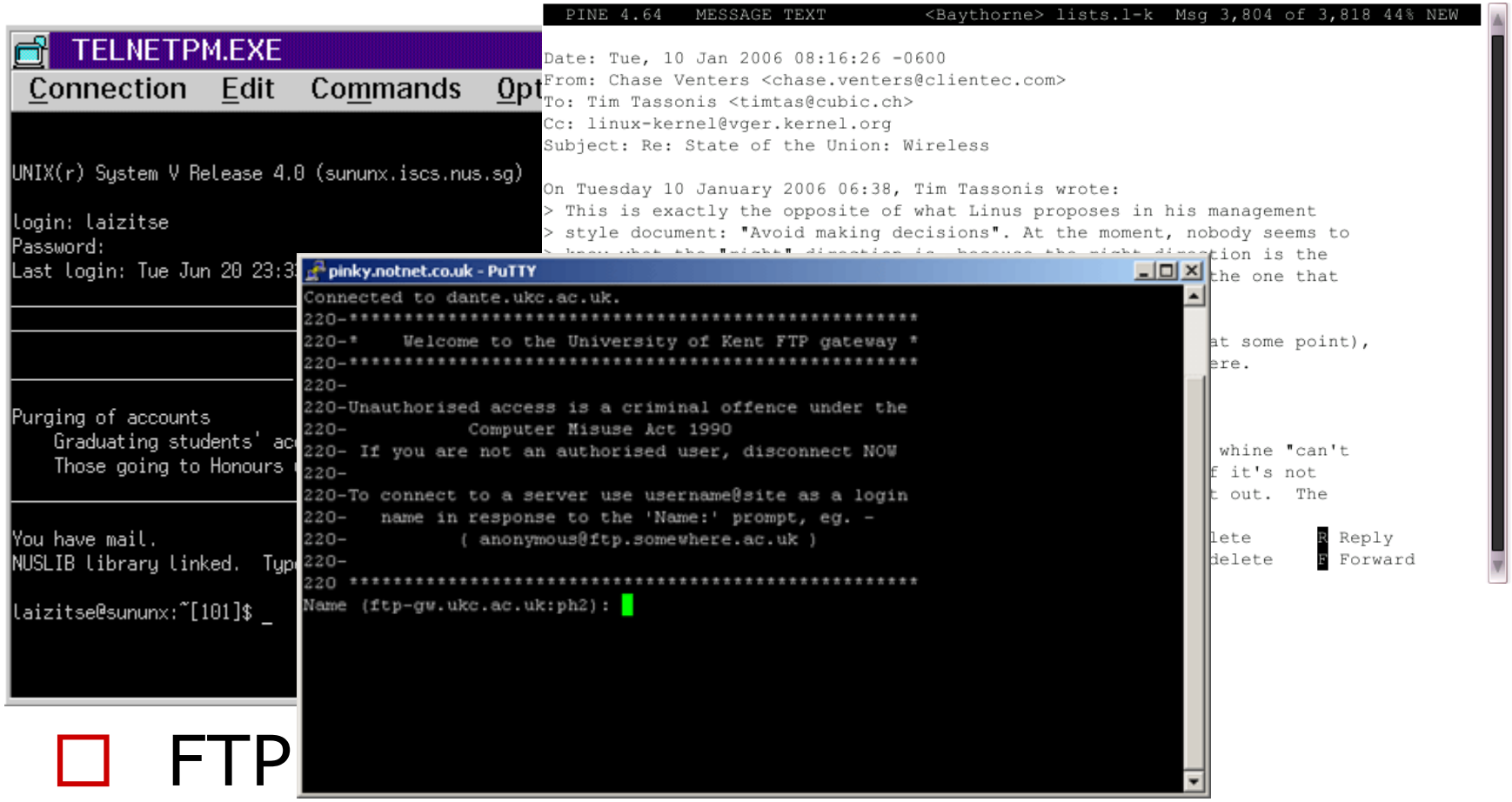
- **1982**: SMTP protocol definition
- **1983**: TCP/IP replace NCP
- **1983**: DNS definition
- **1985**: FTP definition
- **1988**: TCP congestion control

- New national nets: Csnet, BITnet, NSFnet, Minitel
- 100.000 hosts worldwide



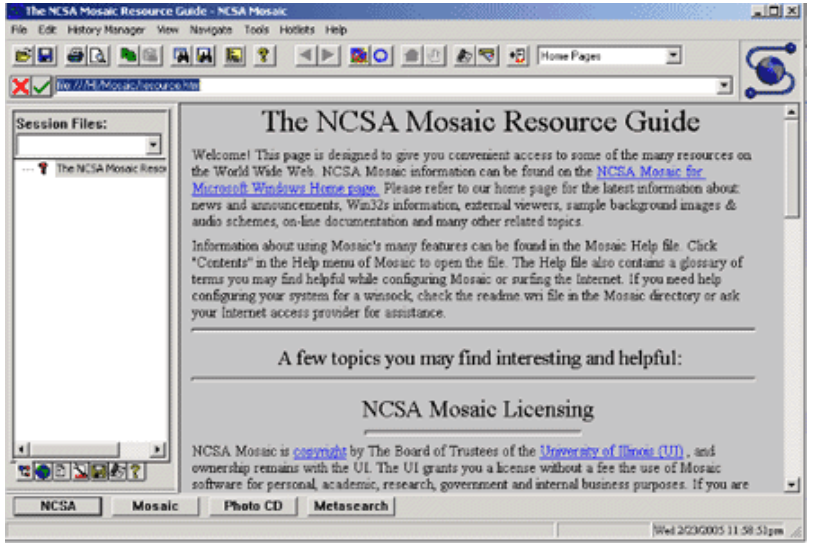
The First Applications

- Telnet
- Email
- FTP



Internet Birth Days: The ’90s

- **1990**: ARPAnet discontinued
- **1991**: NSFnet to be used for commercial purposes also
- Early 90s: Tim Berners-Lee invents the web (Cern, Geneve)
- **1994**: Mosaic, and Netscape
- Late 90s : Web is invaded by commercials

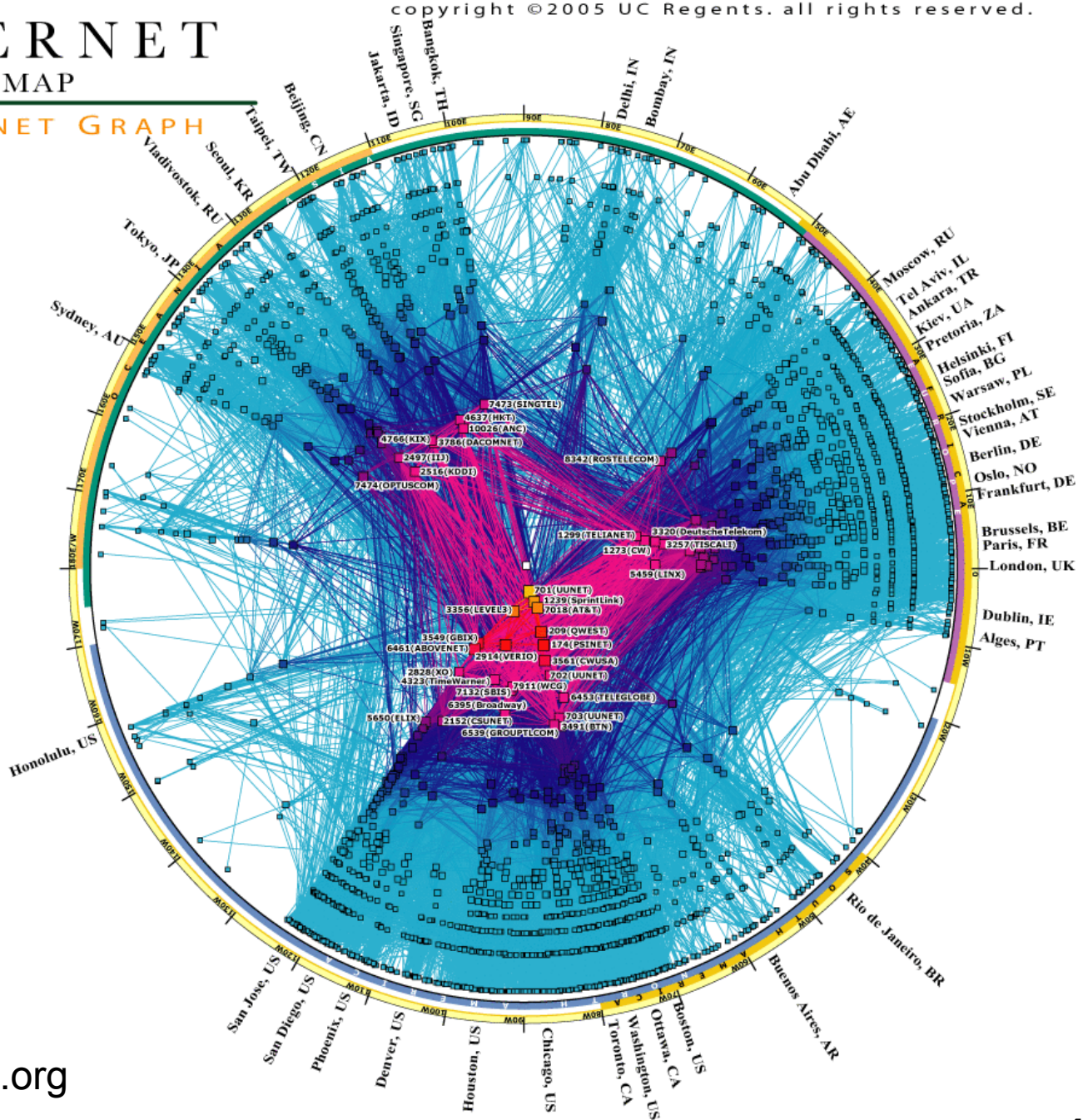


Internet Today

2000 – today:

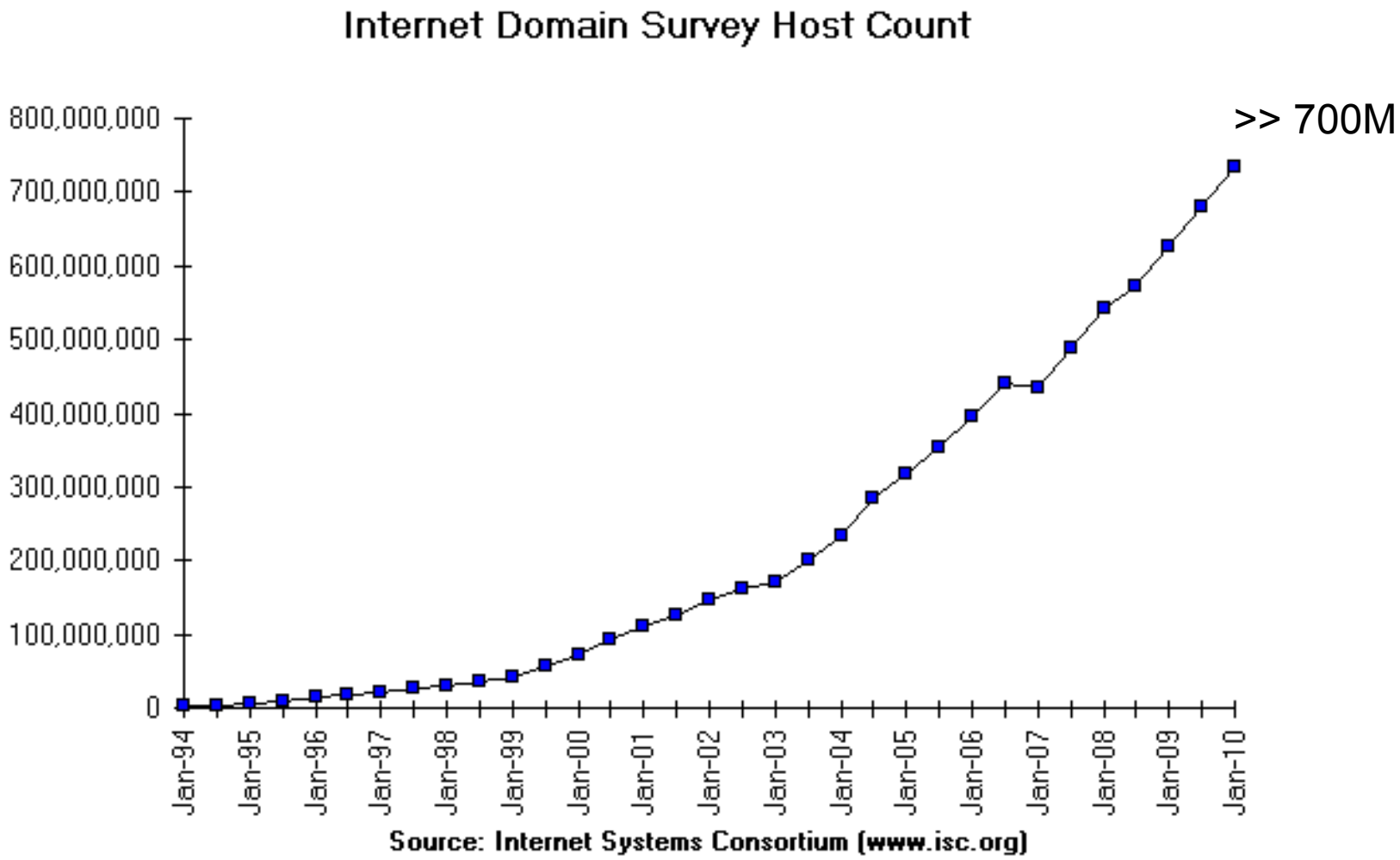
- New “killer applications”: messaging, file sharing, IP Telephony
- Network security
- Hundreds of Millions of host, Billions of users
- Fastest Backbones [Gb/s]

IPv4 INTERNET
TOPOLOGY MAP
AS-level INTERNET GRAPH

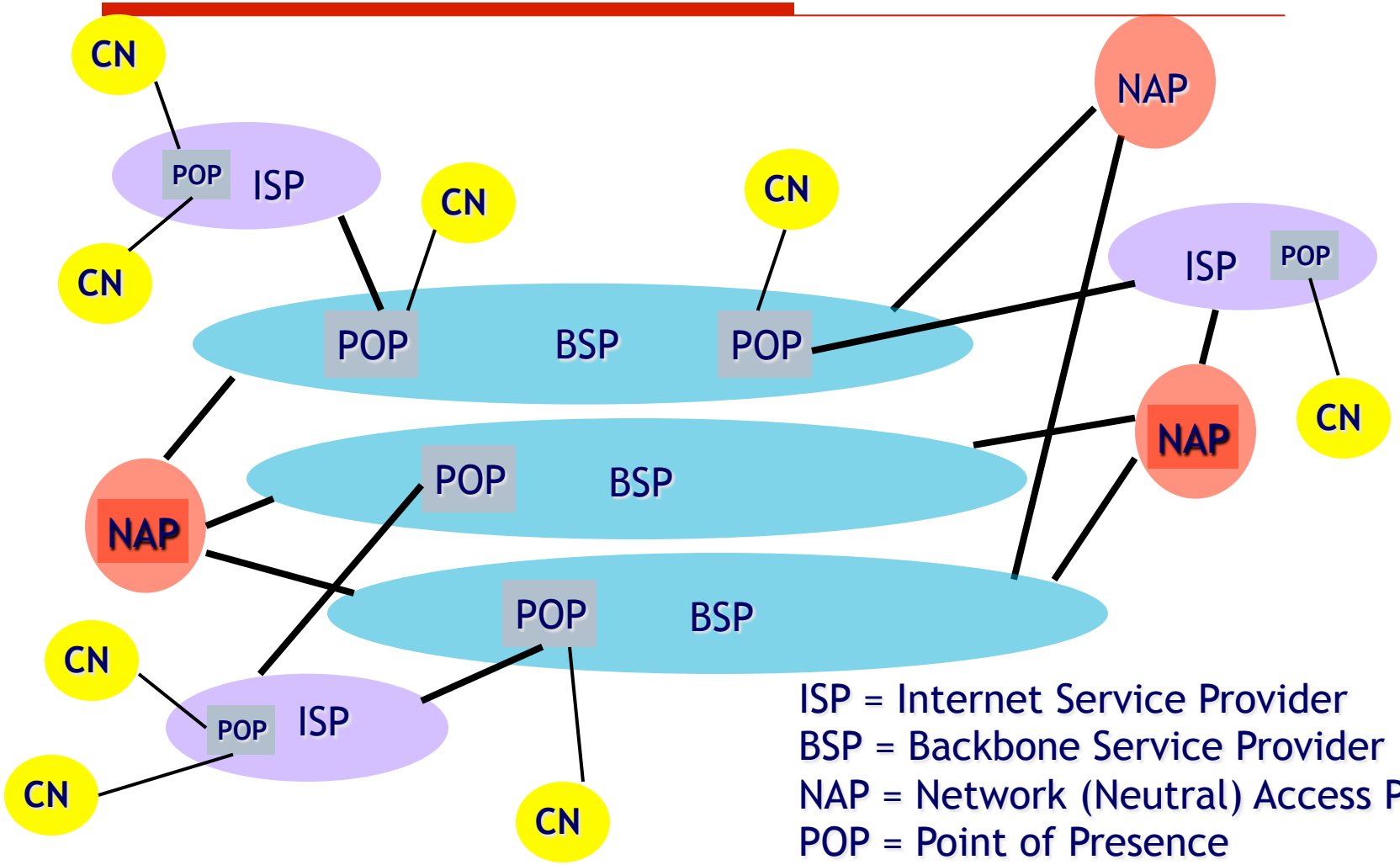


http://www.caida.org

Internet Growth

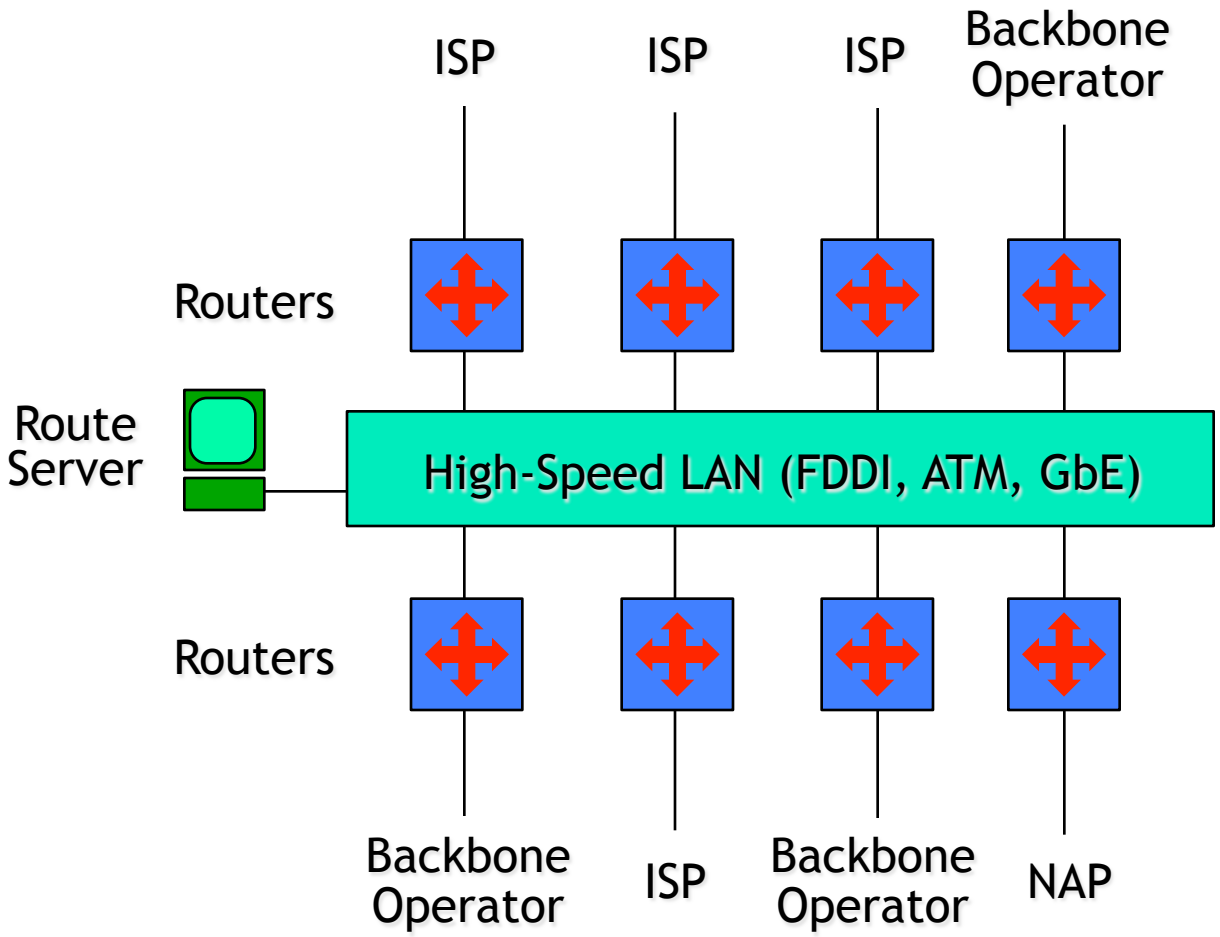


Internet Architecture



ISP = Internet Service Provider
BSP = Backbone Service Provider
NAP = Network (Neutral) Access Point
POP = Point of Presence
CN = Customer Network

NAP Architecture



Examples:

www.mix-it.net

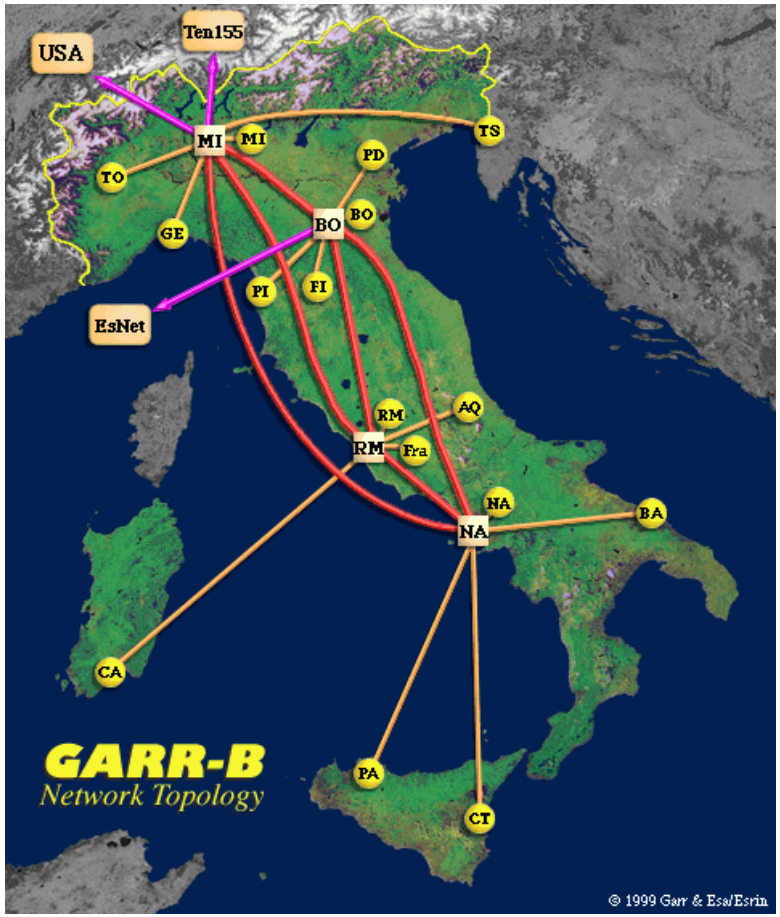
Milan Internet eXchange

www.namex.it

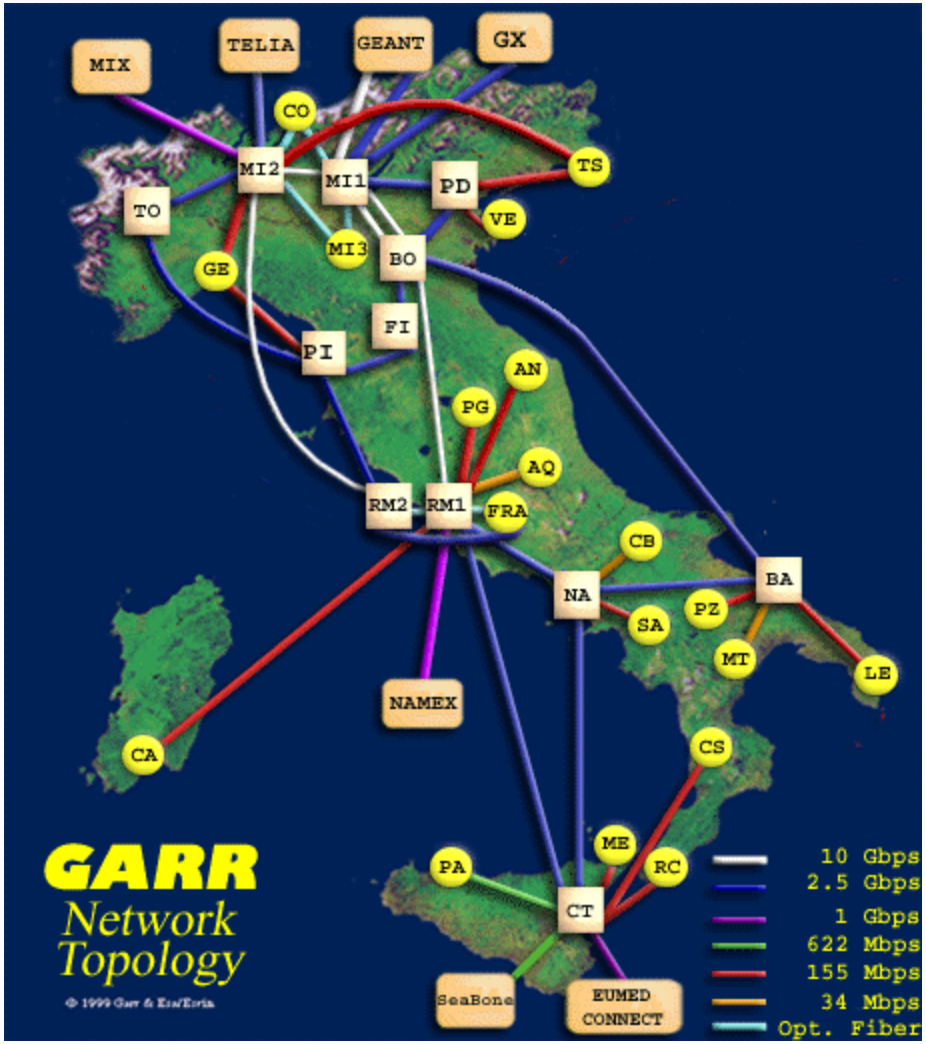
Nautilus Mediterranean Exchange Point

www.topix.it

National ISP: An Italian Example

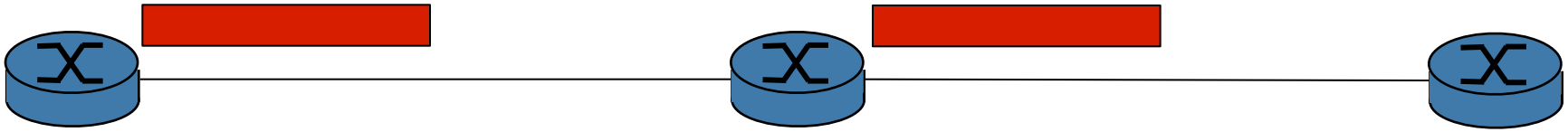


1999



2005

Store and forward



T_0=transmission start

T_1=transmission end

T_2=first bit arrival

T_3=last bit arrival

Transmission Time:

$T=T_1-T_0=L/R$ **L**=packet length [bit]

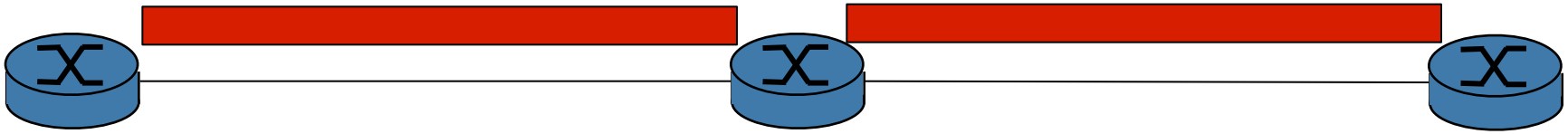
R=transmission rate [bit/s]

Propagation Time:

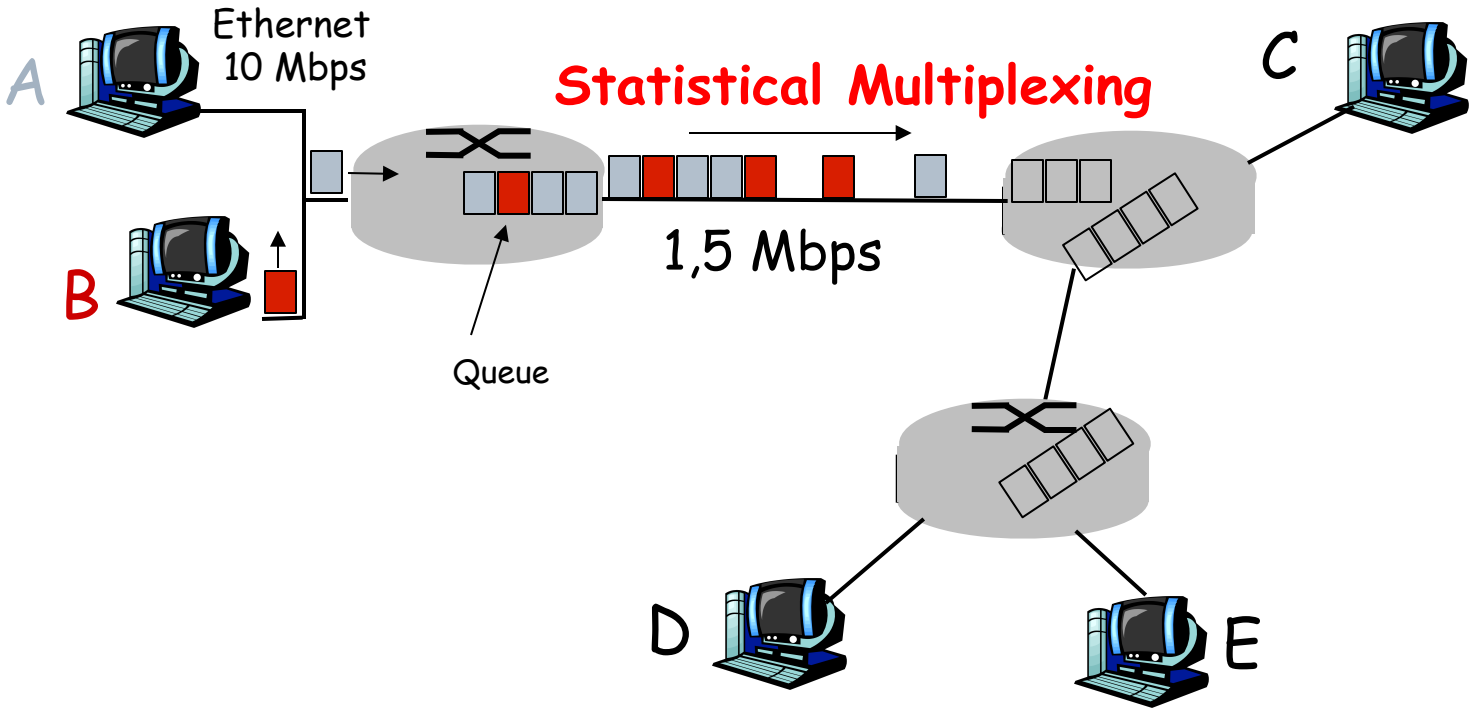
$\tau=T_2-T_0=l/C$ **l**=link length [m]

C=wave speed [m/s]

Store and forward



Statistical Multiplexing

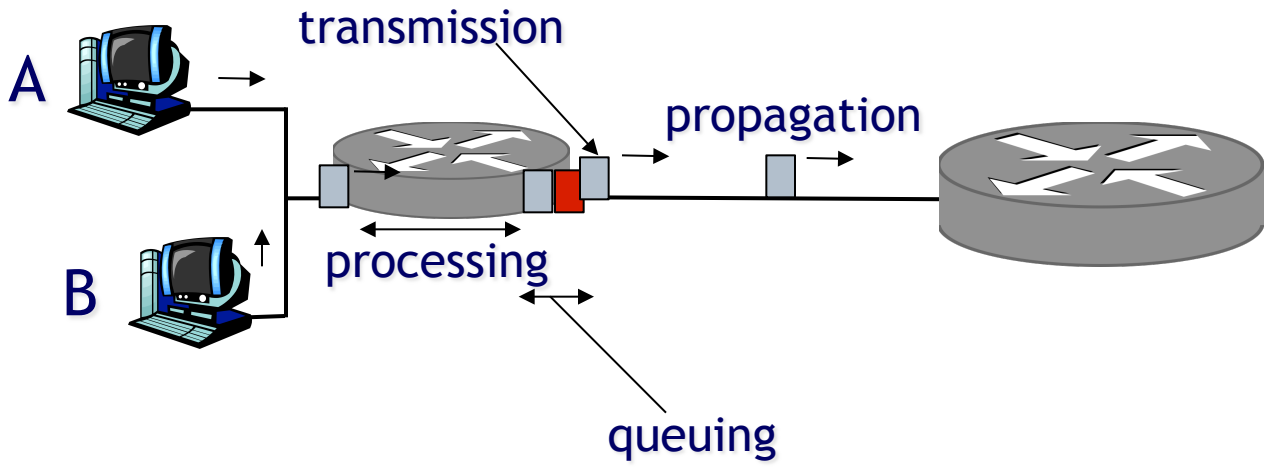


Packet transmission does not follow a fixed sequencing but resources are statistically shared ➡ ***statistical multiplexing***.

Packet (or Nodal) Delay

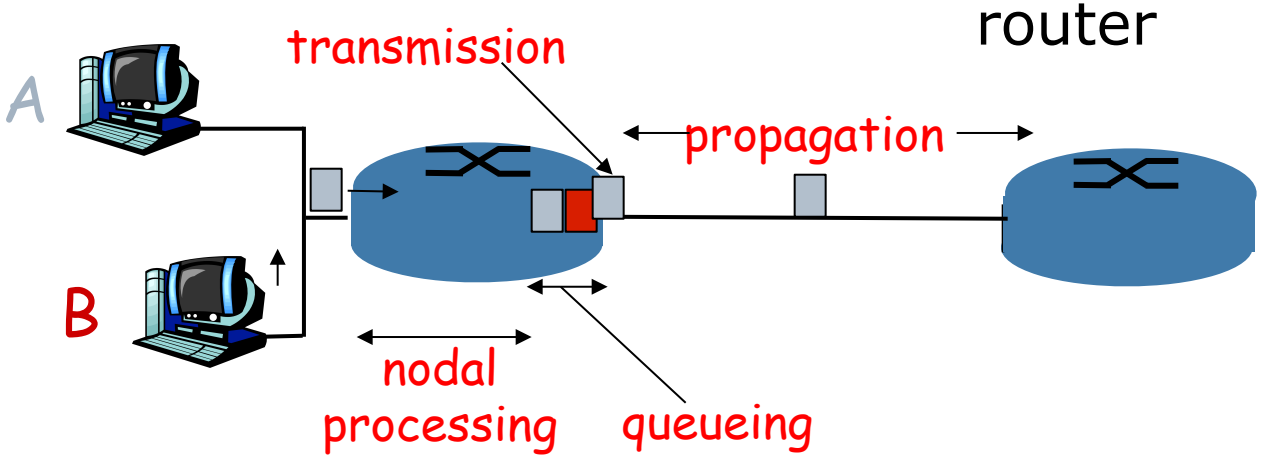
Each packet experiments a variable delay due to:

- Processing
- Queuing
- Transmission
- Propagation



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



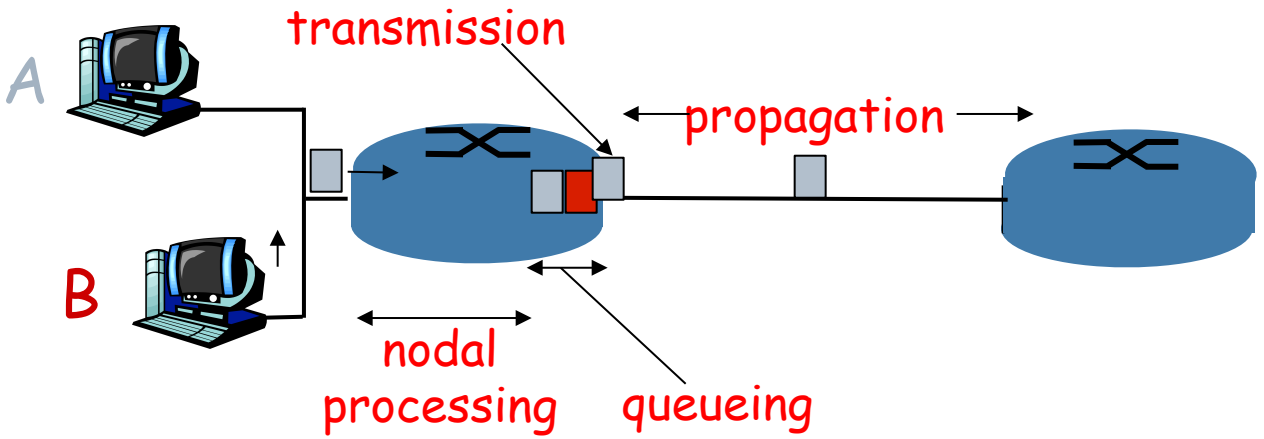
Delay in packet-switched networks

3. Transmission delay:

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

4. Propagation delay:

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

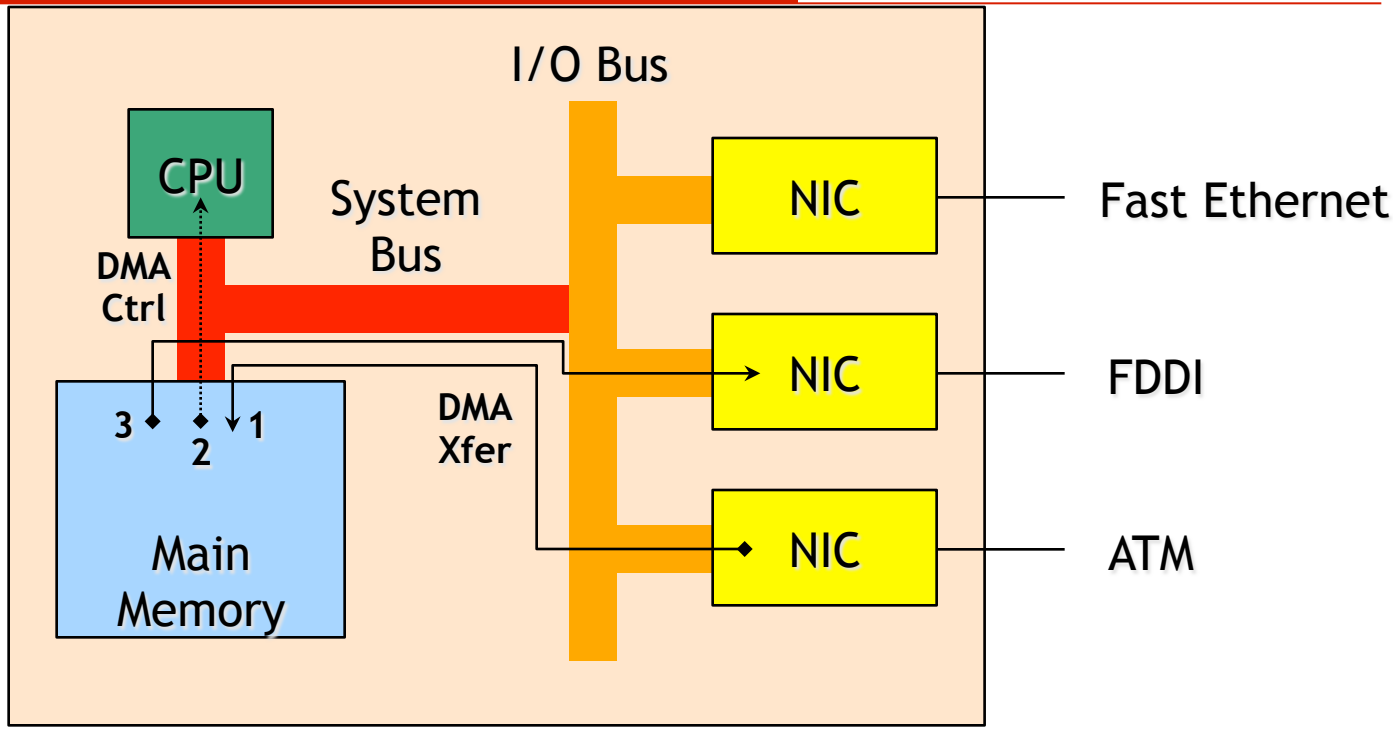


Nodal delay

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

- 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

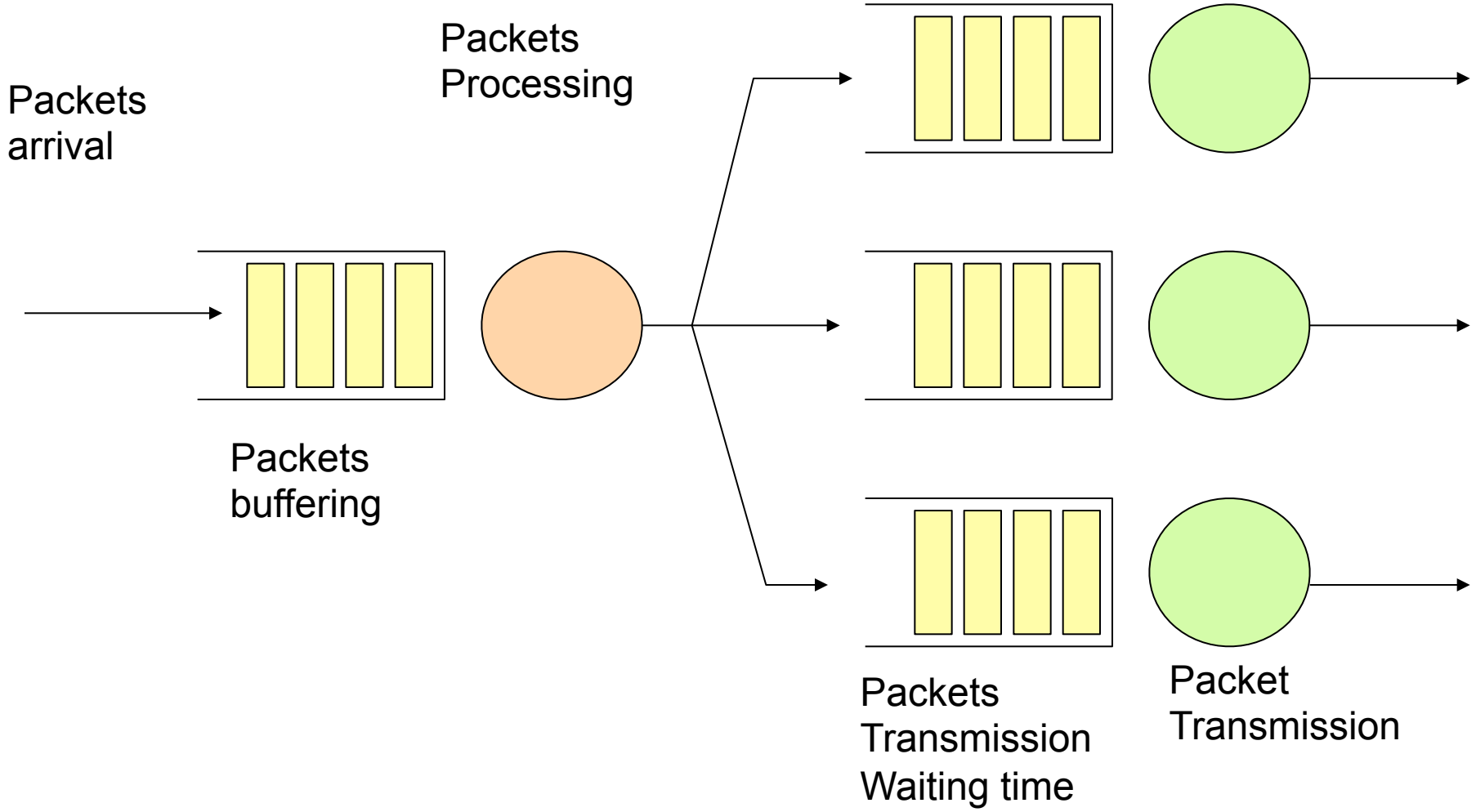
Node Architecture



1. Packet input
2. Header processing
   - Routing table lookup
   - DMA transaction
3. Packet output

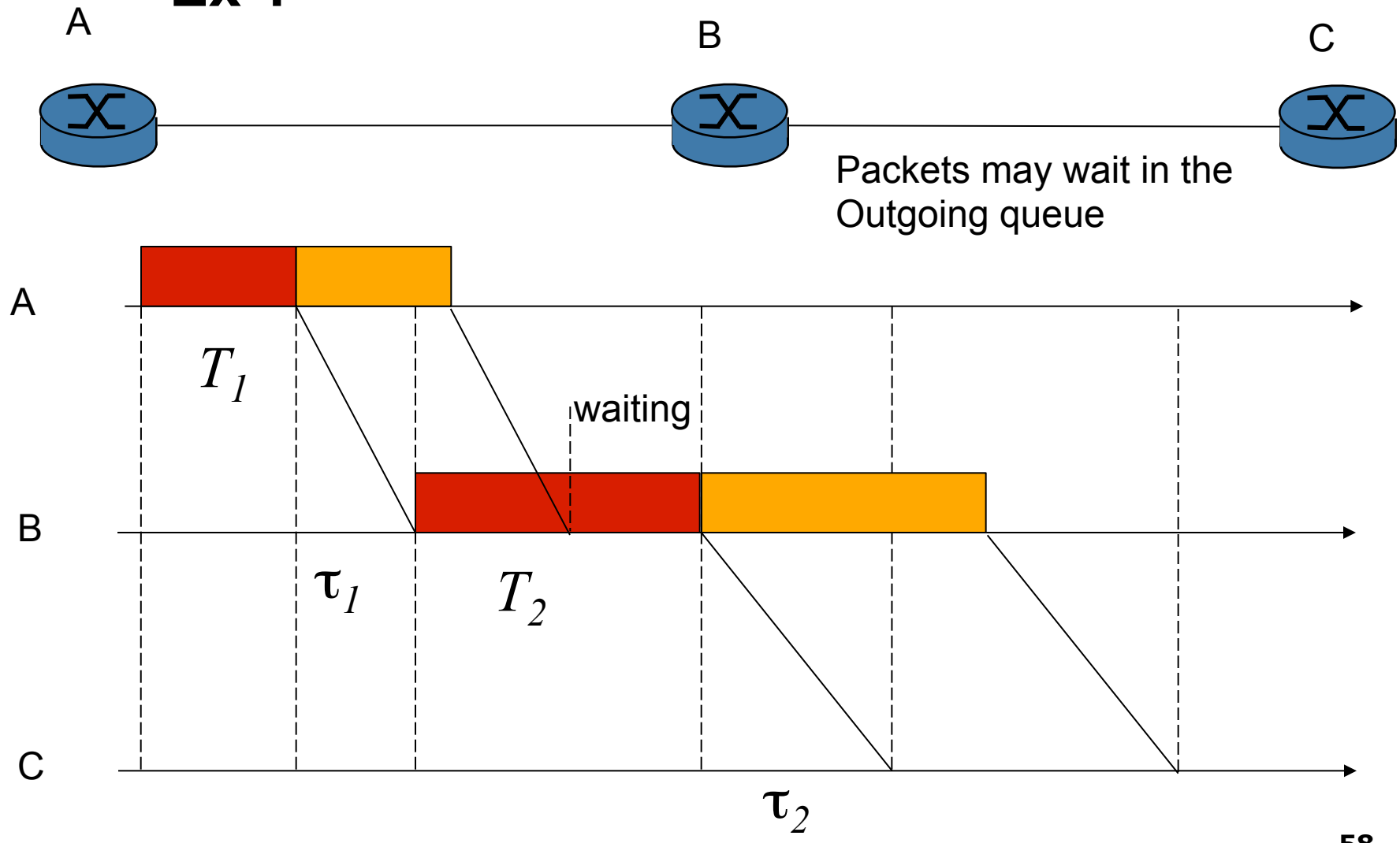
NIC = Network Interface Controller
DMA = Direct Memory Access

Node Model


Packets
arrival
Packets
Processing
Packets
buffering
Packets
Transmission
Waiting time
Packet
Transmission

Queuing Delay

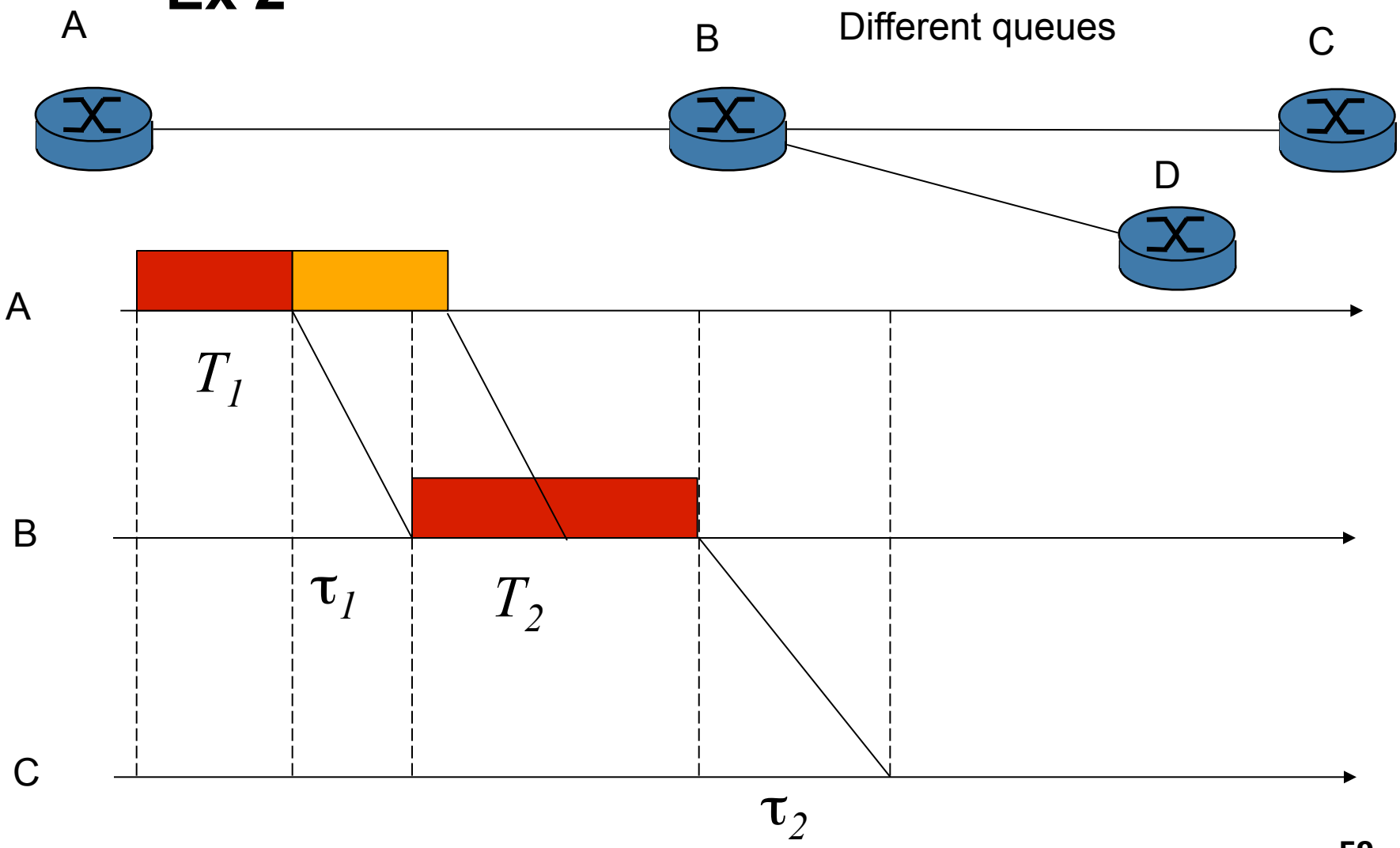
Ex 1



Queuing Delay

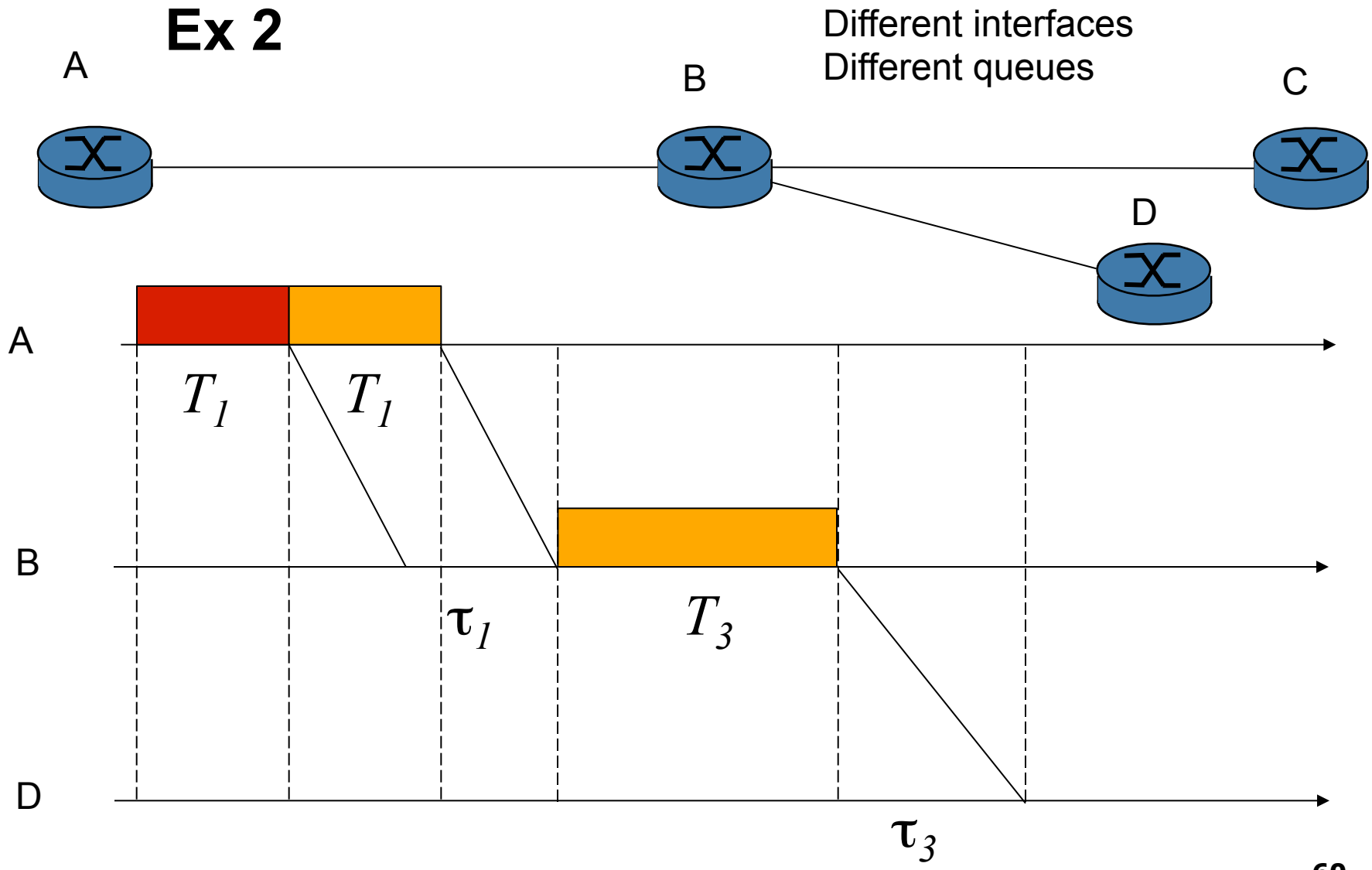
Ex 2

Different interfaces
Different queues



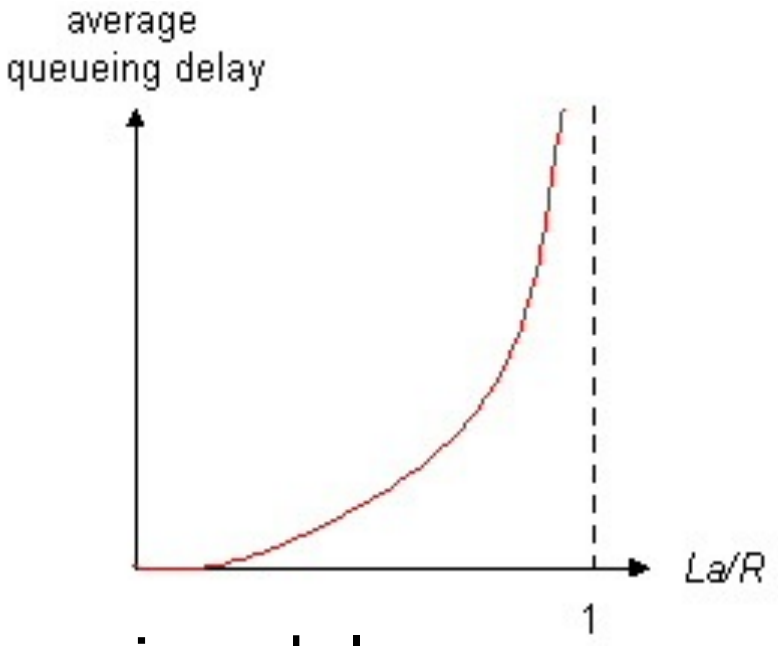
Queuing Delay

Ex 2



Queueing delay

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

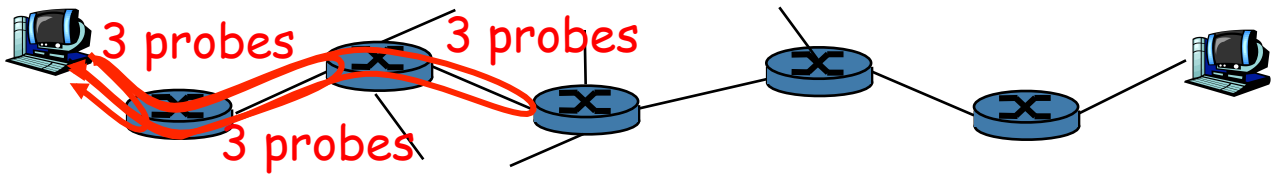


traffic intensity = La/R

- La/R ~ 0: average queueing delay small
- La/R -> 1: delays become infinite

"Real" Internet delays and routes

- **`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 and routes

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


```
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)

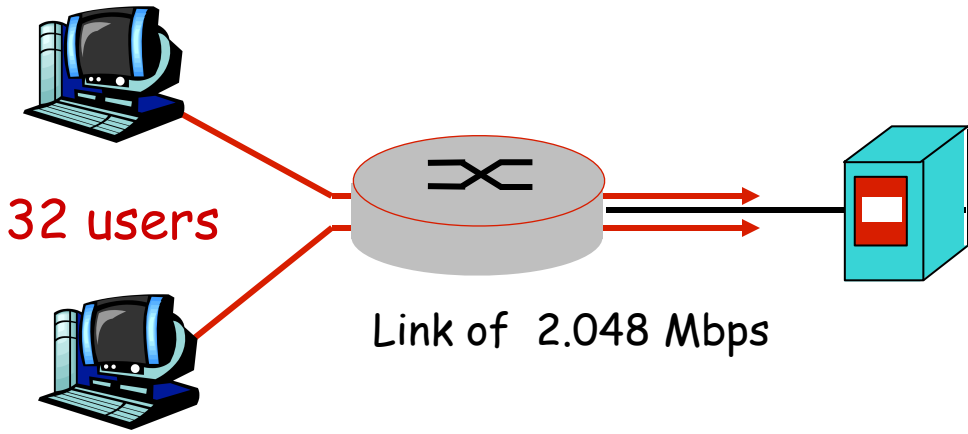
Packet loss

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

Packet vs Circuit Switching

Packet switching provides lower transfer delays!

- 1 link of 2.048 Mpbs
- Each user:
  - Calls for 50KB web pages every 62.5s on average
- Circuit switching:
  - 1 64 kbps channel for each user
  - Average page Transfer delay: 6.25s

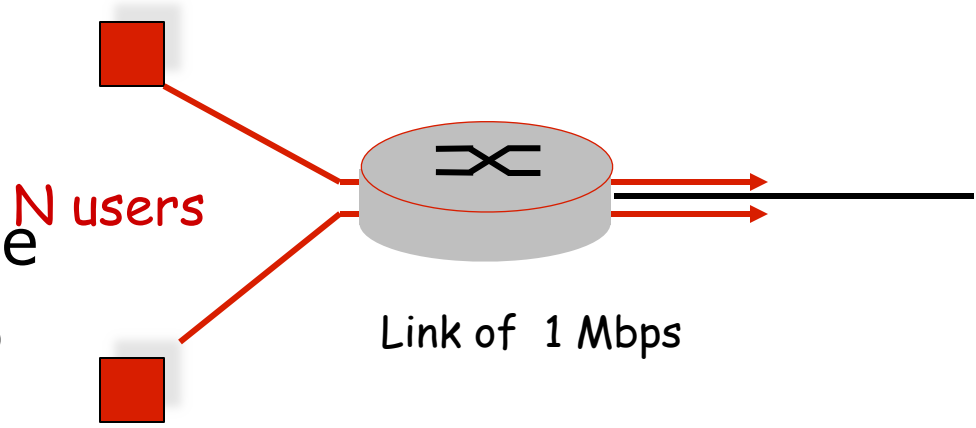


- Packet switching:
  - Average page transfer delay: 0.22s

Packet vs Circuit Switching

Packet switching supports greater number of users!

- 1 link of 1 Mpbs
- Each user:
  - 100 kpbs when active
  - Activity cycle = 10%
- Circuit switching:
  - 10 supported users



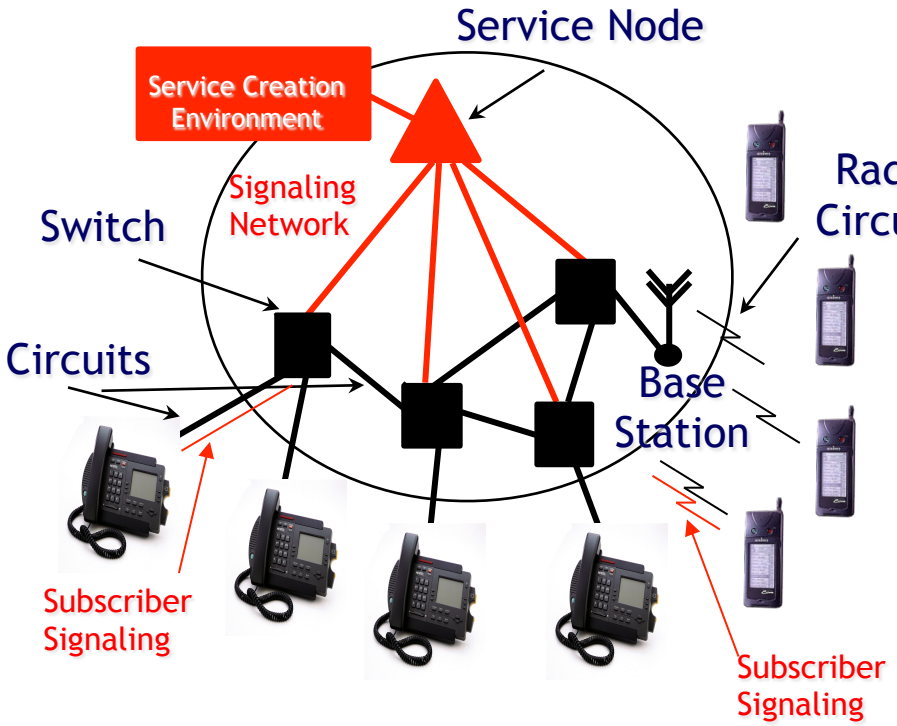
- Packet switching:
  - with 35 users, the probability of having more than 10 active users simultaneously is less than 0,0004

Packet Switching: PROs and CONs

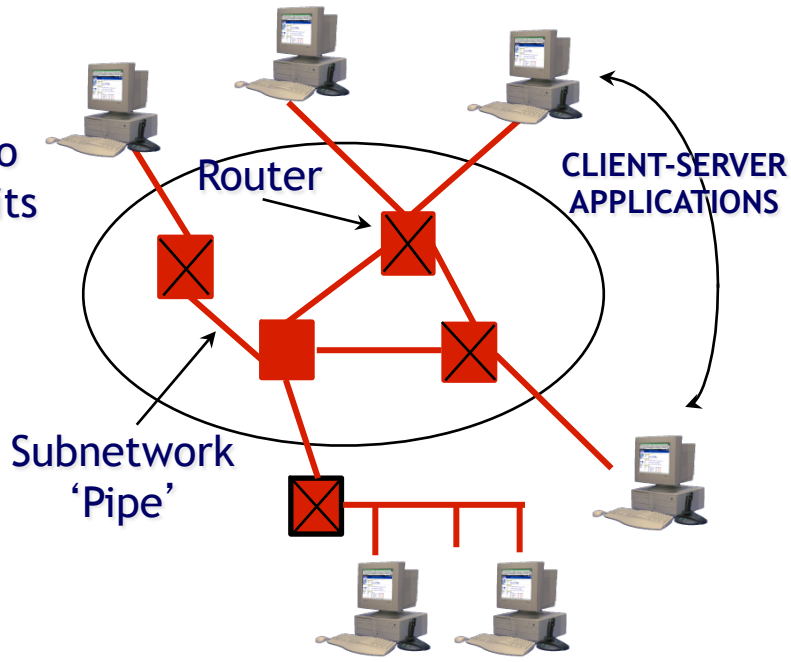
- Very simple to implement (fewer signalling)
- Very well suited for bursty traffic
  - Resource sharing
- Delay and Losses
  - Protocols for reliable data transfer are needed (congestion control, loss recovery)

PSTN vs Internet

Clever Networks



Dumb Network



Dumb Terminals

Clever Terminals