POLYTECH
PARIS-SUD

Réseaux

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Le Professeur

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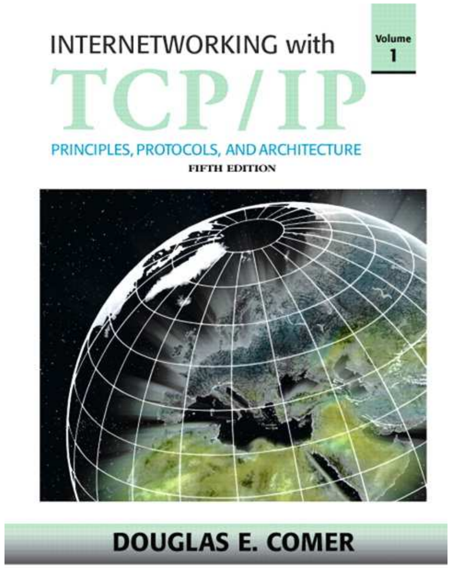
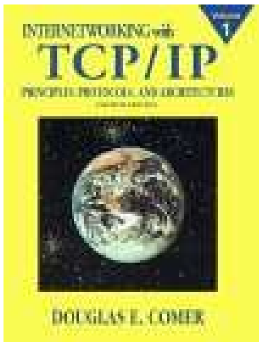
Matériel Didactique

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





- ✓ **5ème Edition**
- ✓ **… mais aussi les éditions précédentes (4ème, par exemple)**

Matériel Didactique

- **Transparents**
- **Autre matériel signalé durant le cours et disponible sur la page Web du cours**
- **Internet (RFCs …)**

- **Page Web du cours :**

http://www.lri.fr/~fmartignon/reseaux.html

ou, alternativement :

http://129.175.15.11/~fmartignon/reseaux.html

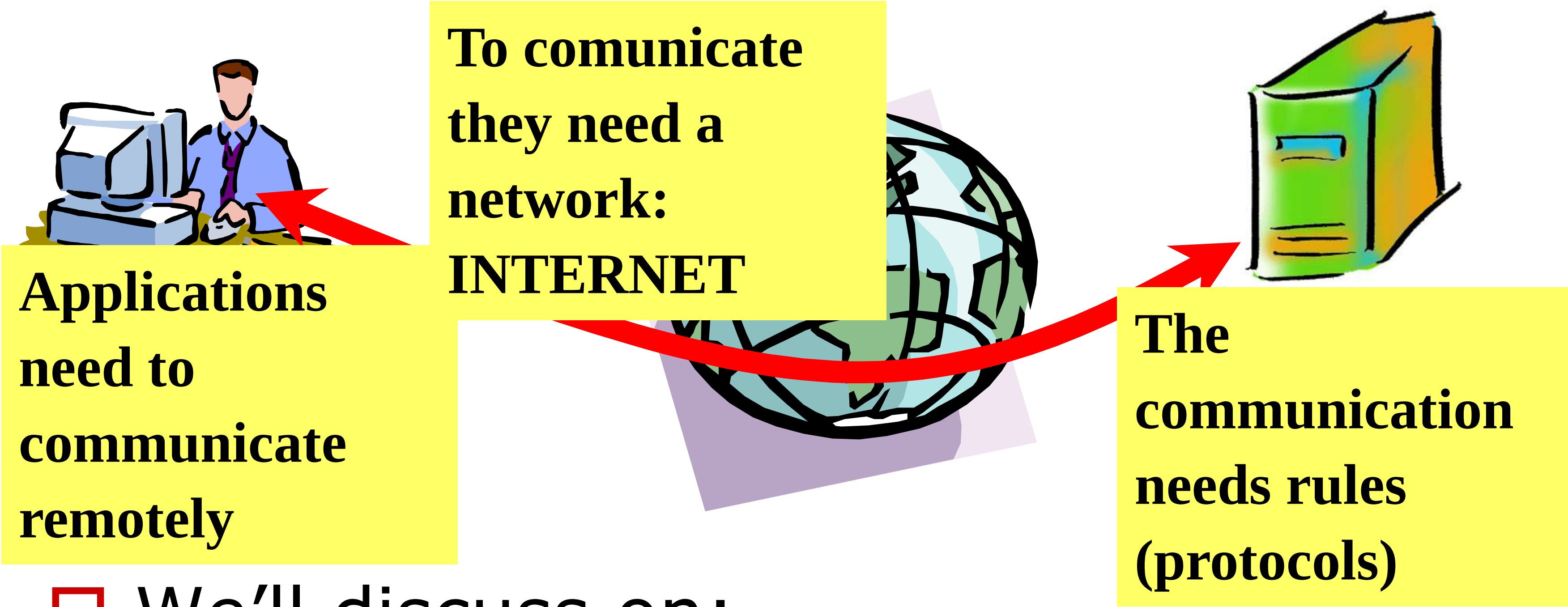
Target

- 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*

Course Agenda

- Internet Evolution and Organization
- Access Technologies
  - LAN protocols and devices
  - Multiplexing / Multiple Access techniques
    - Example: Cellular (Mobile) Networks
- The Network Layer (Internet Protocol, IP)
  - Network Addresses
  - Forwarding and Routing Policies
  - Protocol Rules
  - Control Layer Protocols (ARP, RARP, ICMP)
  - Routing

..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

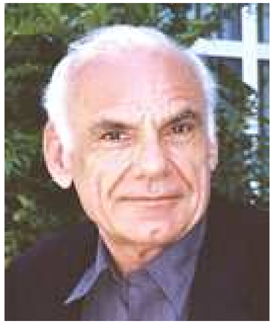
...Course Agenda

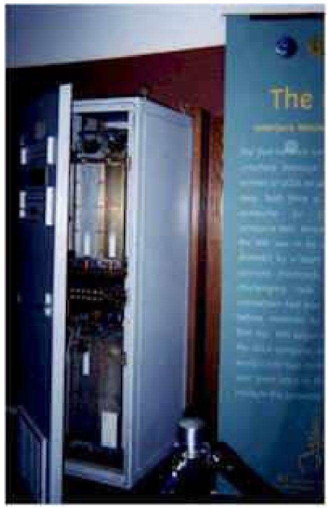
- Intranetting
  - *Network Address Translation* (NAT)
  - Virtual Private Networks (VPN)
- Internet Evolutions
  - IPv6, MPLS
- Wireless networks
- Voice Over IP

Internet Evolution

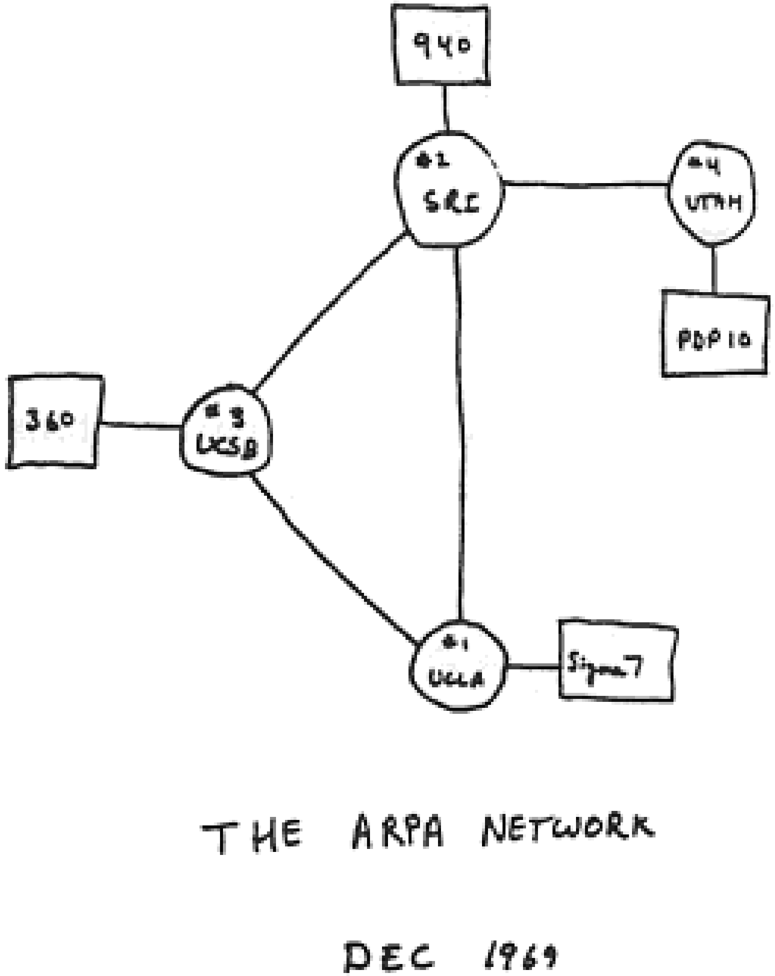
Internet Birth Days: The ’60s

- **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



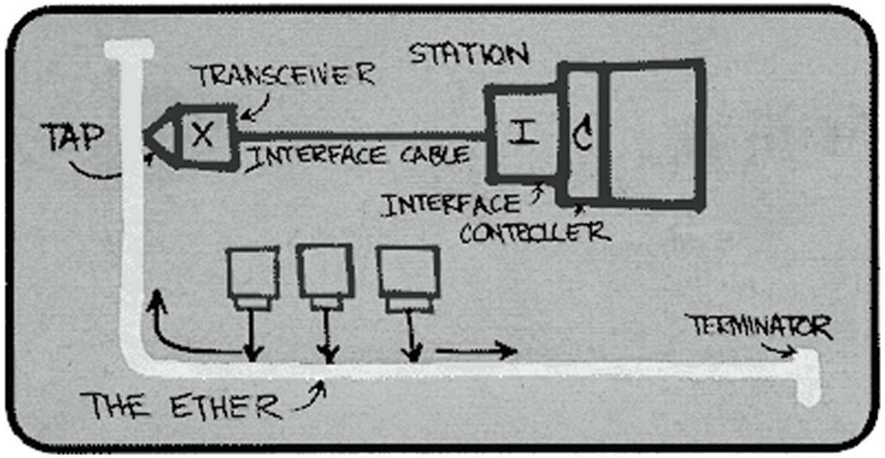


A Bit of History



Internet Birth Days: The ’70s

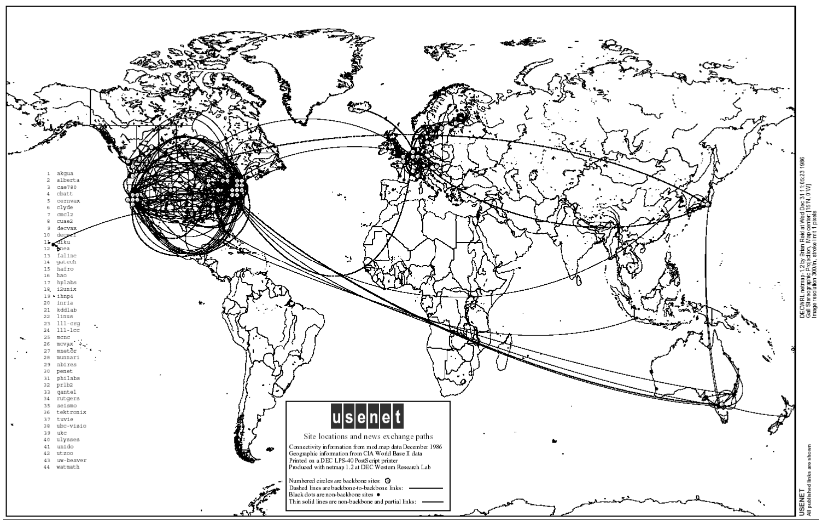
- **1972:**
  - NCP (Network Control Protocol) first internet protocol
  - First email application
  - ARPAnet has 15 nodes
- **1970:**
  - ALOHAnet packet switched network at Univ. of Hawaii
- **1974:**
  - Cerf and Kahn –study the internetworking principles (Network of Networks)
- **1976:**
  - Ethernet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



Internet Birth Days: The ’80s

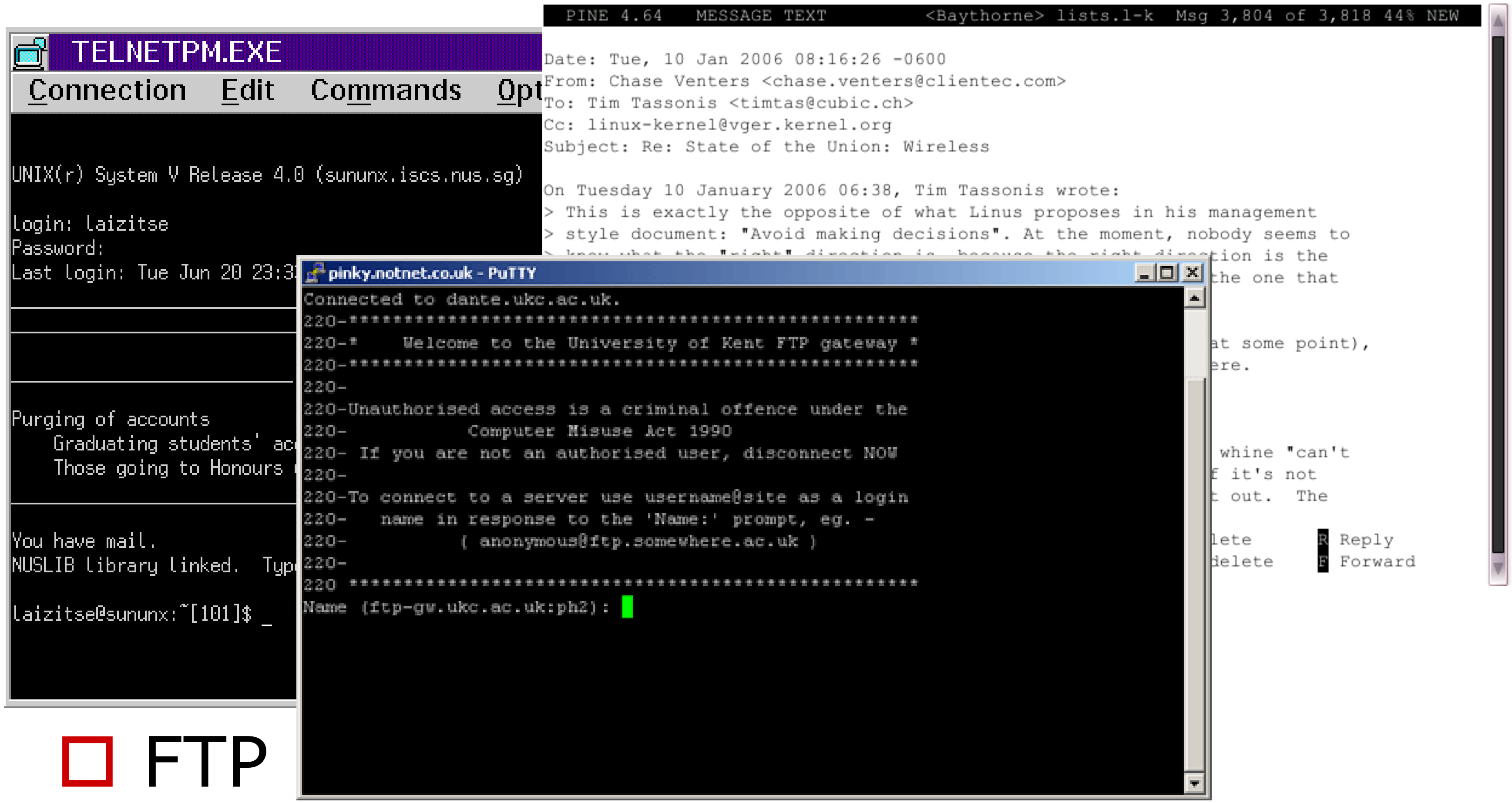
- **1982**: SMTP protocol definition
- **1983**: TCP/IP replace NCP
- **1983**: DNS definition
- **1985**: FTP definition
- **1988**: TCP *congestion control*

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



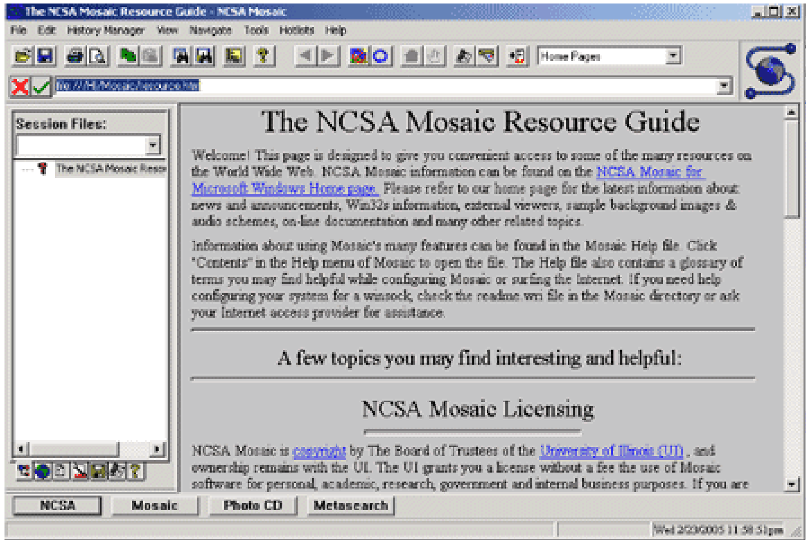
The First Applications

- Telnet
- Email
- FTP



Internet Birth Days: The ’90s

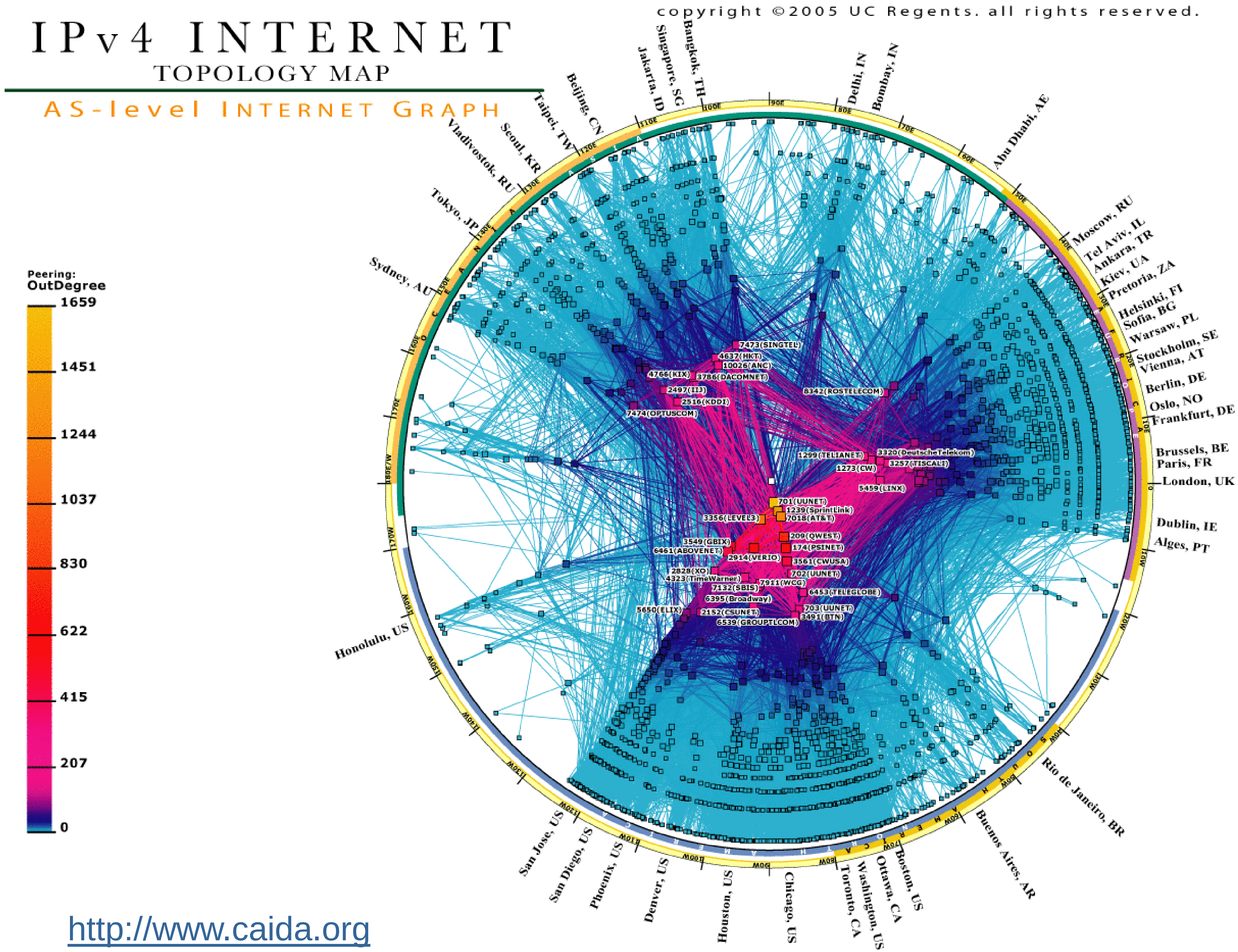
- **1990**: ARPAnet discontinued
- **1991**: NSFnet to be used for commercial purposes also
- Early 90s: Tim Berners-Lee invents the web (Cern, Geneve)
- **1994**: Mosaic, and Netscape
- Late 90s : Web is invaded by commercials



Internet Today

2000 – today:

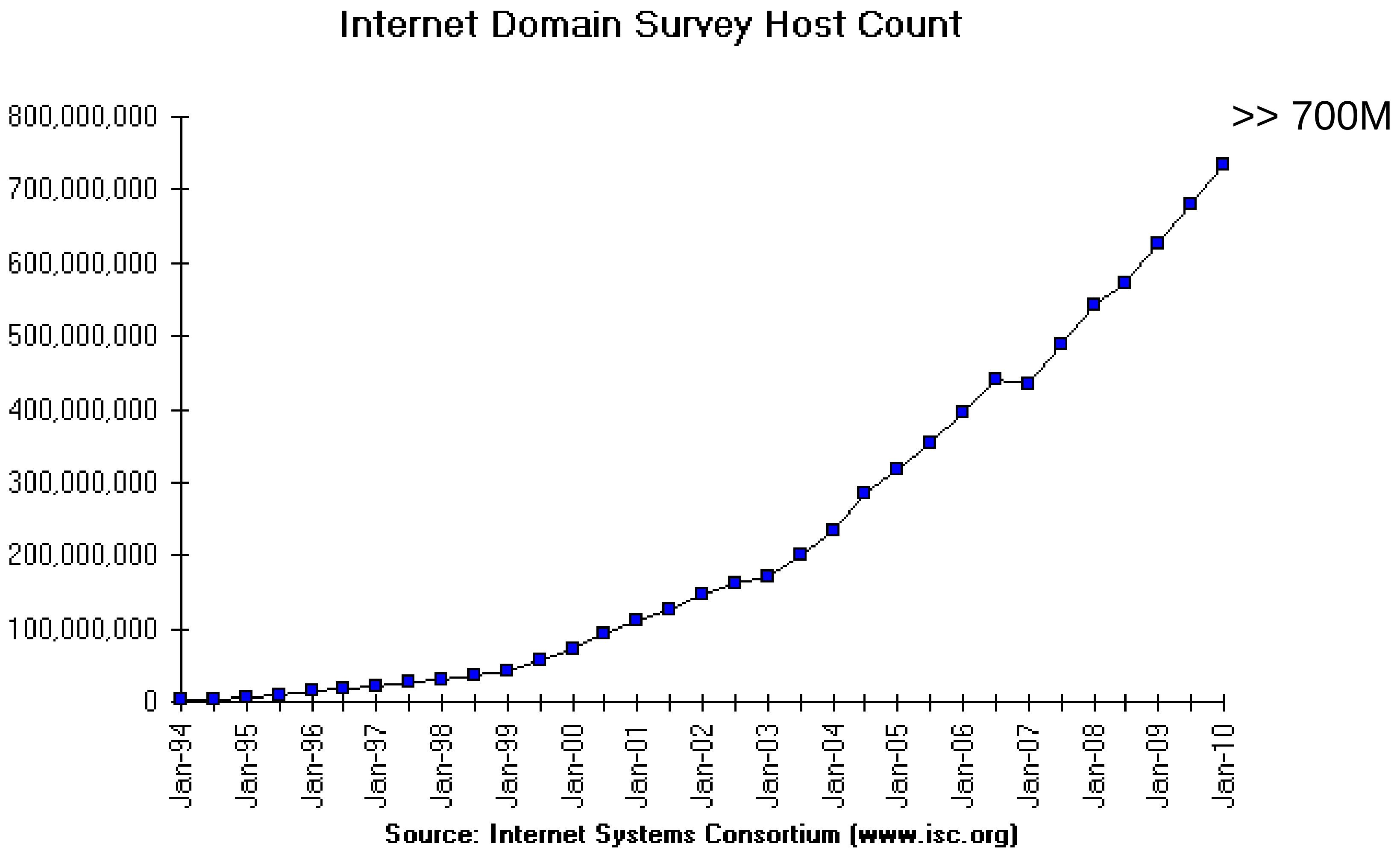
- New “killer applications”: social networking, messaging, file sharing, IP Telephony
- Network security
- Hundreds of Millions of hosts, Billions of users
- Fastest Backbones [Gb/s]



http://www.caida.org

The Cooperative Association for Internet Data Analysis

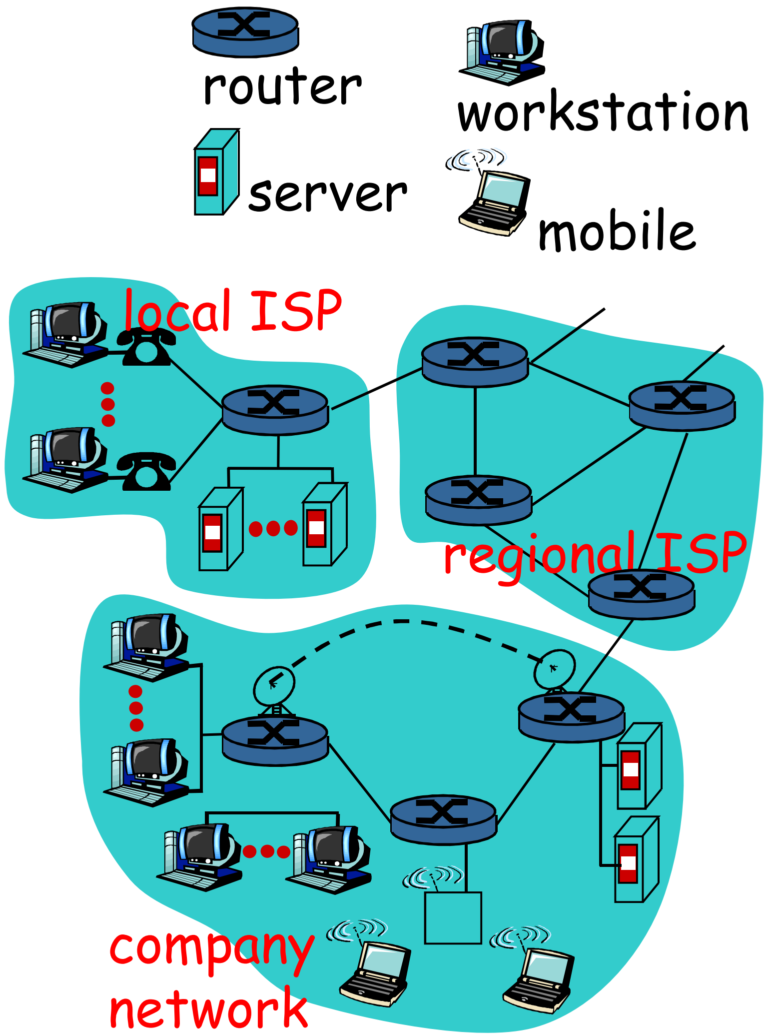
Internet Growth



What is The Net?

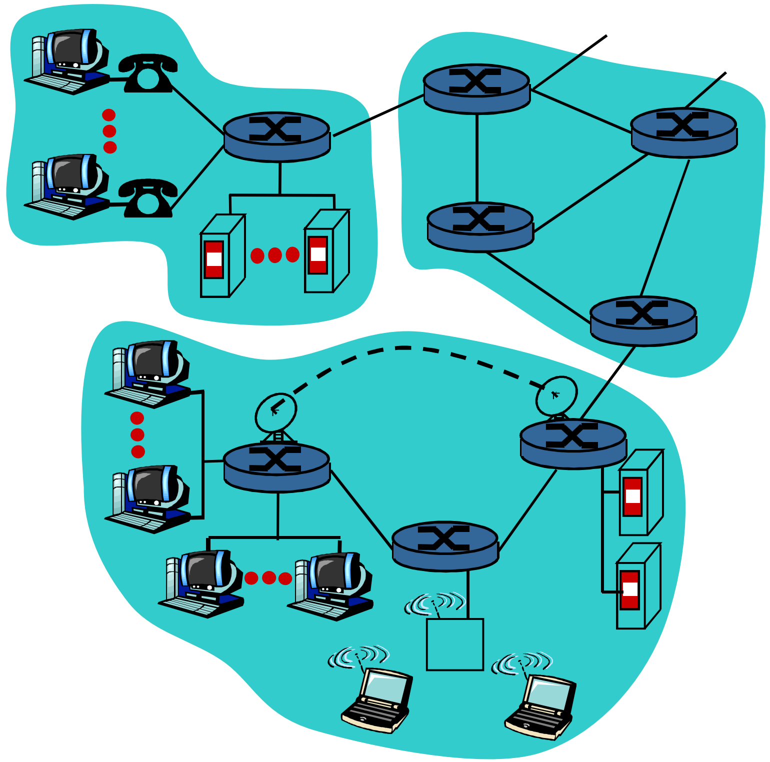
What's Internet?

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



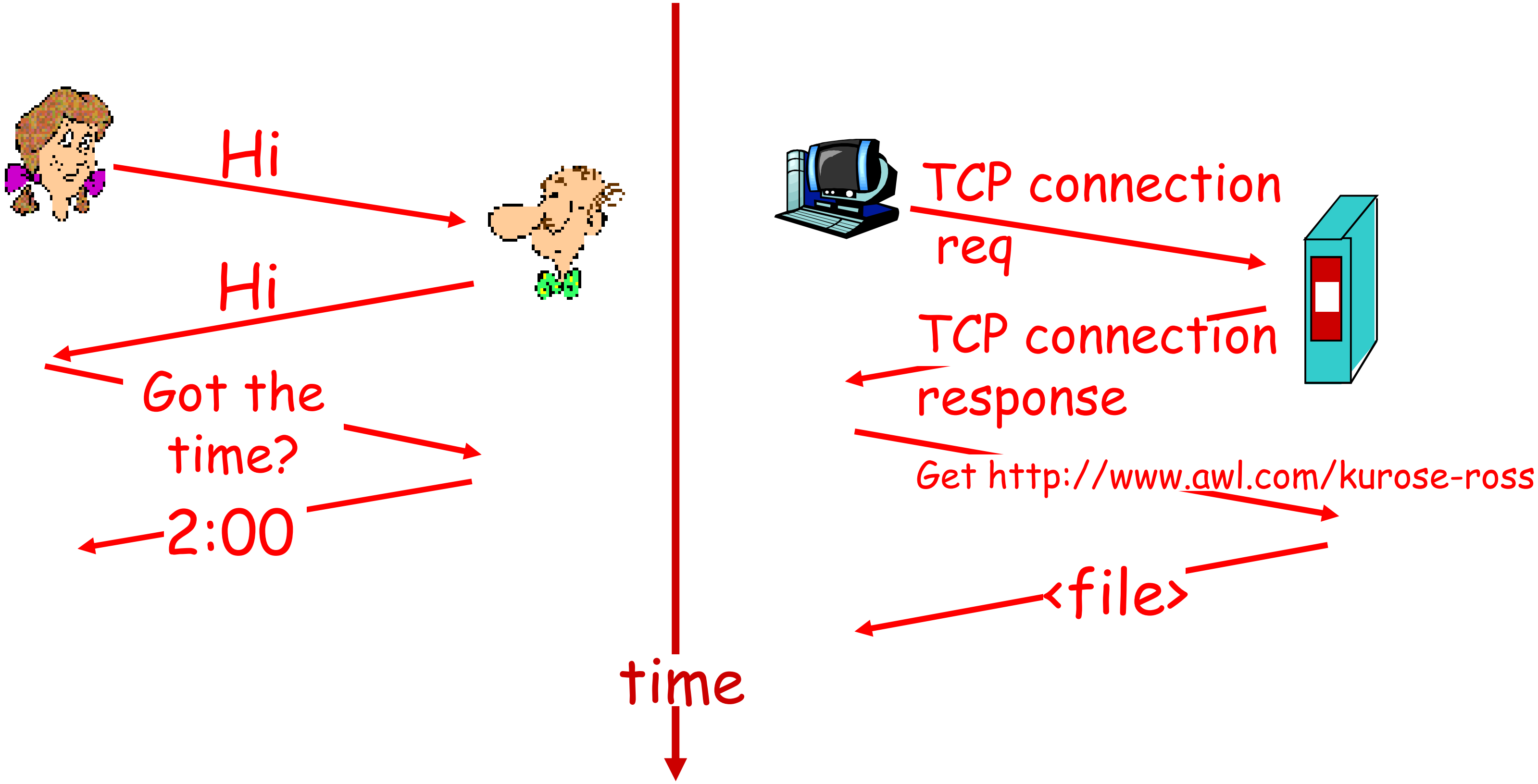
What's Internet?

- 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:



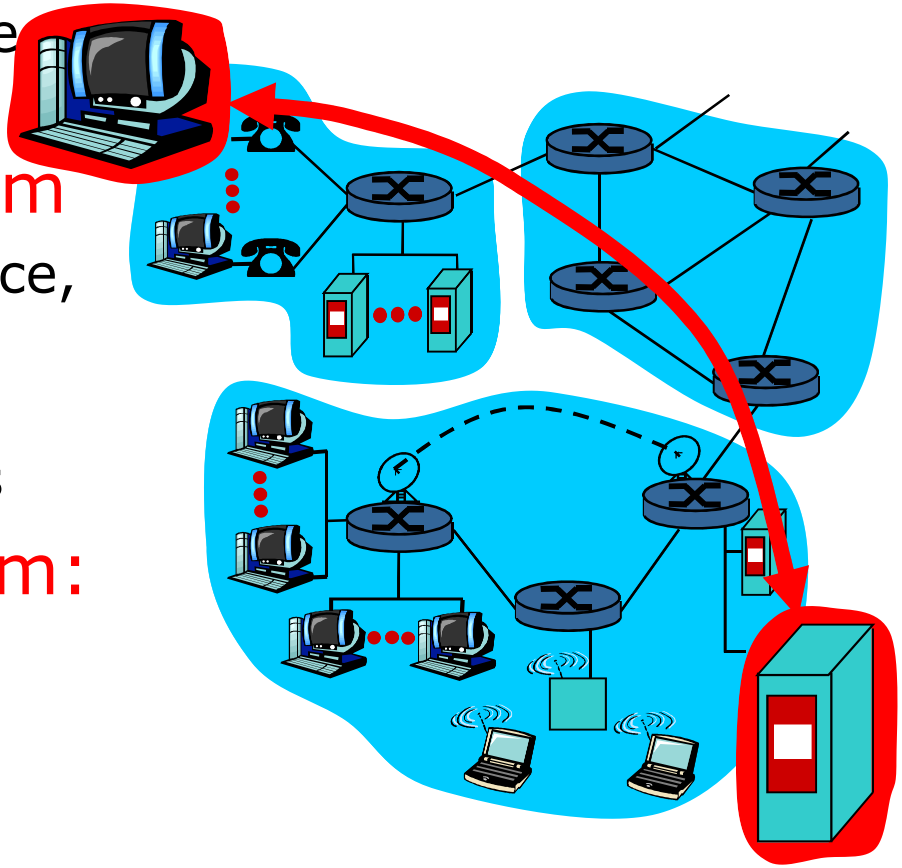
Source: ***Computer Networking: A Top Down Approach Featuring the Internet***,
Jim Kurose, Keith Ross, Addison-Wesley, July 2004.

The Protocol handling email exchange

```
S: 220 hamburger.edu
C: HELO crepes.fr
S: 250 Hello crepes.fr, pleased to meet you
C: MAIL FROM: <alice@crepes.fr>
S: 250 alice@crepes.fr... Sender ok
C: RCPT TO: <bob@hamburger.edu>
S: 250 bob@hamburger.edu ... Recipient ok
C: DATA
S: 354 Enter mail, end with "." on a line by itself
C: Do you like ketchup?
C: How about pickles?
C: .
S: 250 Message accepted for delivery
C: QUIT
S: 221 hamburger.edu closing connection
```

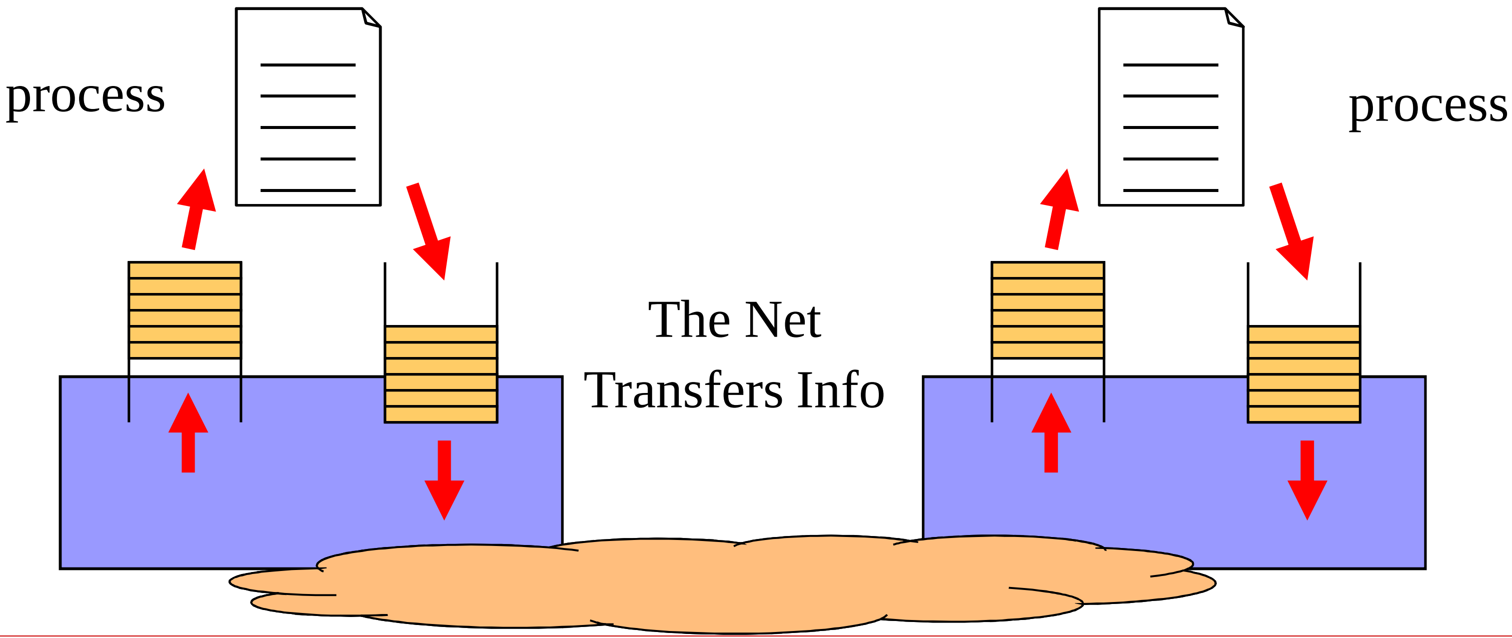
At the Edges of The Internet

- 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 Paradigm:
  - No strict distinctions
  - Flat architecture



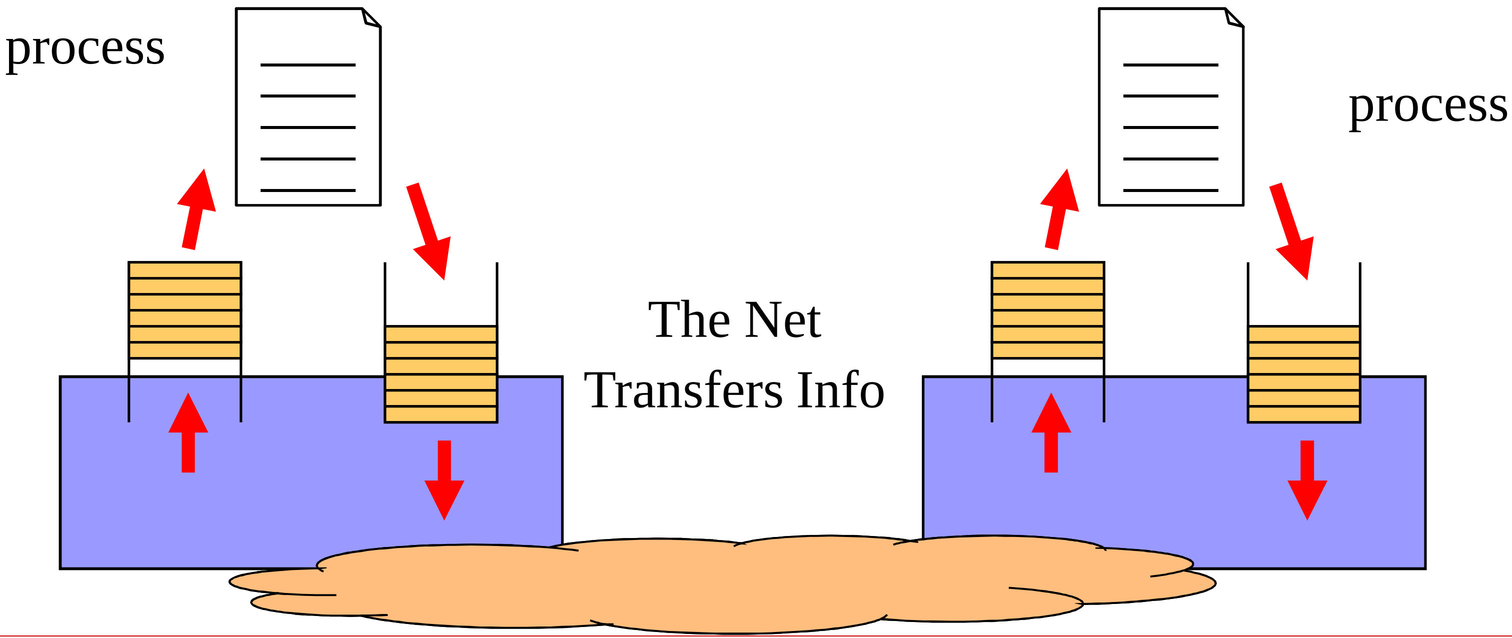
Applications over The Net

- 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



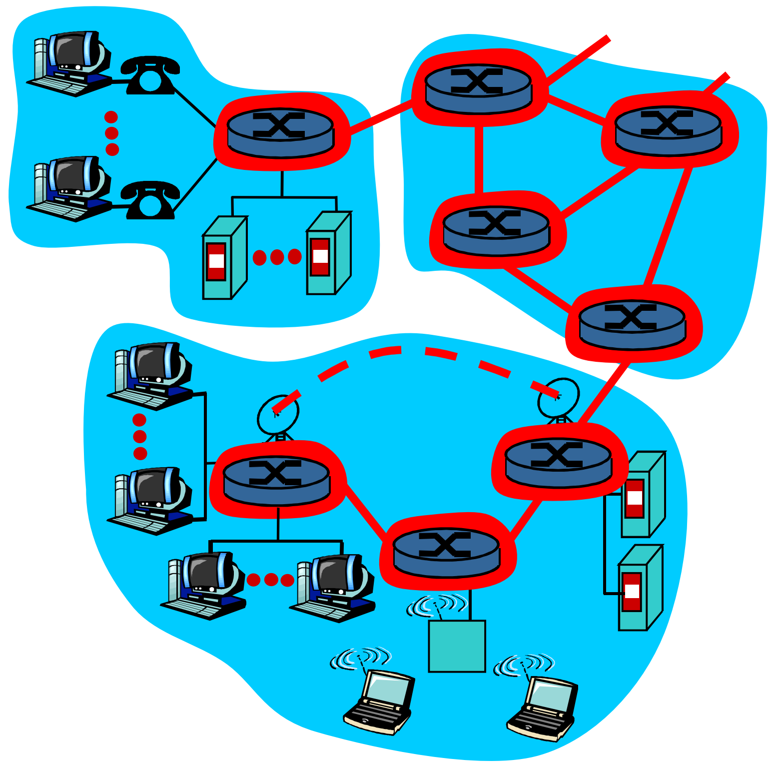
Types of Transport

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



Network Core

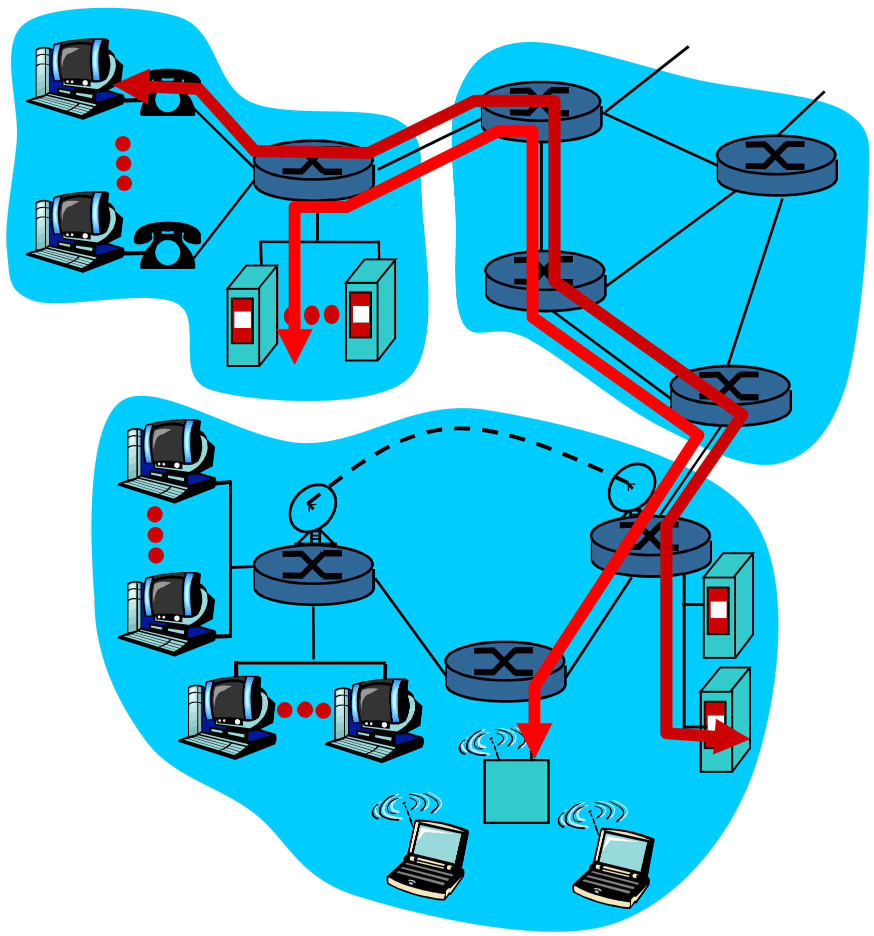
- Bunch of Interconnected routers
- How to transfer information?
  - Circuit Switched communication: each call is assigned a *circuit*
  - Packet Switched communication: info divided into *messages* (packets)



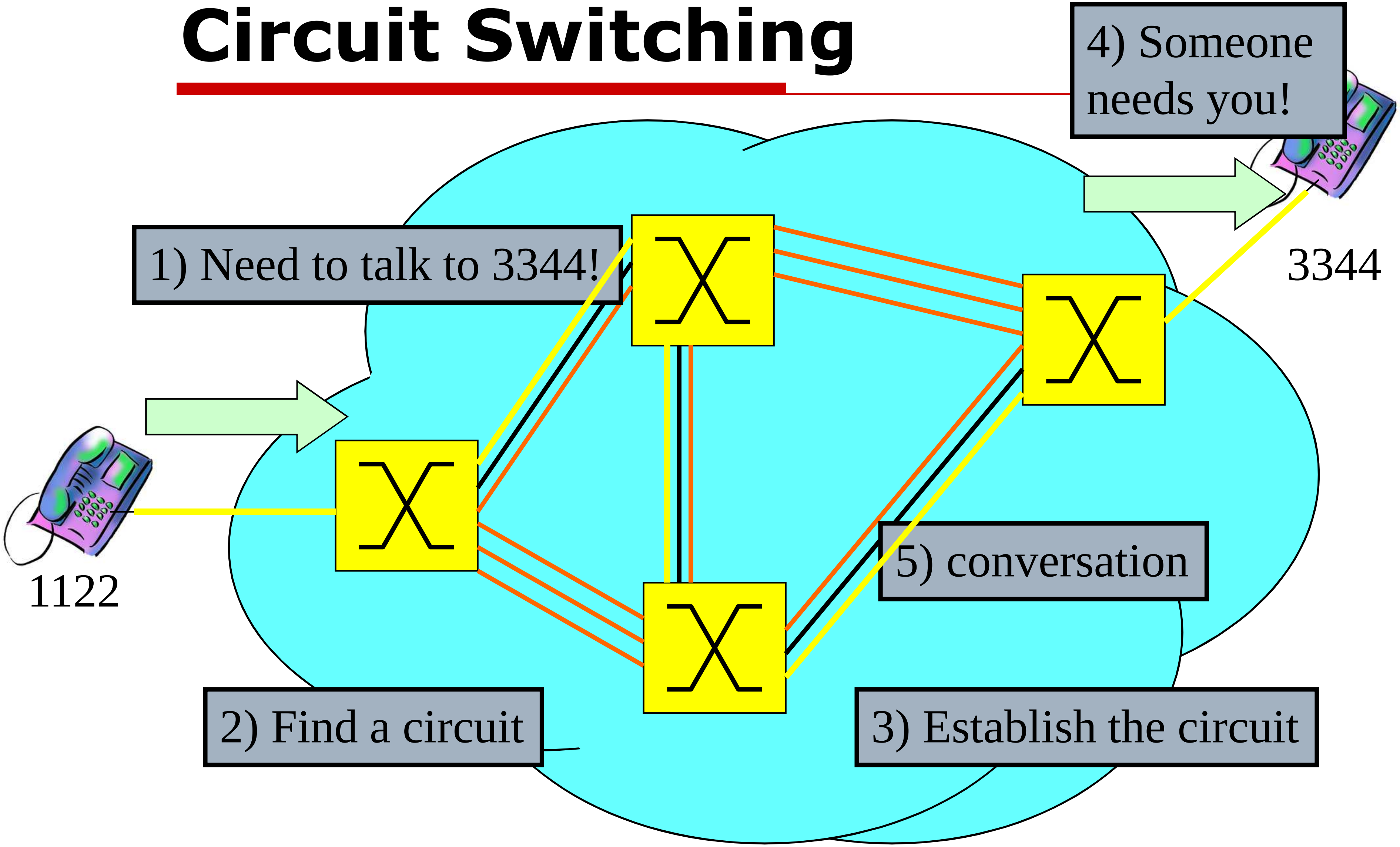
Circuit Switching

Communication resources are reserved on call basis

- E.g. PSTN



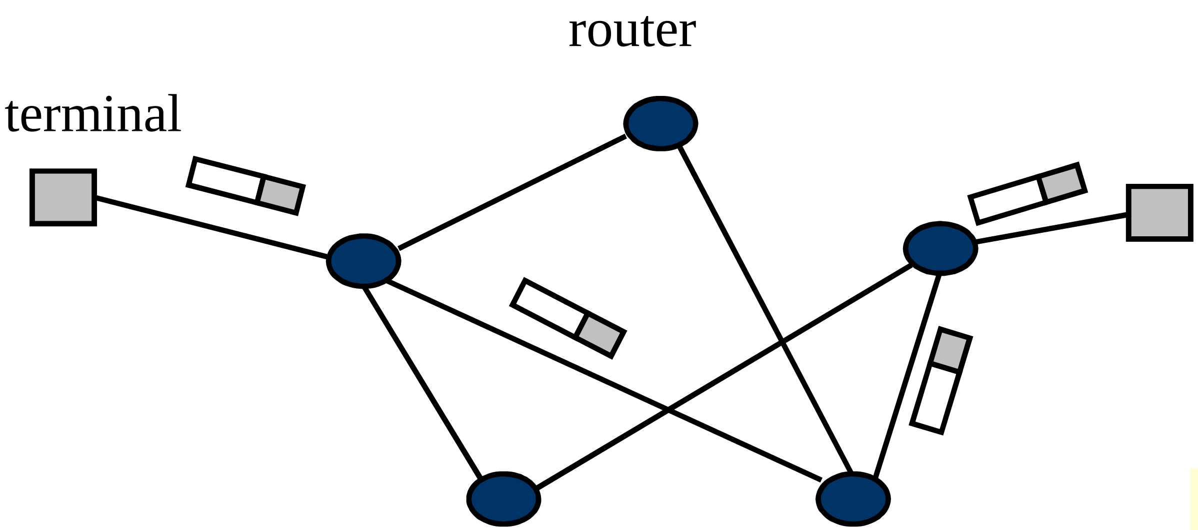
Circuit Switching

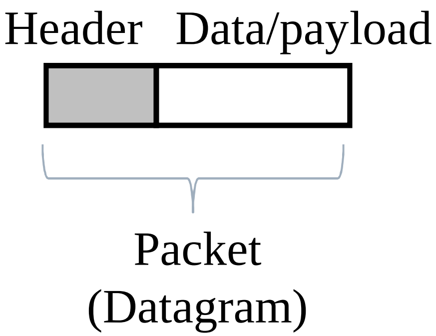


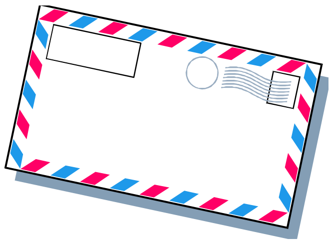
Circuit Switching

- 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 multiplexing:
  - *Time* division
  - *Frequency* division
  - *Wavelength* division
  - *Code* division

Packet Switching

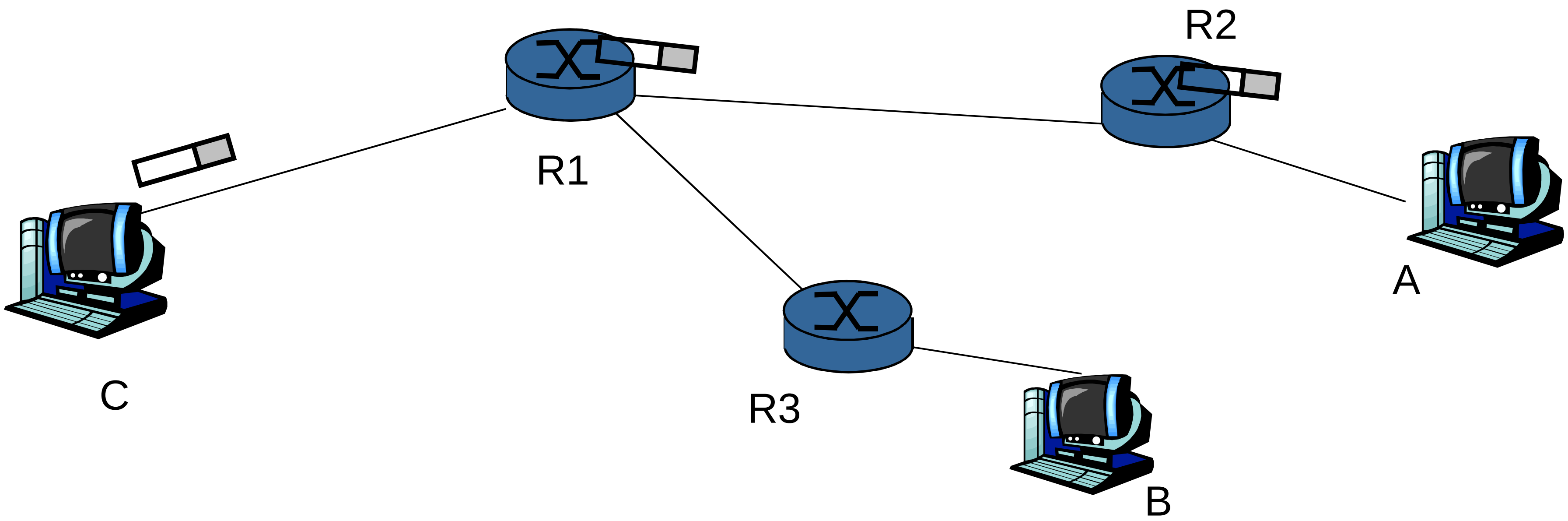






Packet Switching

Routing Table	
Destination	Next router
A	R2
B	R3



Packet Switching

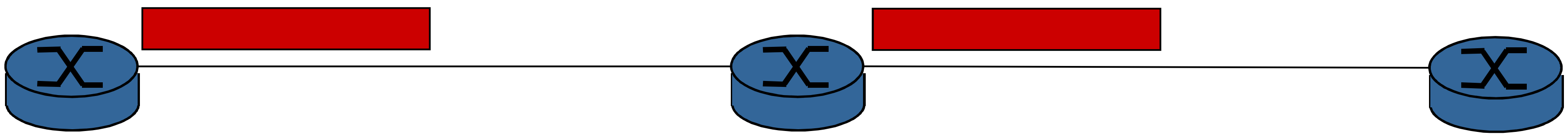
Data Flow is split up into *packets*

- 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

Store and forward



$\mathbf{T_0}$=transmission start

$\mathbf{T_1}$=transmission end

$\mathbf{T_2}$=first bit arrival

$\mathbf{T_3}$=last bit arrival

Transmission Time:

$\mathbf{T=T_1-T_0=L/R}$ **L**=packet length [bit]

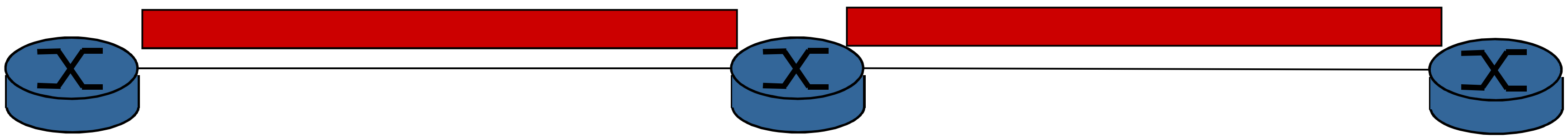
R=transmission rate [bit/s]

Propagation Time:

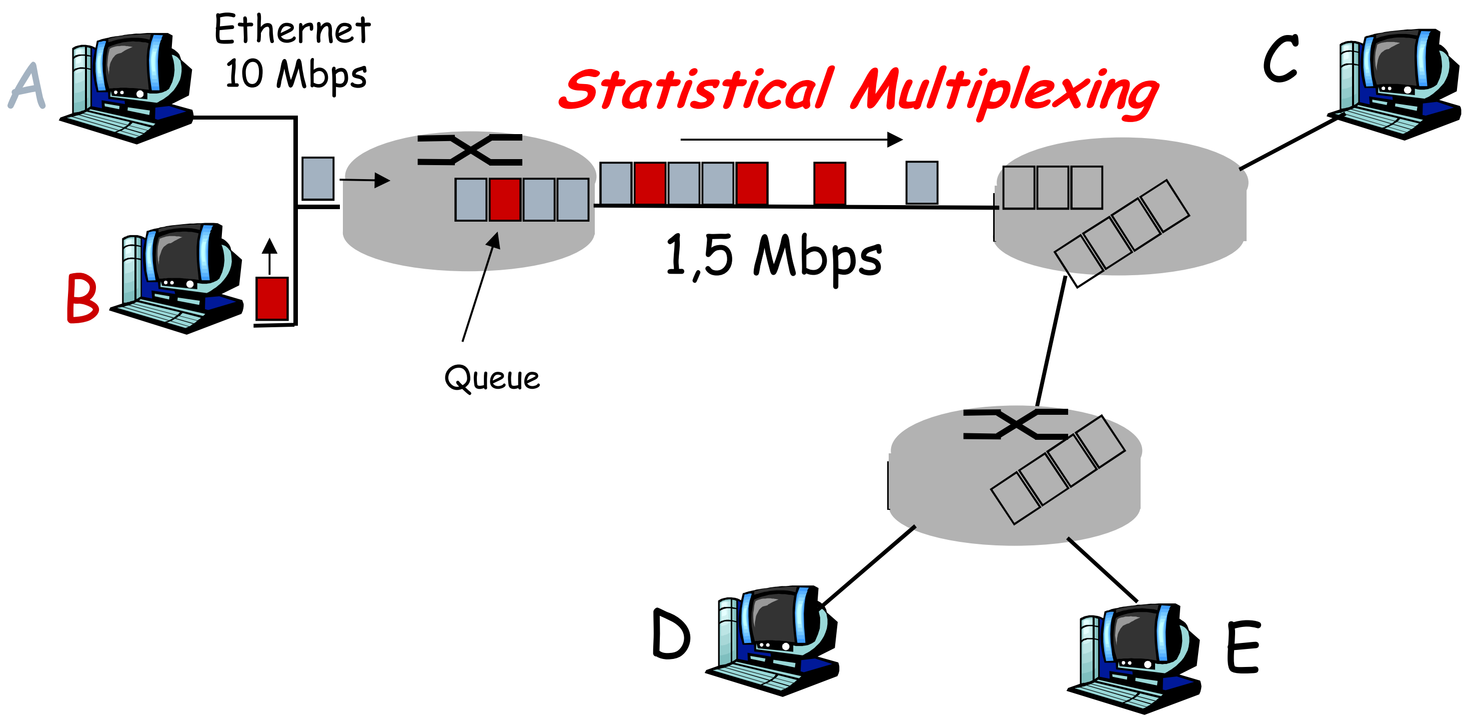
$\tau=\mathbf{T_2-T_0=l/C}$ **l**=link length [m]

C=wave speed [m/s]

Store and forward



Statistical Multiplexing

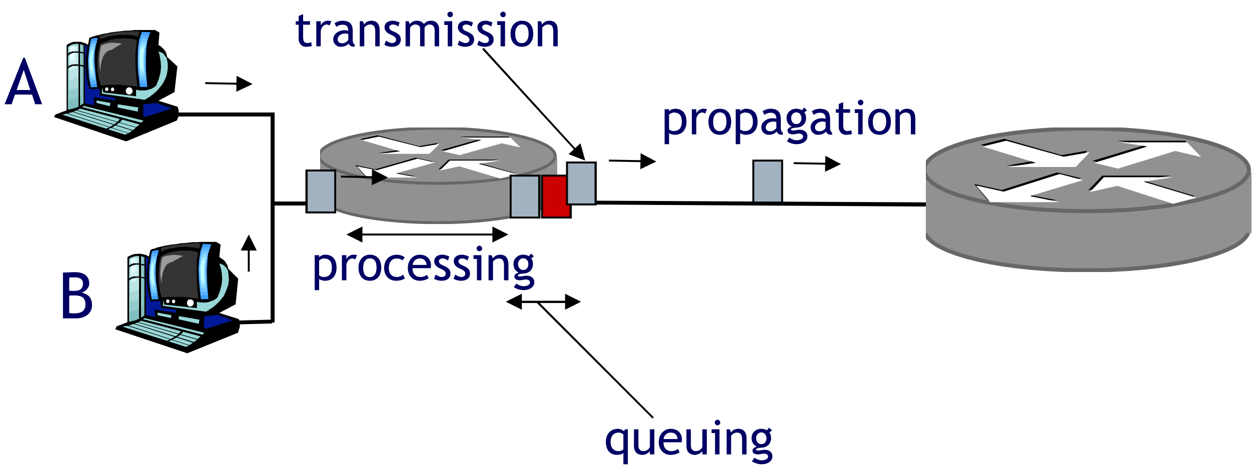


Packet transmission does not follow a <u>fixed</u> sequencing
Instead, resources are <u>statistically</u> shared ➔ ***statistical multiplexing***.

Packet (or Nodal) Delay

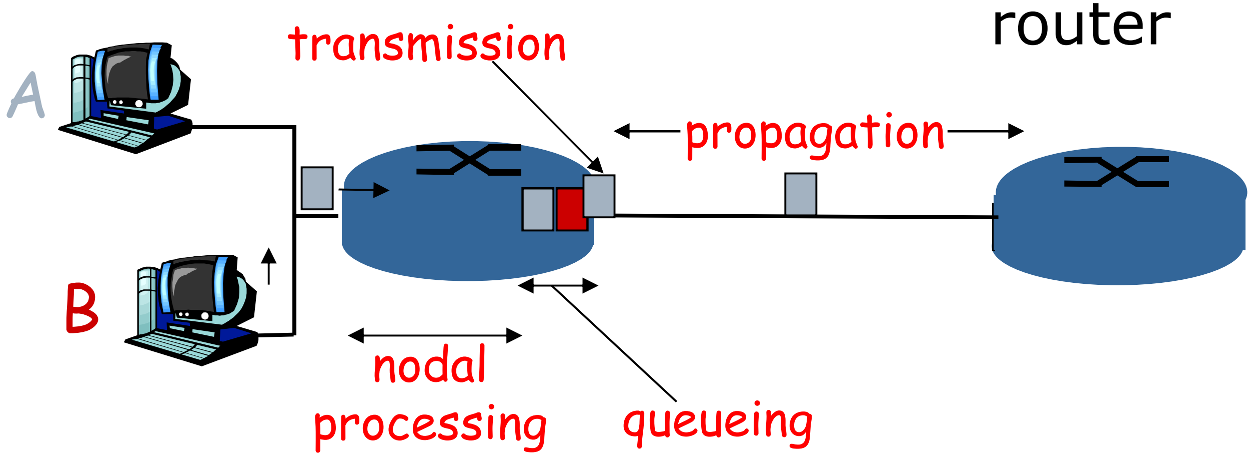
Each packet experiments a variable delay due to:

- 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



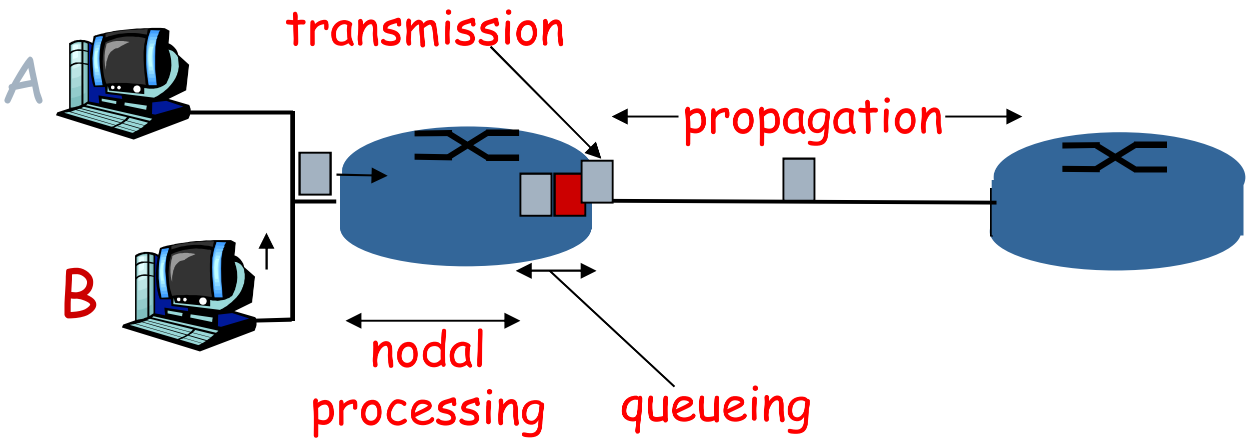
Delay in packet-switched networks

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

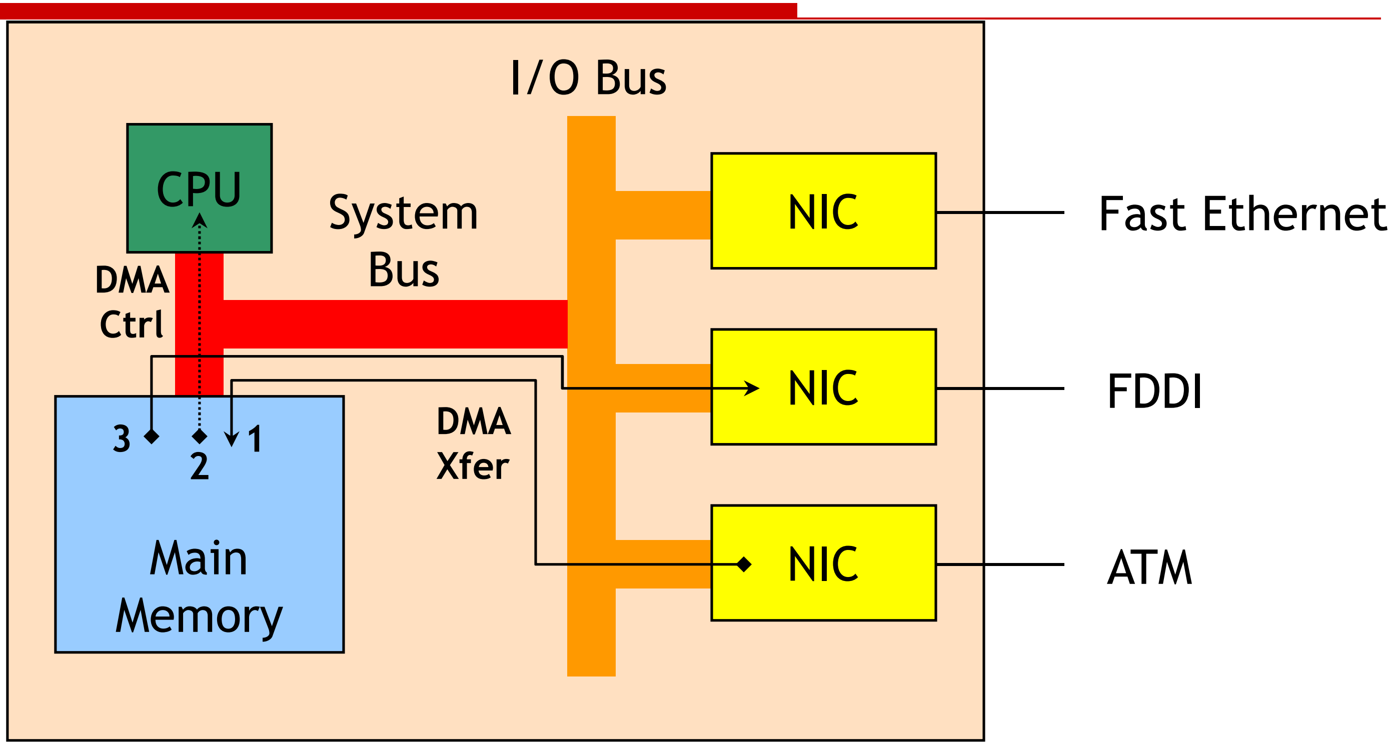


Nodal delay

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

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

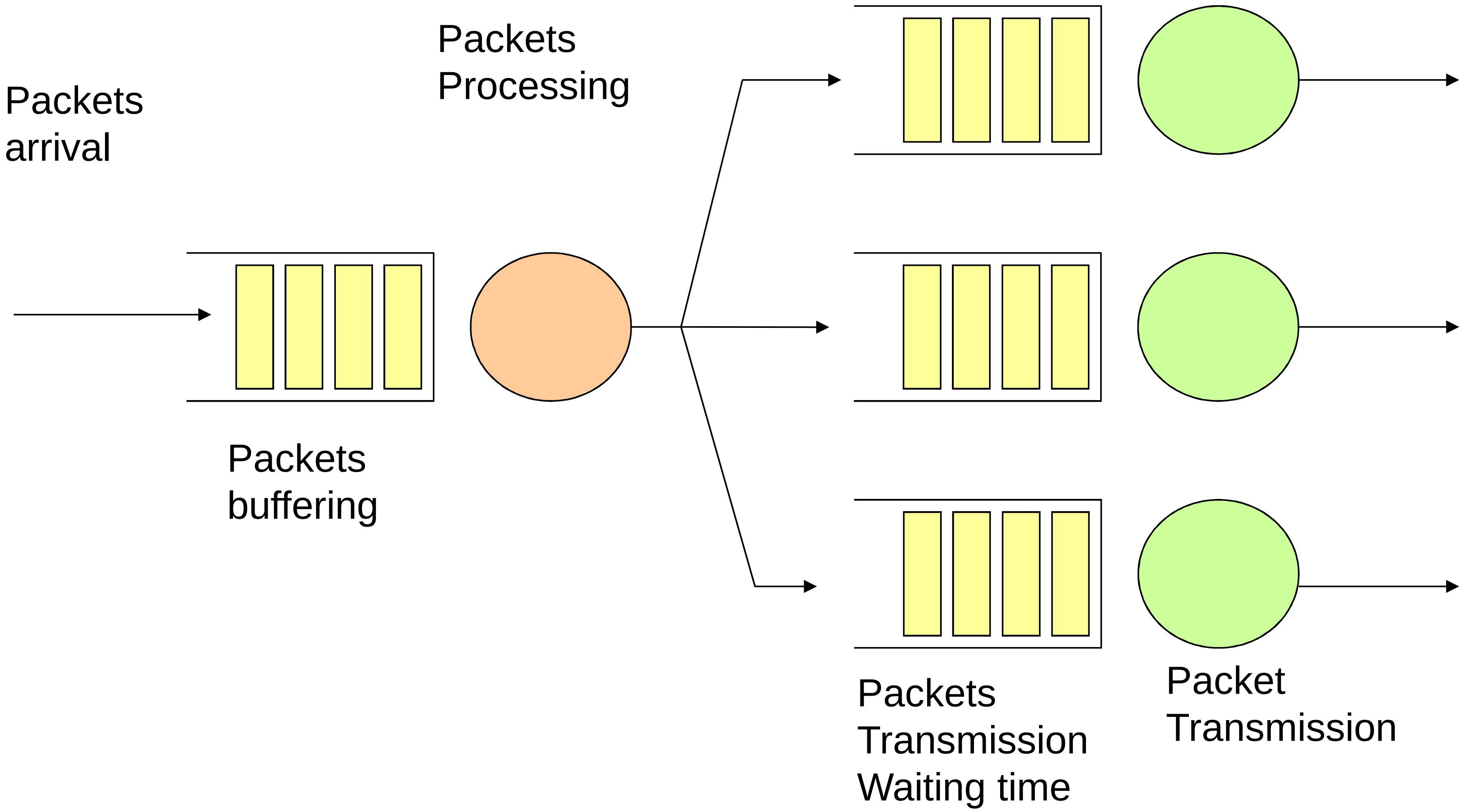
Node Architecture



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

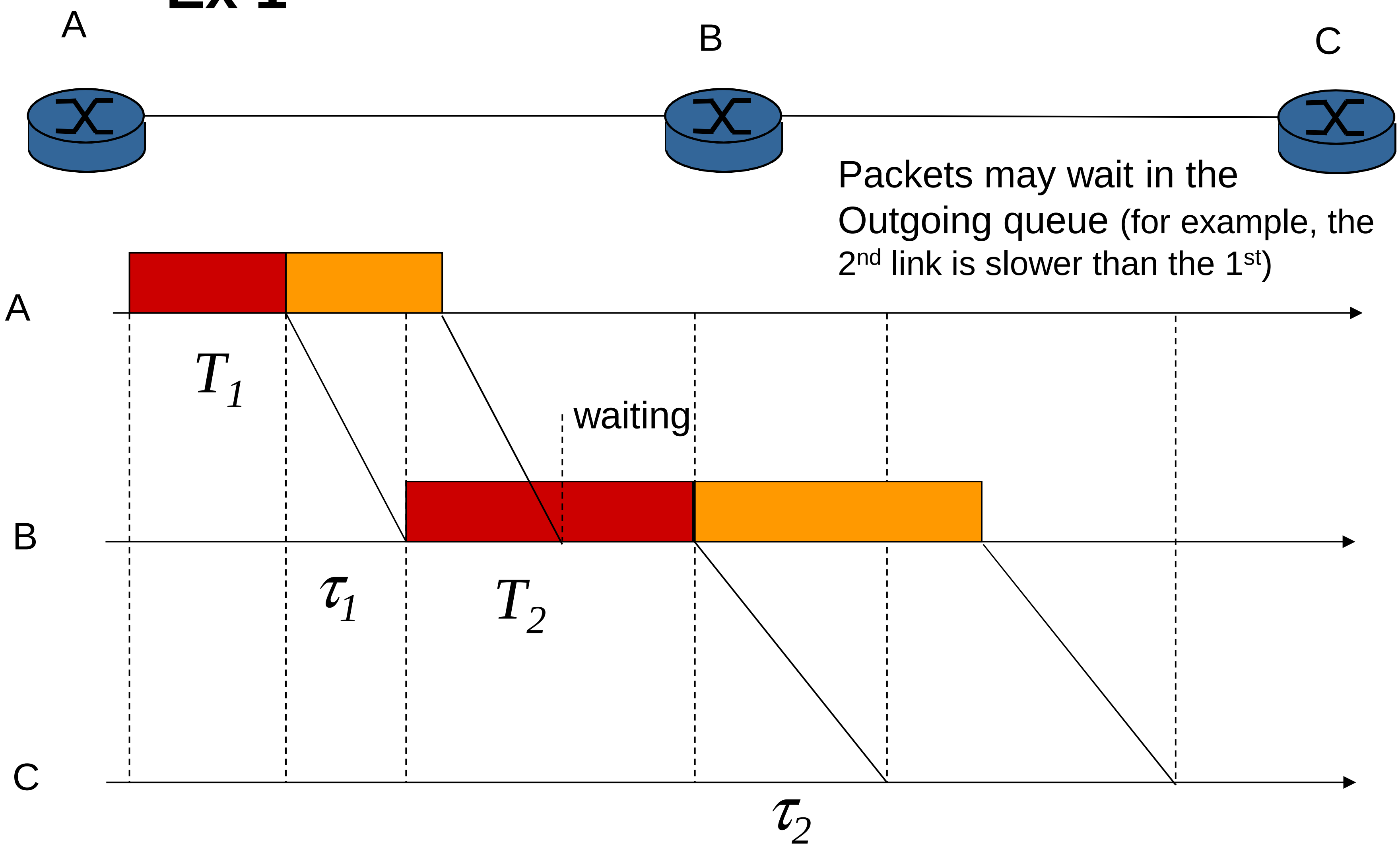
NIC = Network Interface Controller
DMA = Direct Memory Access

Node Model


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

Queuing Delay

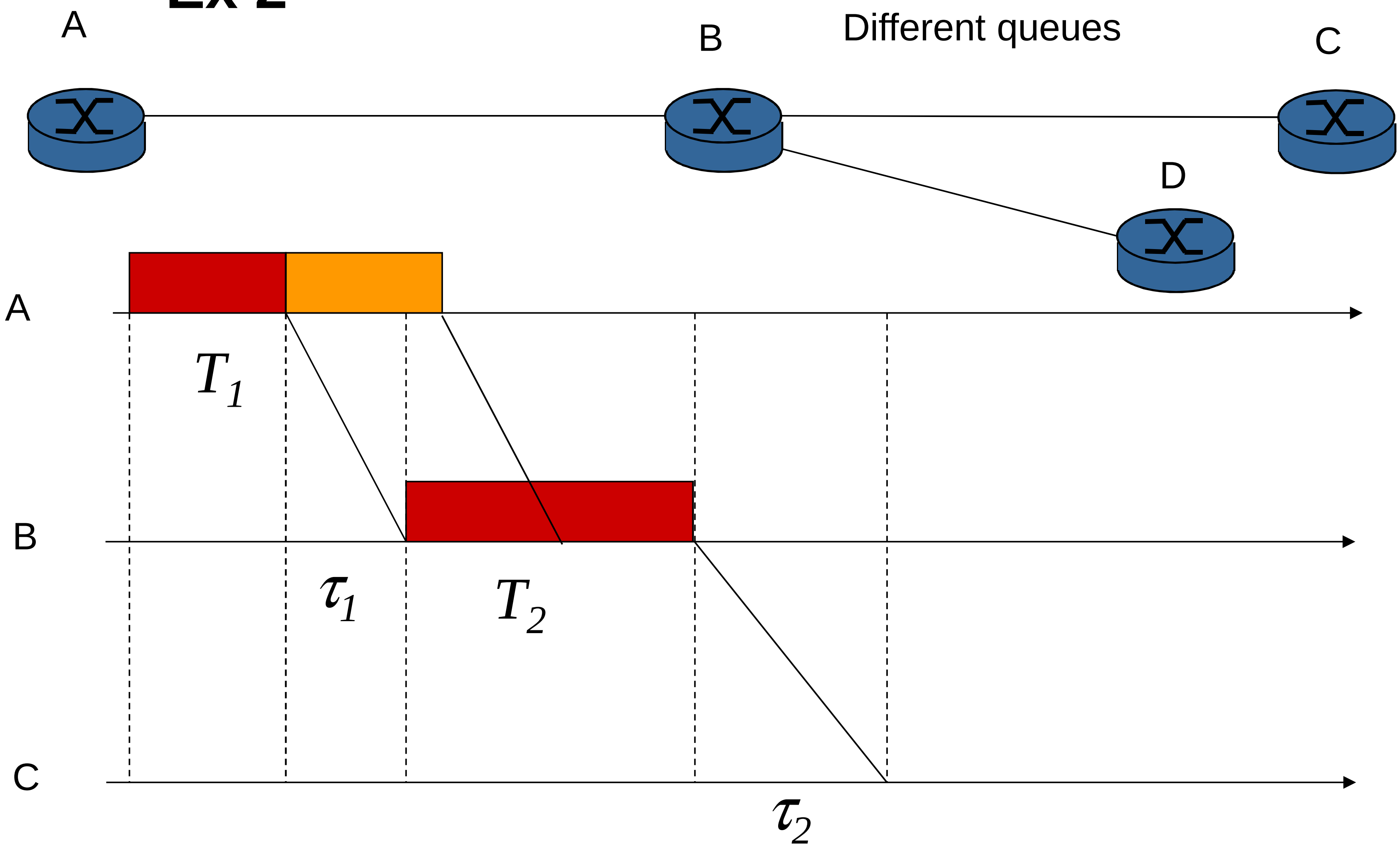
Ex 1



Queuing Delay

Ex 2

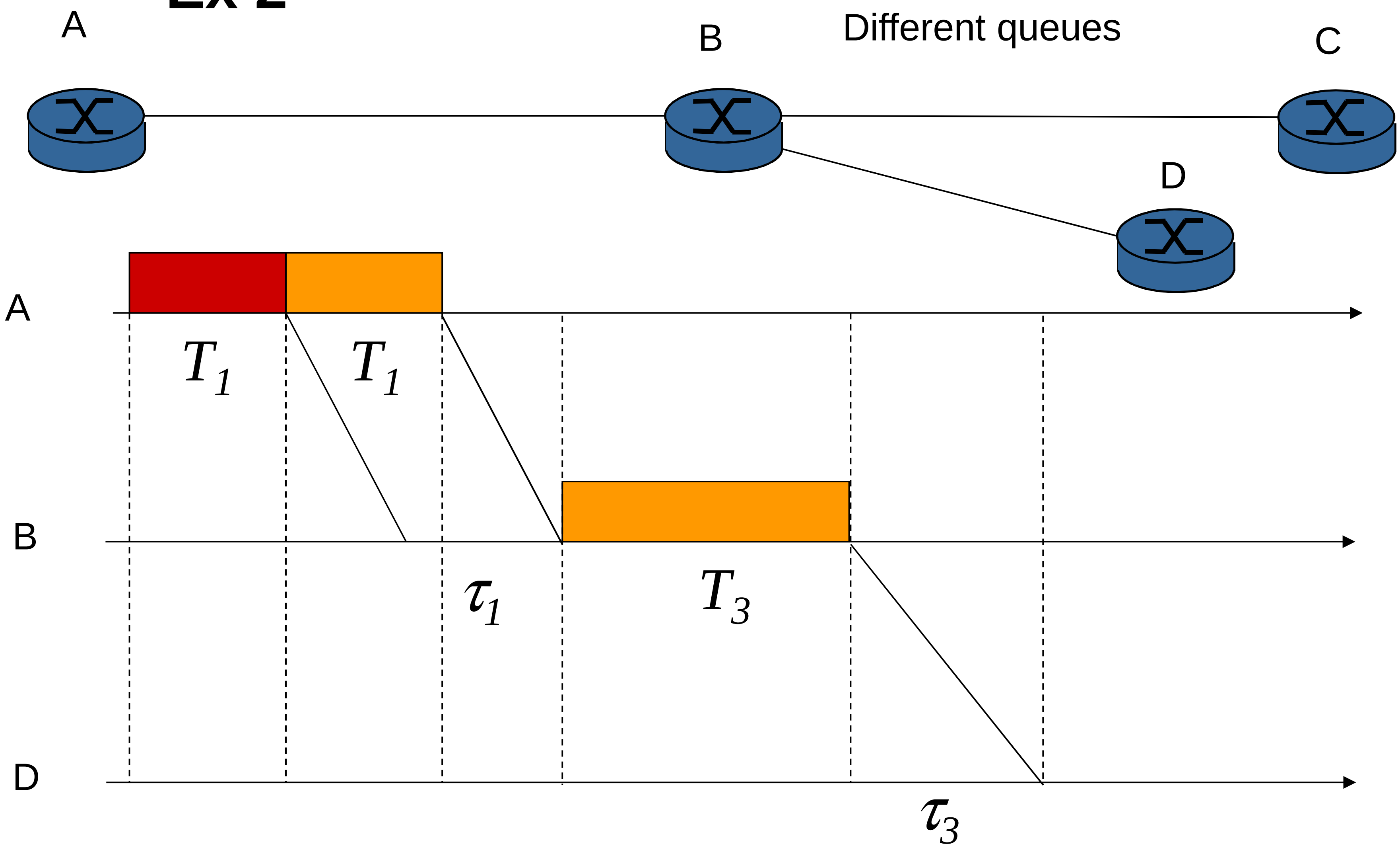
Different interfaces
Different queues



Queuing Delay

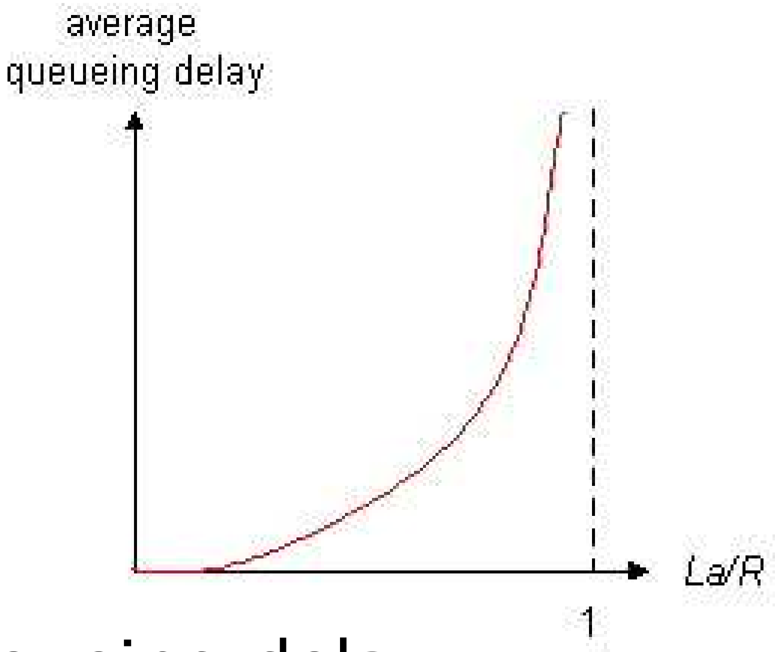
Ex 2

Different interfaces
Different queues



Queueing delay

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

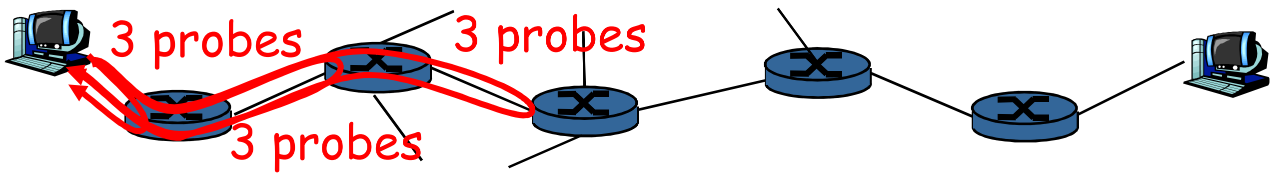


Traffic intensity = La/R

- La/R ~ 0: average queueing delay small (queues are almost empty)
- La/R -> 1: delays become infinite (queues are *very* full!)

“Real” Internet delays and routes

- **Traceroute Program**: provides delay measurement from the source to any router along end-to-end Internet path towards the destination. For all *i=1, 2 …,* the sender*:*
  - sends three packets that will reach router *i* along the path towards the destination
  - router *i* will return packets (replies) to the sender
  - The sender measures the time intervals between *transmissions* and *replies*



"Real" Internet delays and routes

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

Three delay measurements from gaia.cs.umass.edu to cs-gw.cs.umass.edu

1 cs-gw (128.119.240.254) 1 ms 1 ms 2 ms
2 border1-rt-fa5-1-0.gw.umass.edu (128.119.3.145) 1 ms 1 ms 2 ms
3 cht-vbns.gw.umass.edu (128.119.3.130) 6 ms 5 ms 5 ms
4 jn1-at1-0-0-19.wor.vbns.net (204.147.132.129) 16 ms 11 ms 13 ms
5 jn1-so7-0-0-0.wae.vbns.net (204.147.136.136) 21 ms 18 ms 18 ms
6 abilene-vbns.abilene.ucaid.edu (198.32.11.9) 22 ms 18 ms 22 ms
7 nycm-wash.abilene.ucaid.edu (198.32.8.46) 22 ms 22 ms 22 ms
8 62.40.103.253 (62.40.103.253) 104 ms 109 ms 106 ms
9 de2-1.de1.de.geant.net (62.40.96.129) 109 ms 102 ms 104 ms
10 de.fr1.fr.geant.net (62.40.96.50) 113 ms 121 ms 114 ms
11 renater-gw.fr1.fr.geant.net (62.40.103.54) 112 ms 114 ms 112 ms
12 nio-n2.cssi.renater.fr (193.51.206.13) 111 ms 114 ms 116 ms
13 nice.cssi.renater.fr (195.220.98.102) 123 ms 125 ms 124 ms
14 r3t2-nice.cssi.renater.fr (195.220.98.110) 126 ms 126 ms 124 ms
15 eurecom-valbonne.r3t2.ft.net (193.48.50.54) 135 ms 128 ms 133 ms
16 194.214.211.25 (194.214.211.25) 126 ms 128 ms 126 ms
17 * * *
18 * * *
19 fantasia.eurecom.fr (193.55.113.142) 132 ms 128 ms 136 ms

trans-oceanic link

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

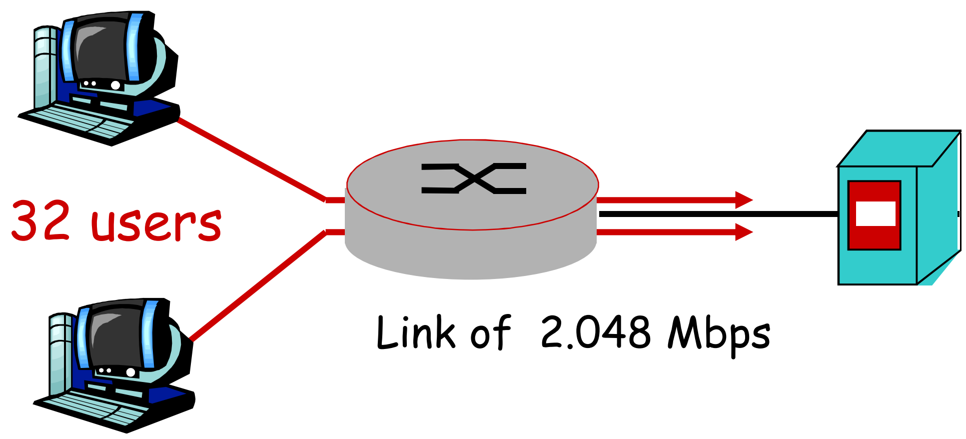
Packet loss

- Queue preceding link in buffer has *finite* capacity
- When a packet arrives to a full queue, such packet is dropped
- A 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 Mbps
- 32 users
- Each user:
  - Calls for a 50KB-web page every 62.5s, on average
- Circuit switching:
  - One 64 kbps channel for each user
  - Average page Transfer delay: 6.25s
    (50000*8/64000 = 6.25s)

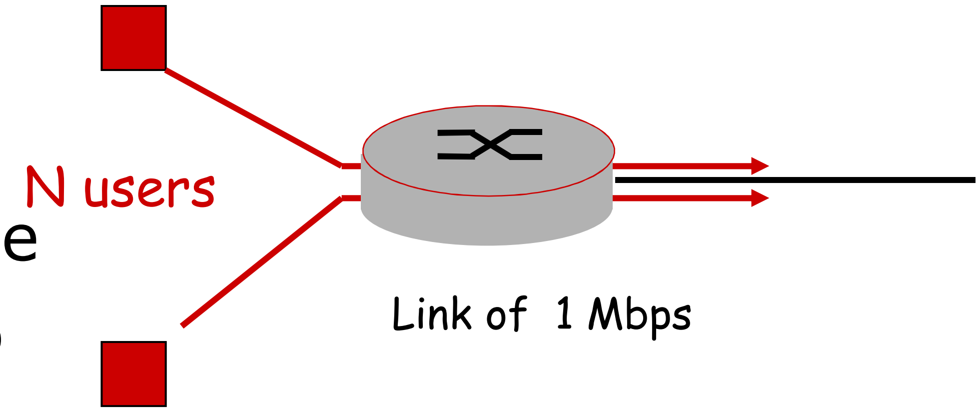


- Packet switching:
  - Average page transfer delay: 0.22s
    (rho=1/10,
    T=(1/mu)/(1-rho) =
=(1/0.9)*(50000*8/2048000)=
=0.22s)

Packet vs Circuit Switching

Packet switching supports greater number of users!

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

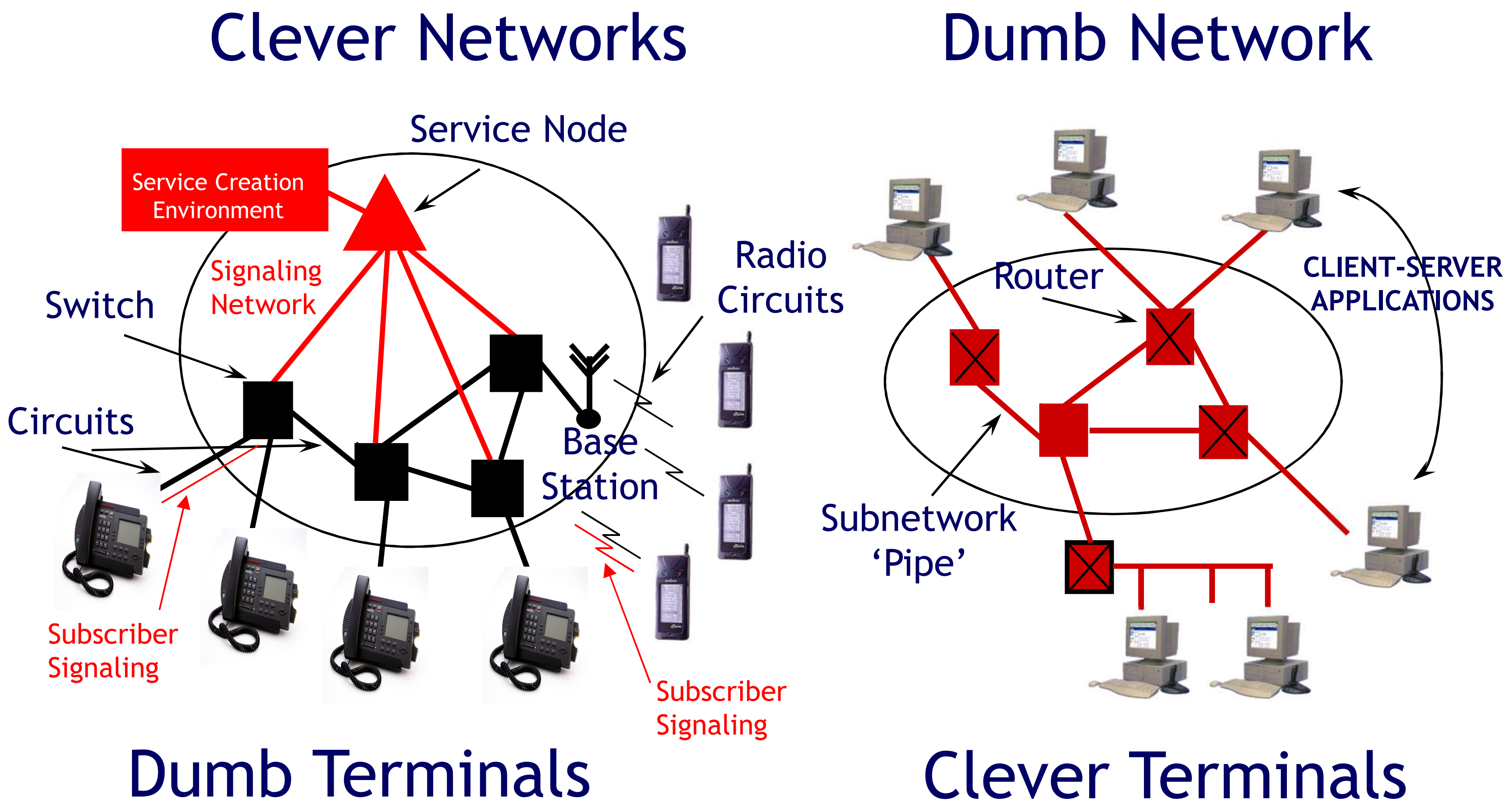


- Packet switching:
  - with 35 users, the probability of having more than 10 active users simultaneously is less than 0,0004

Packet Switching: PROs and CONs

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

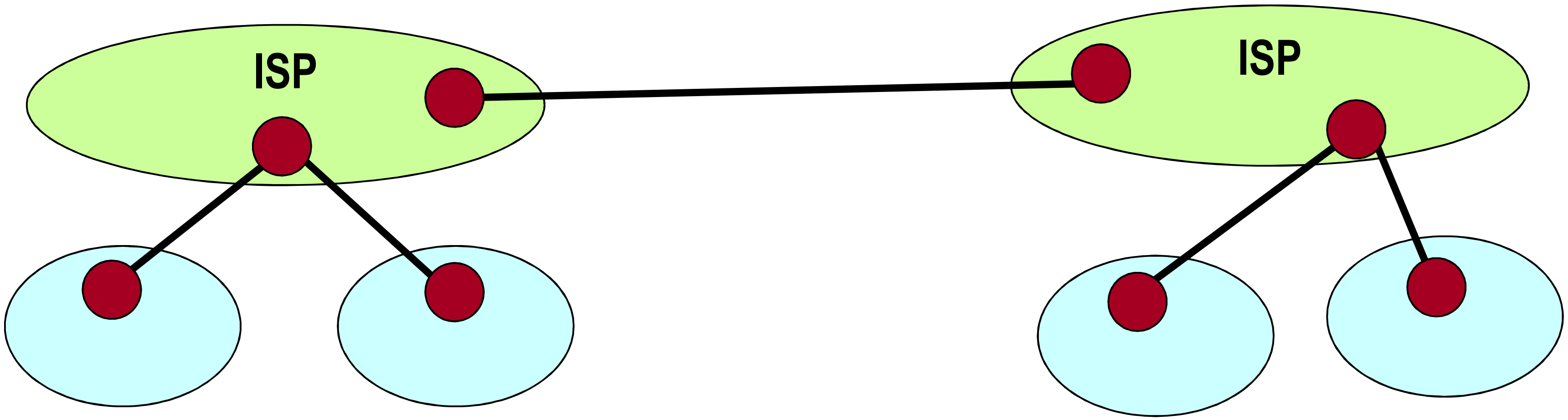
PSTN vs Internet



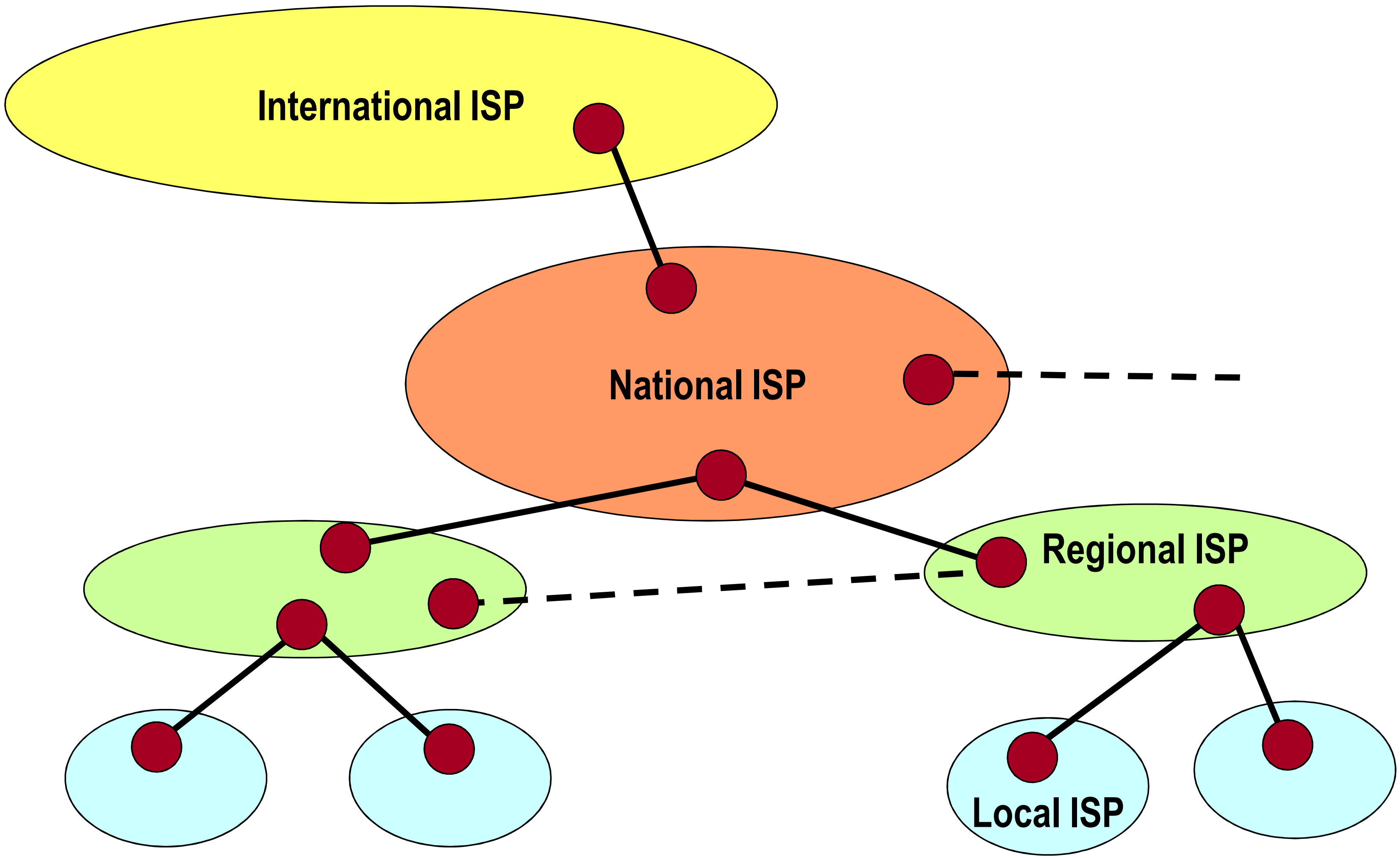
Internet Architecture and Access Technologies

General Architecture

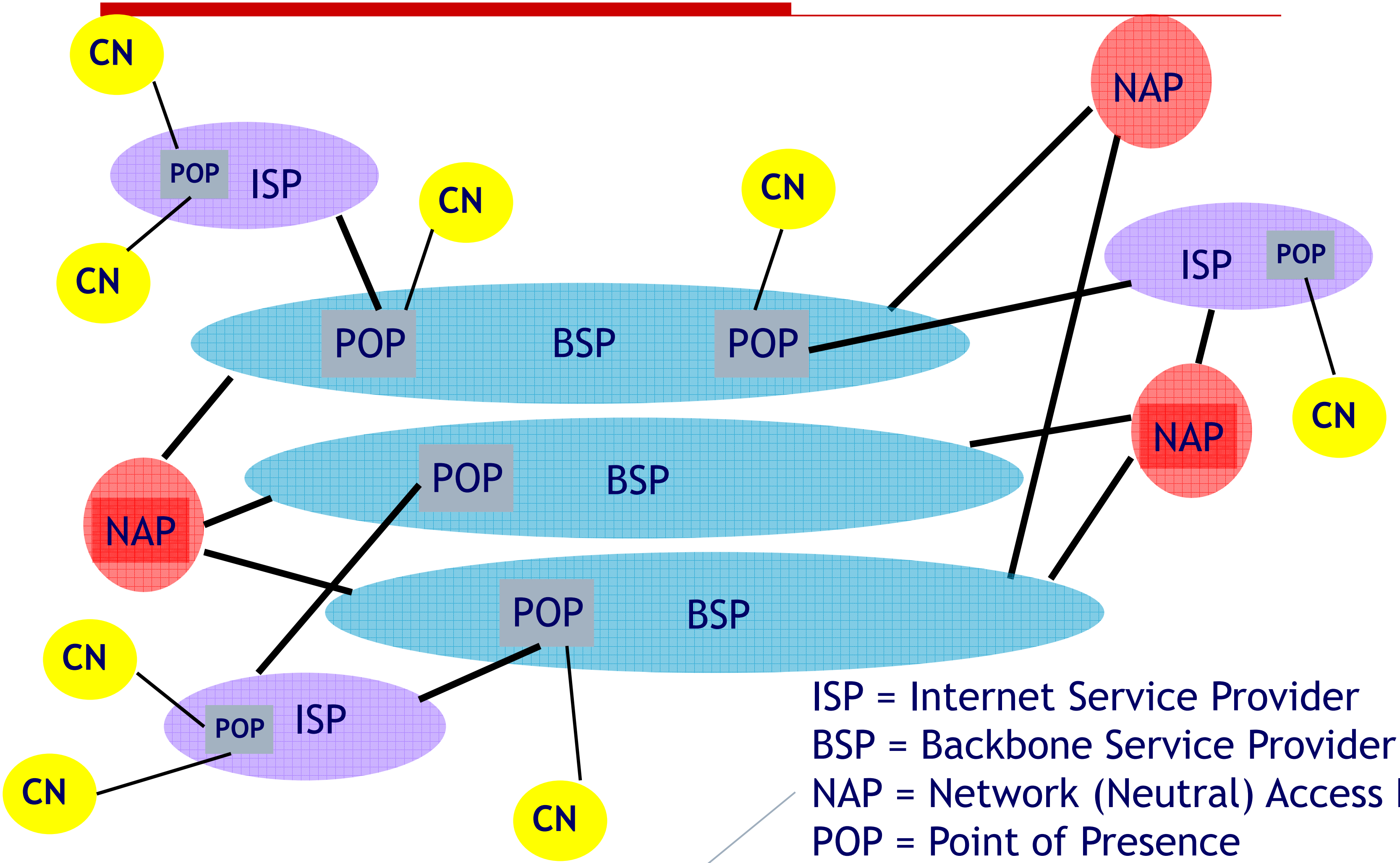
- *Internet Service Providers* (ISP) provide connectivity (AOL, Orange, Free, etc.)
- ISPs share a common backbone



Internet Hierarchy



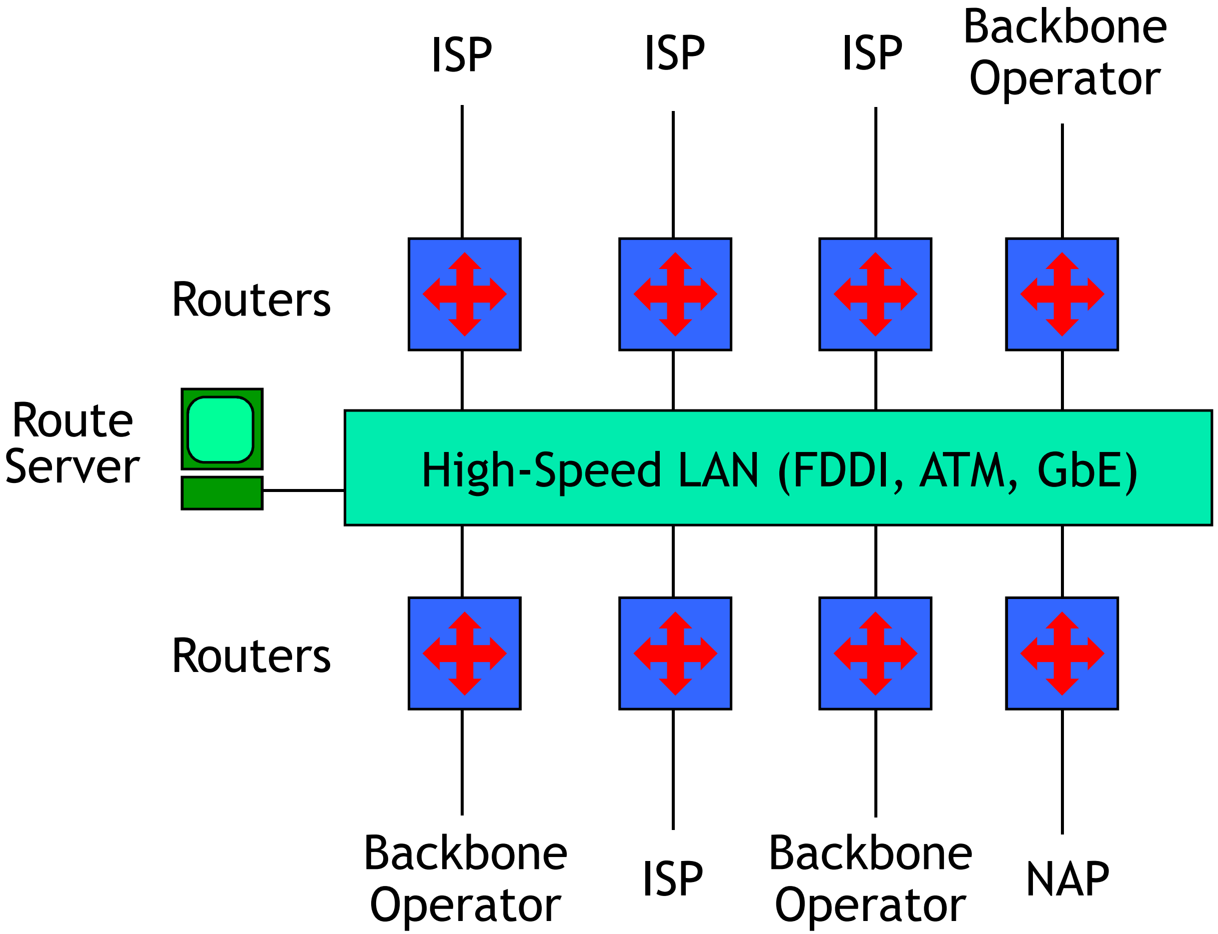
Internet Architecture



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

Now: IXP = Internet Exchange Point

NAP/IXP Architecture



Examples:

www.franceix.net/

www.mix-it.net

MIX milano

Milan Internet eXchange

www.namex.it

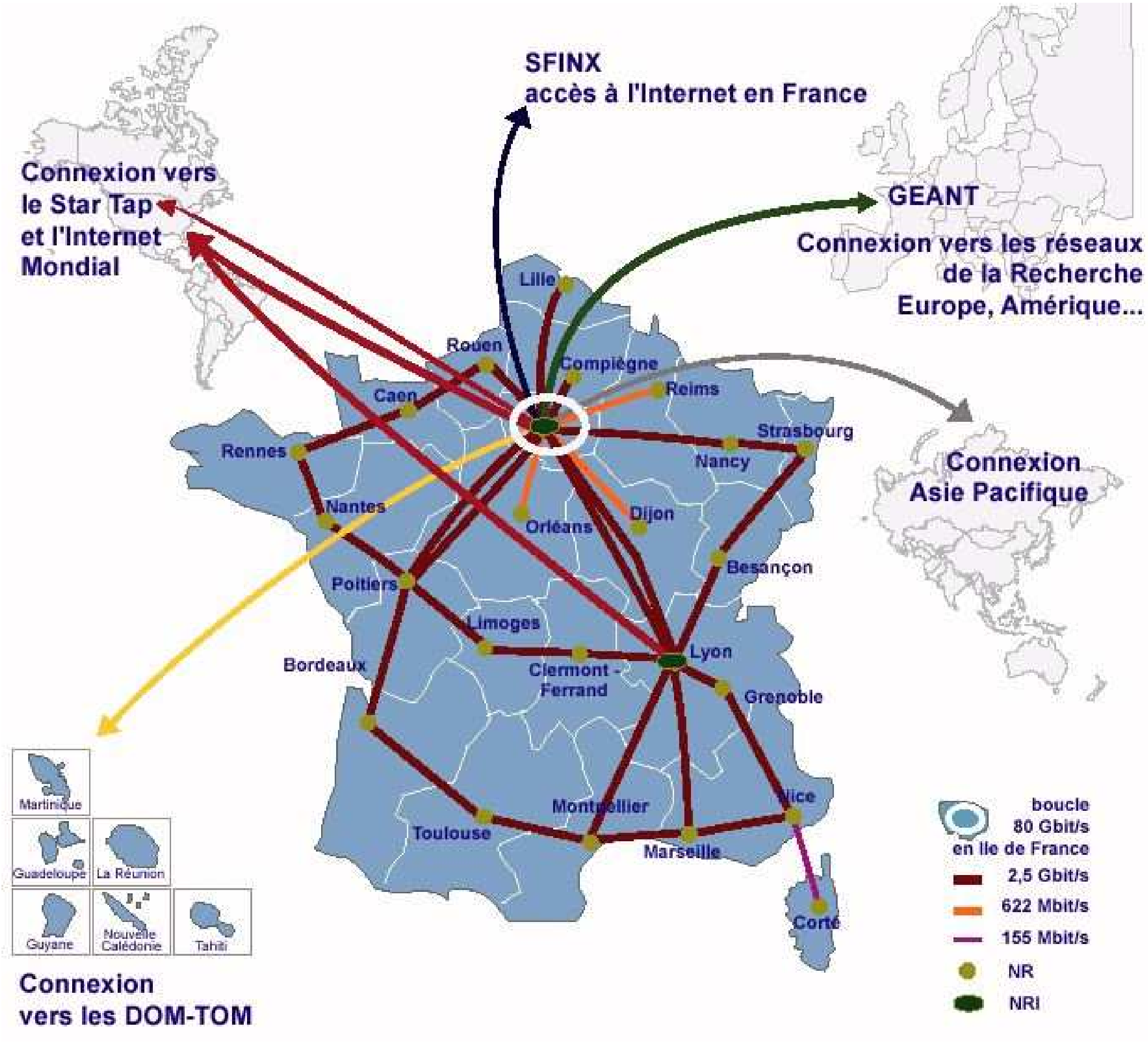
Nautilus Mediterranean Exchange Point

NaMEX

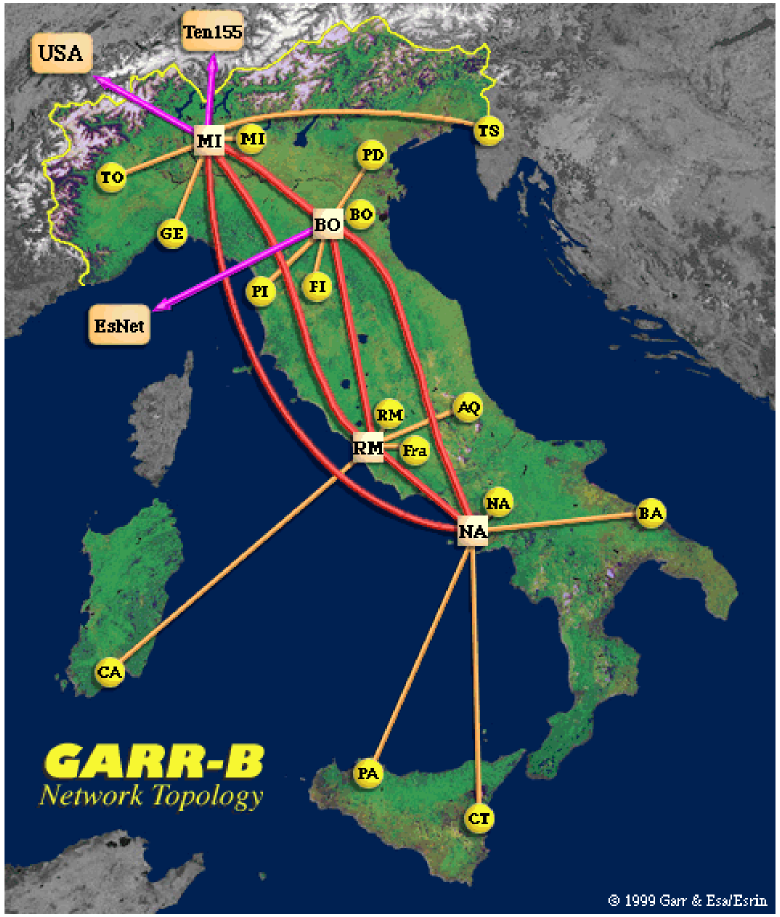
www.topix.it

top IX torino piemonte internet exchange

National ISP: A French Example



National ISP: An Italian Example



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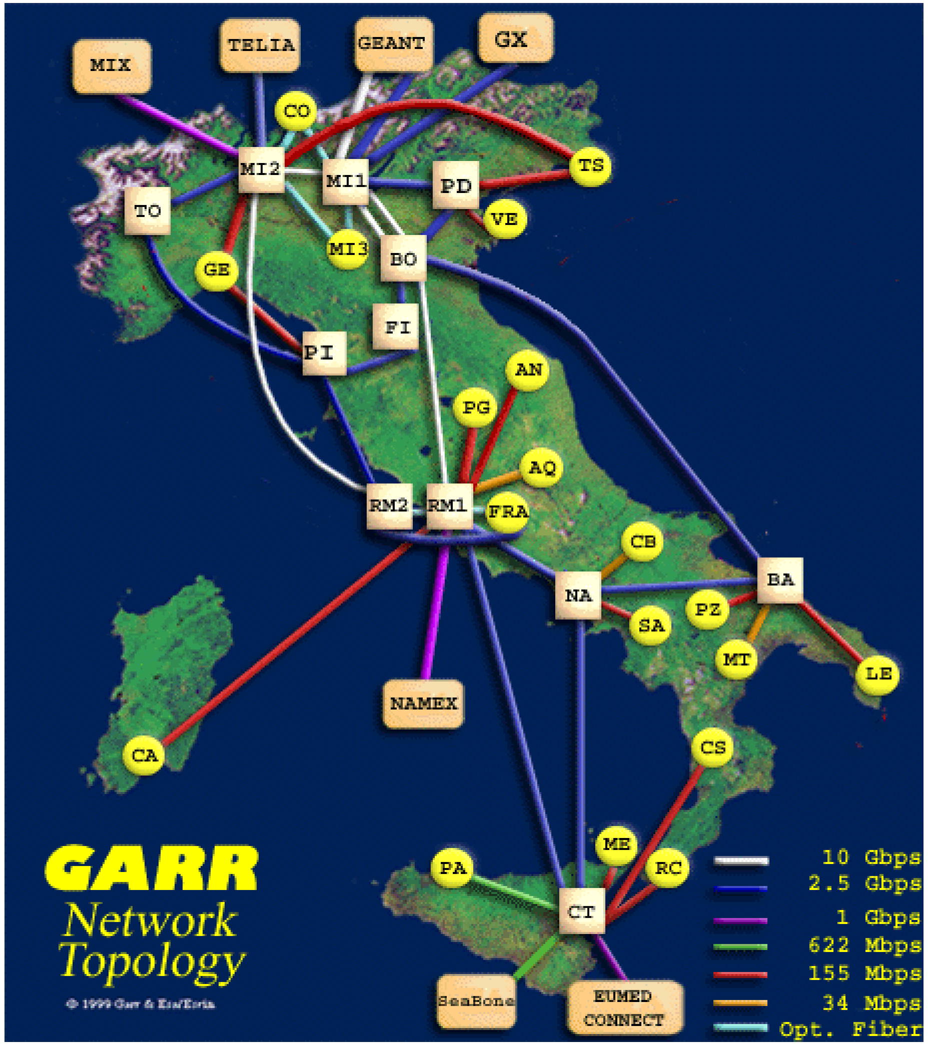

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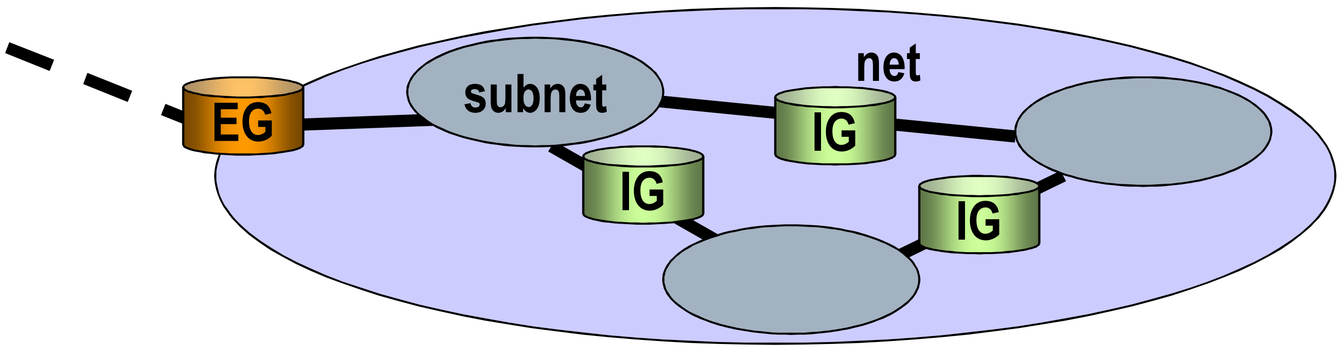
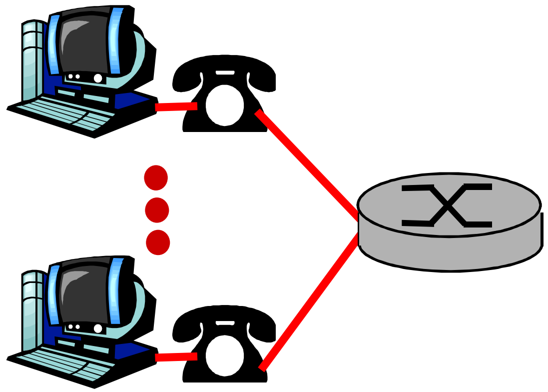
Internet Taxonomy

- 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

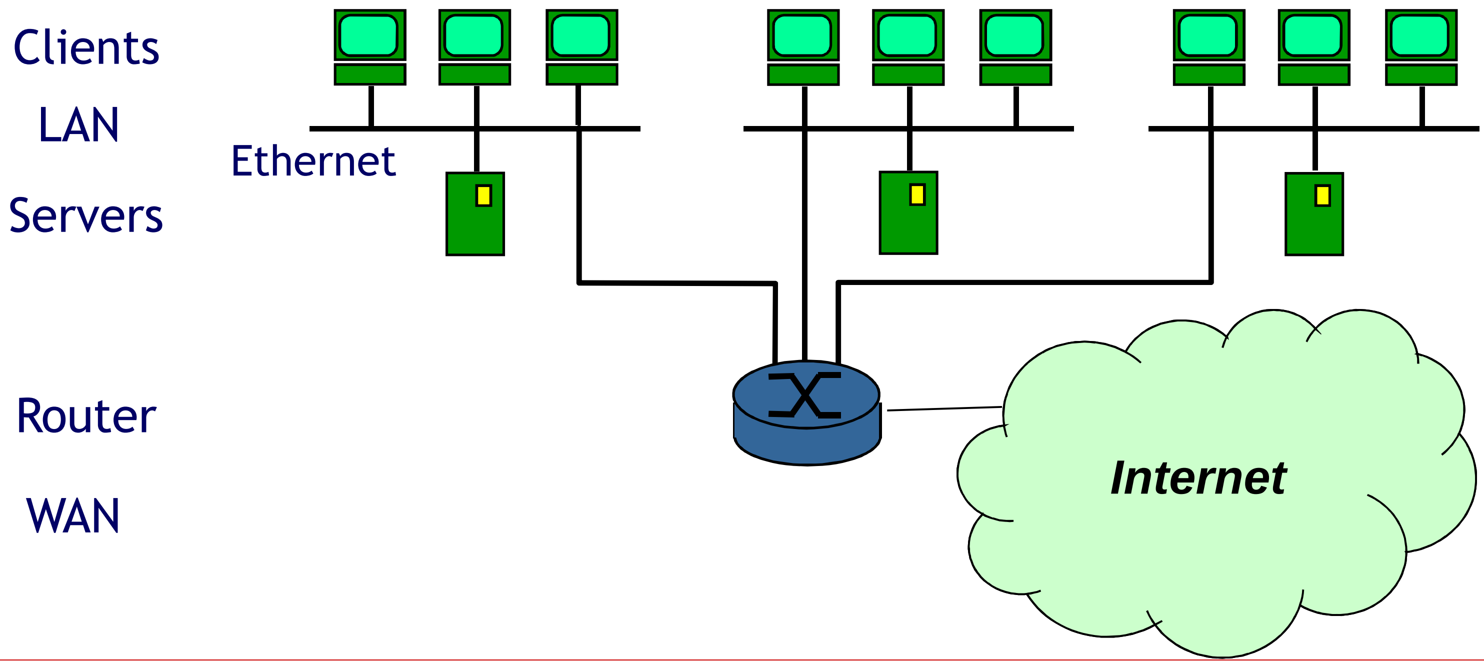
- Dialup
  - Direct access to ISP router through PSTN



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

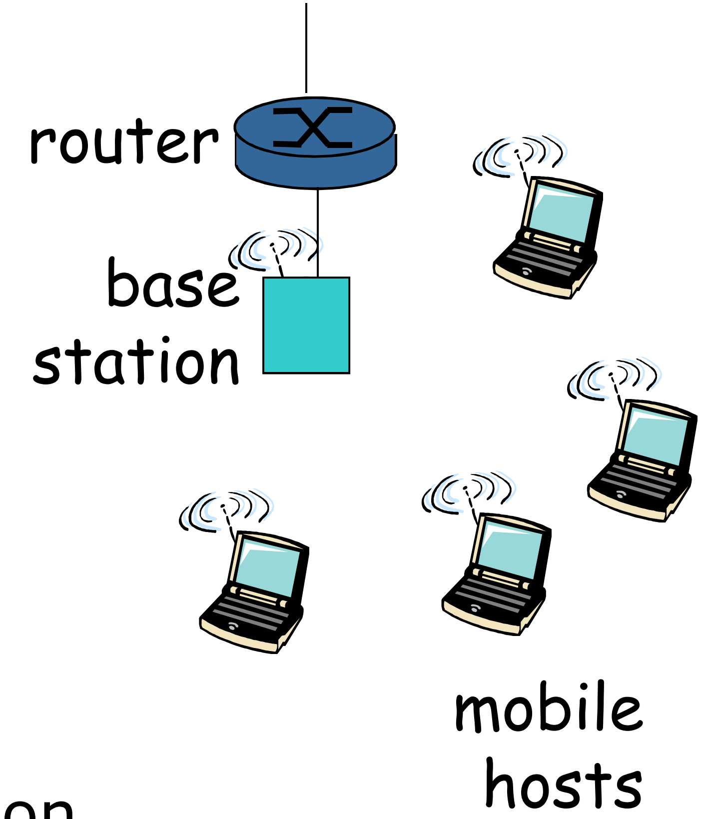
Access to the Internet

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



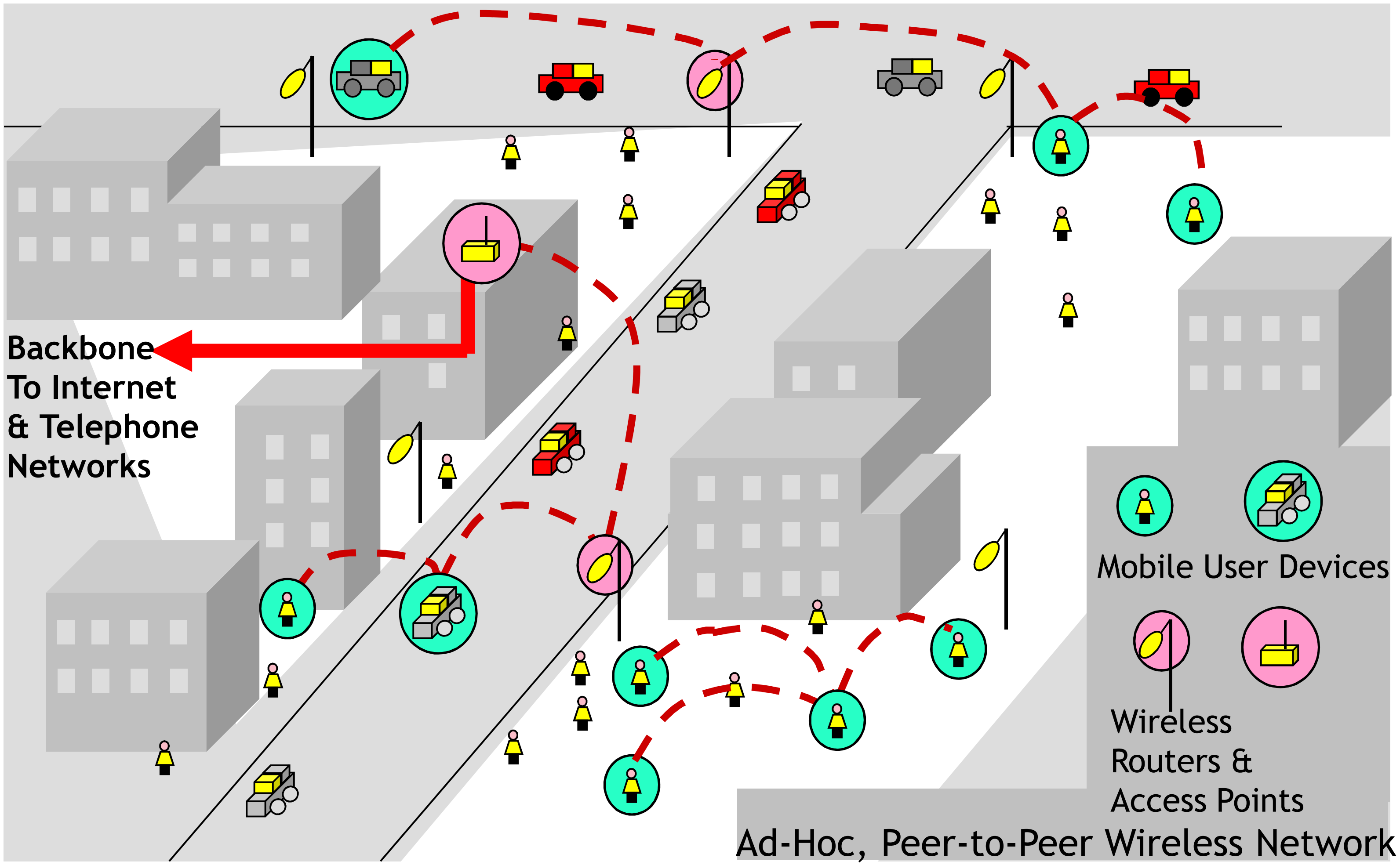
Access to the Internet

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



Access through a base station or access point

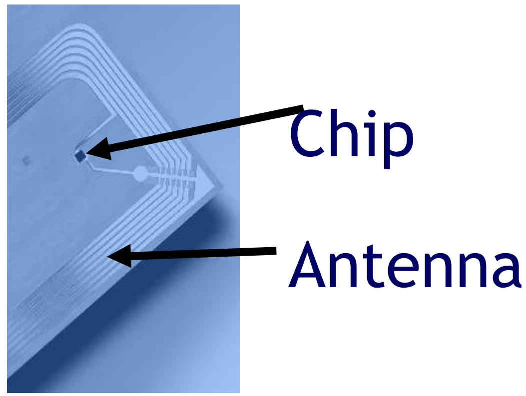
Pervasive Internet
Mesh & Ad hoc Networks



Distributed Networking

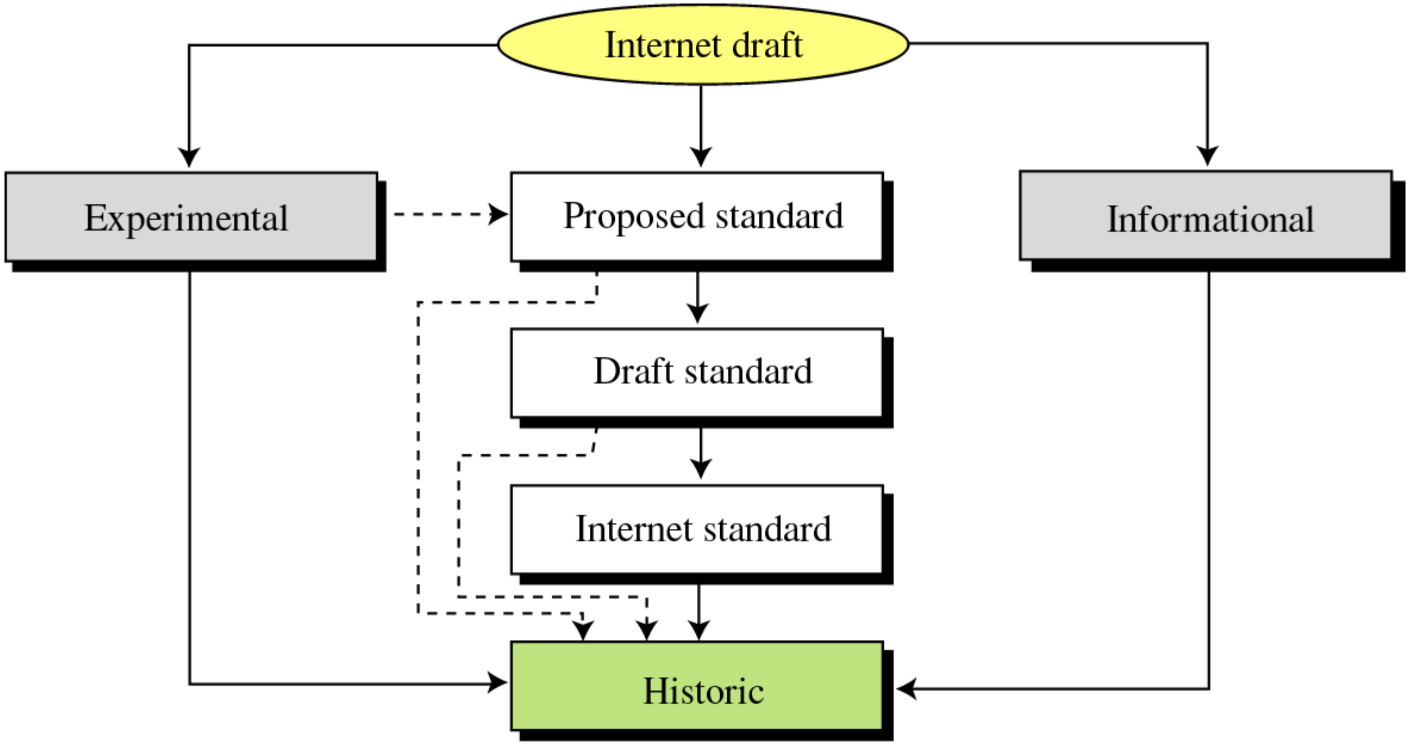
Pervasive Internet
Wireless Sensor Networks

- 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