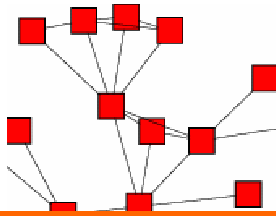
CS2105
Introduction to Computer Networks

In this lesson...

- What is computer networks?
- Evolution of computer networks
- Overview of network technologies: LAN/MAN/WAN/Internet
- Basic concepts and requirements of distributed processing, and its basic working principles: messaging, protocol and network architecture



EPIC 2015 Flash

- **Epic 2014** is the original flash online movie made by Robin Sloan for the Museum of Media History

  Set in 2014 Epic 2014 charts the history of the Internet, the evolving mediascape and the way news and newspapers were affected by the growth in online news.

  It coined the word "Googlezon" from a future merger of Google and Amazon to form the Google grid, and speaks of news wars with the Times becoming a print only paper for the elite culminating in EPIC Evolving Personalised Information Construct

  As a flash animation, this film is extraordinary, not just for it's use of technology but for it's fantastic perception looking forward.

  Epic 2015 is a new updated vision of the future built on Epic 2014 set but now set in 2015.

  http://epic.makingithappen.co.uk/

  http://www.albinoblacksheep.com/flash/epic

Course Outline

I. Introduction of Networked computing (4 hrs)

II. Network Applications (4 hrs)

III. Network security (2 hrs)

iv. Transport Layer Protocols (8 hrs)

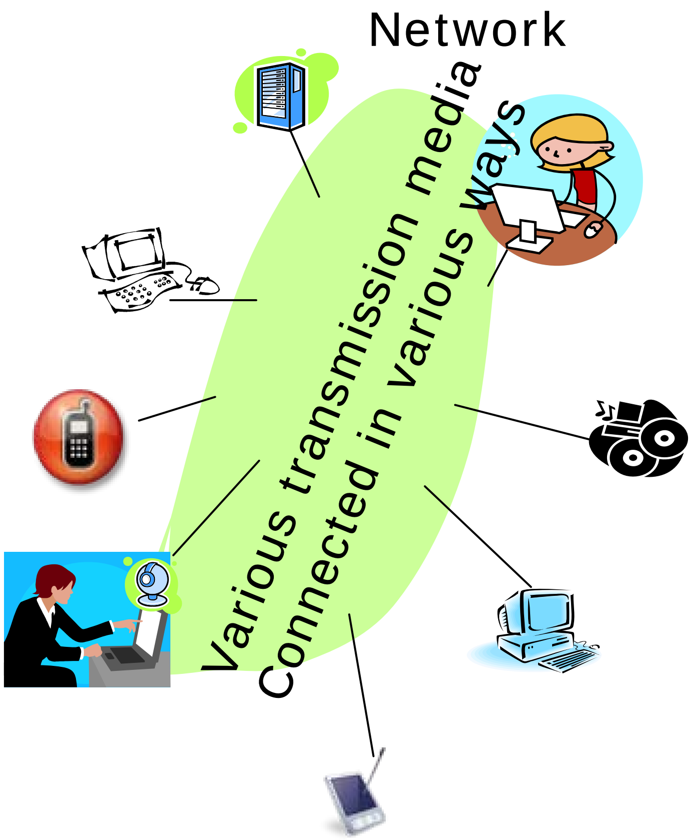
v. Network-layer, link-layer, and physical-layer protocols (8 hrs)

What is a Computer Network?

- A communication network is a set of nodes connected by links and able to communicate with one another.
- **A computer network is a communication network in which nodes are computers.**
- The purpose of the network is to serve users, which can be humans or processes.
- Network links can be point-to-point or multipoint and implemented with several transmission media.
- Information exchanged can be represented in multiple media (audio, text, video, images, etc.)
- Services provided to users can vary widely.

Cont. . .

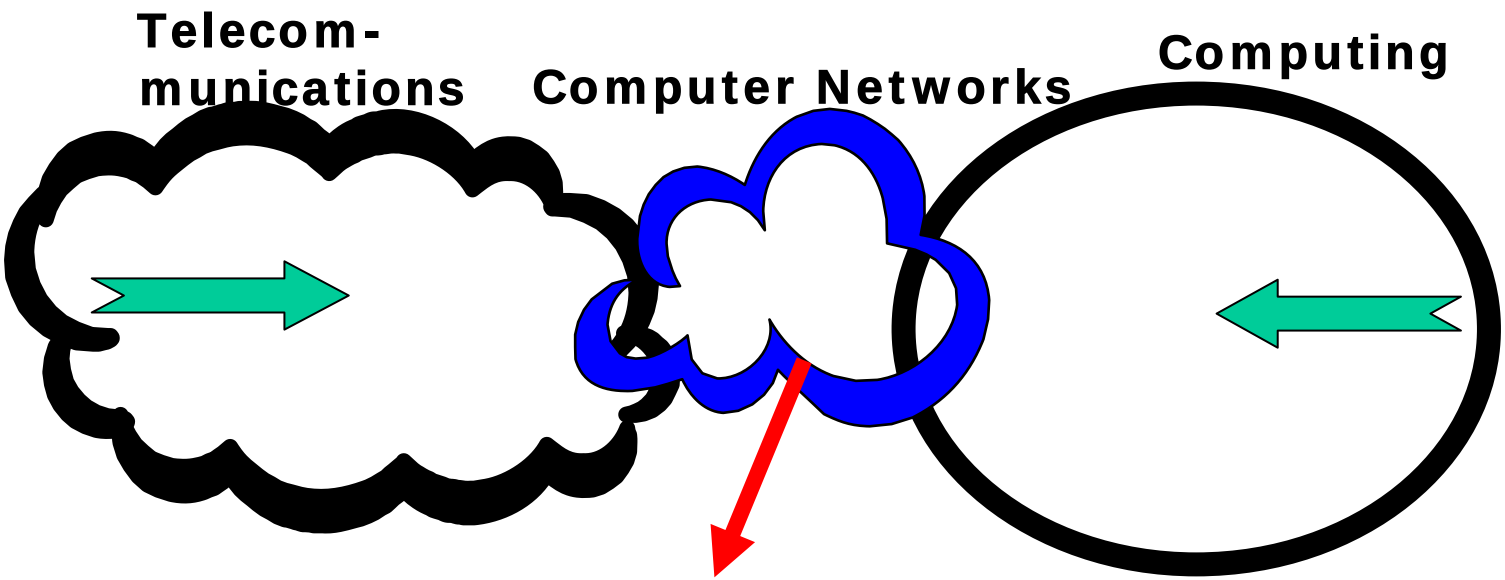
- **Computer networks started as a mean for**
  - ✶Distributed processing
  - ✶Communicating among people (electronic mail, conferencing)
  - ✶Increasing system reliability
- **The "web" and affordable hardware have changed this!**
  - ✶We are evolving into Internet-based enterprises, Internet-based home services, and an Internet society
- **The network will be everywhere NETWORKING = COMPUTING**



Media: Copper, coaxial, fiber, radio..

Topology: Ring, bus, mesh..

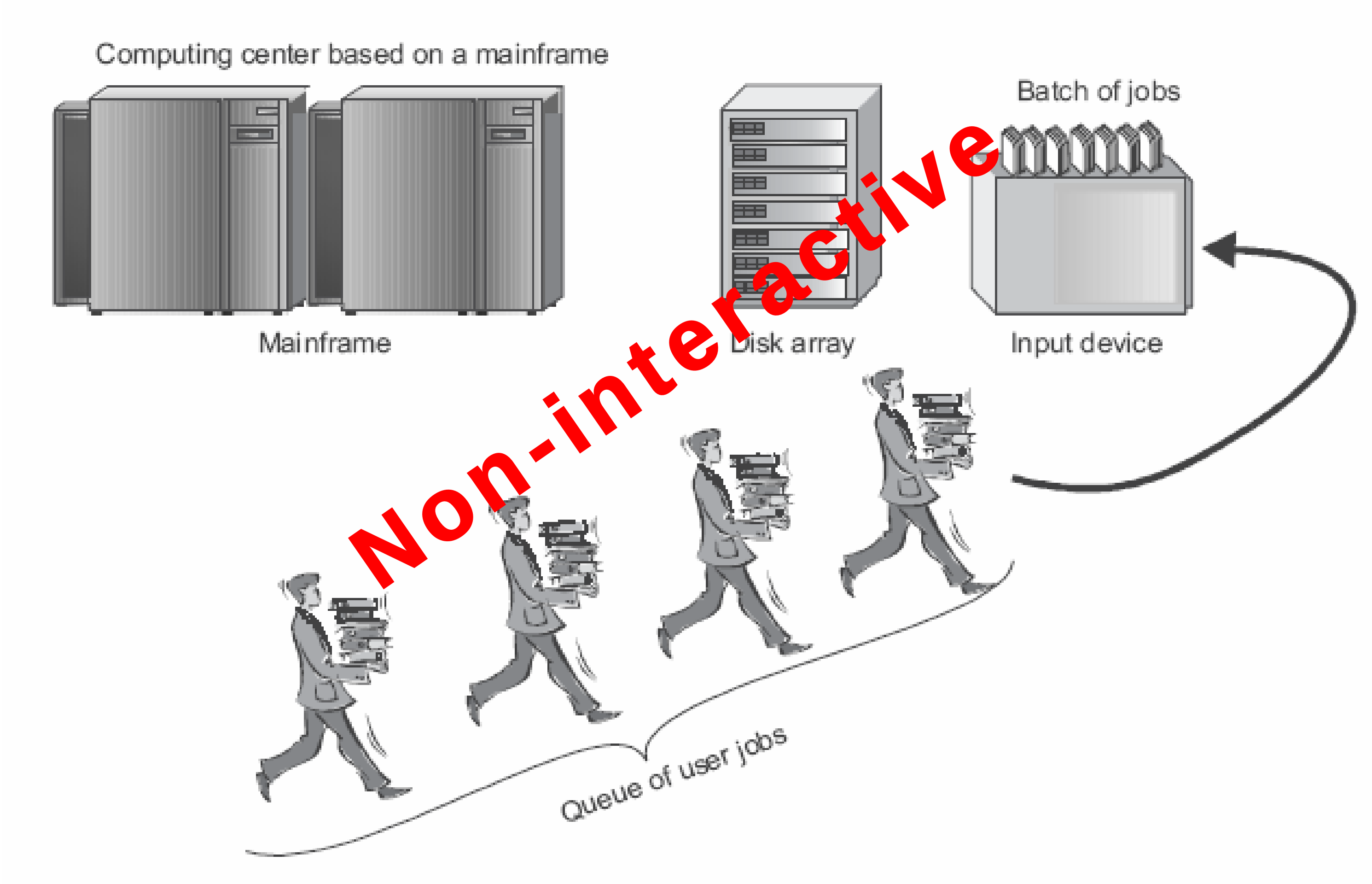
Evolution of computer networks*



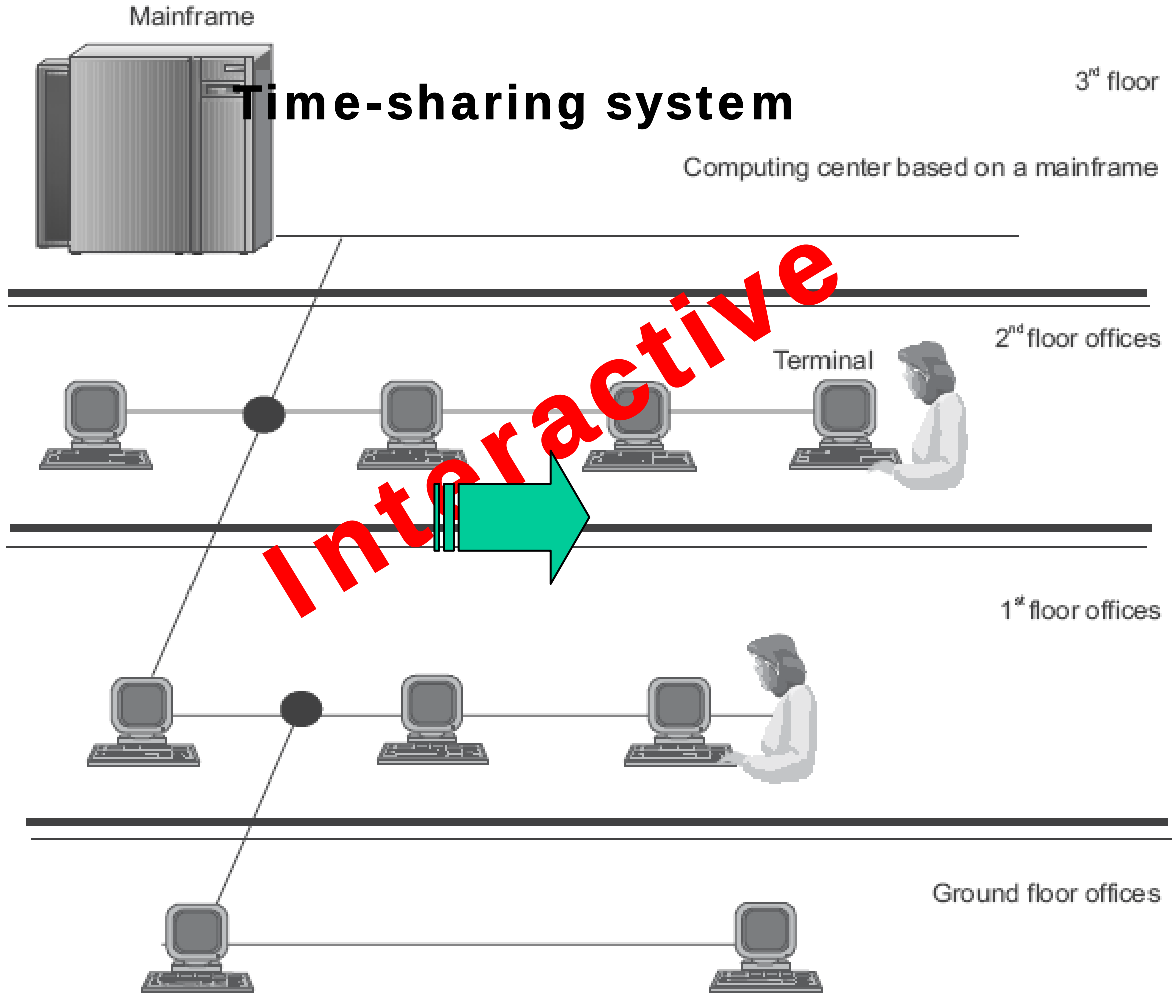
A distributed computing environment in which a group of computers perform in a coordinated manner to perform a set of interrelated tasks by exchanging data automatically

***Further reading:**
[PDF] EVOLUTION OF COMPUTER NETWORKS
Evolution of Networks: From Biological Nets to the Internet and WWW

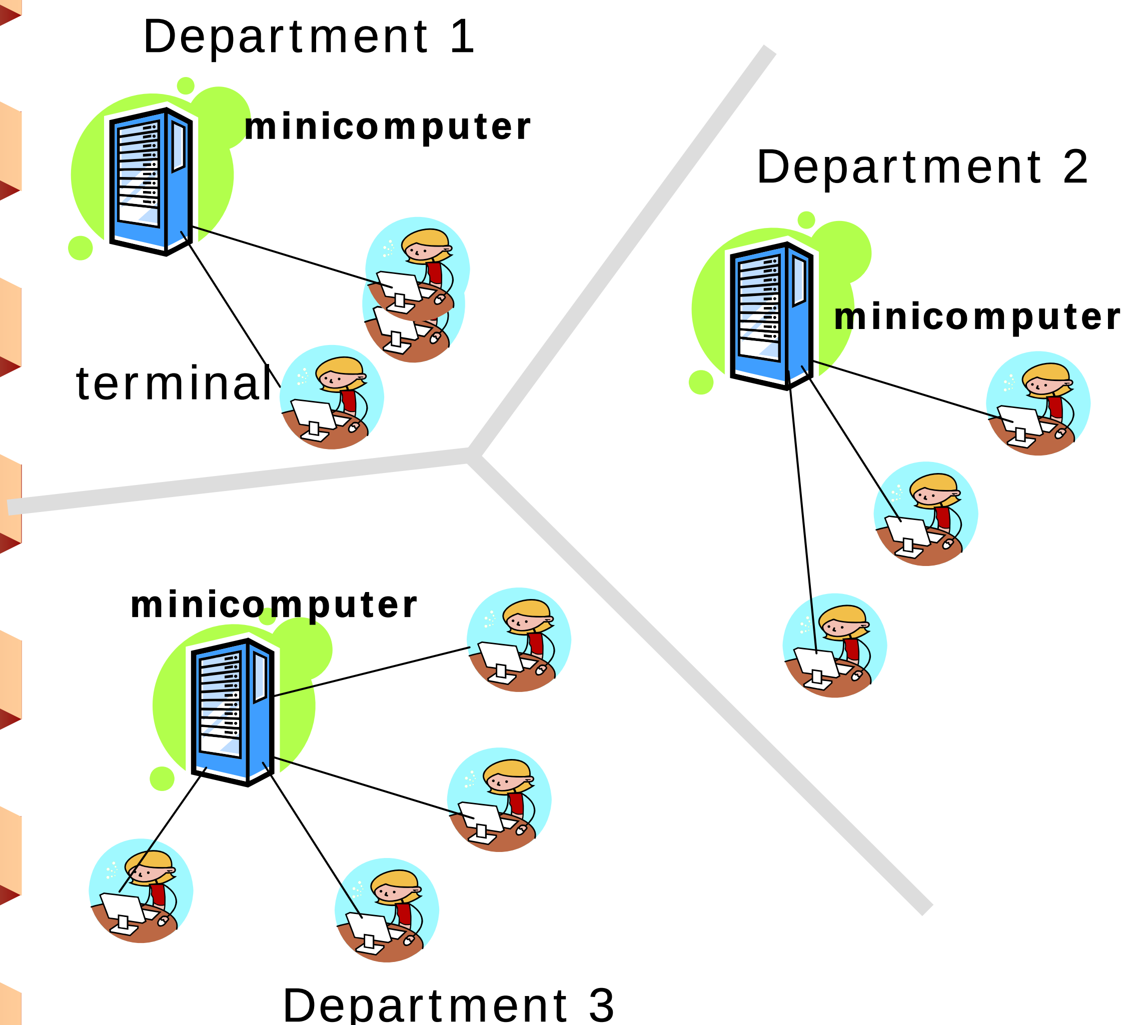
Batch processing system:1950s



An earliest computer network: multi-terminals systems- 1960s



First Local Area Networks (LANs):70s



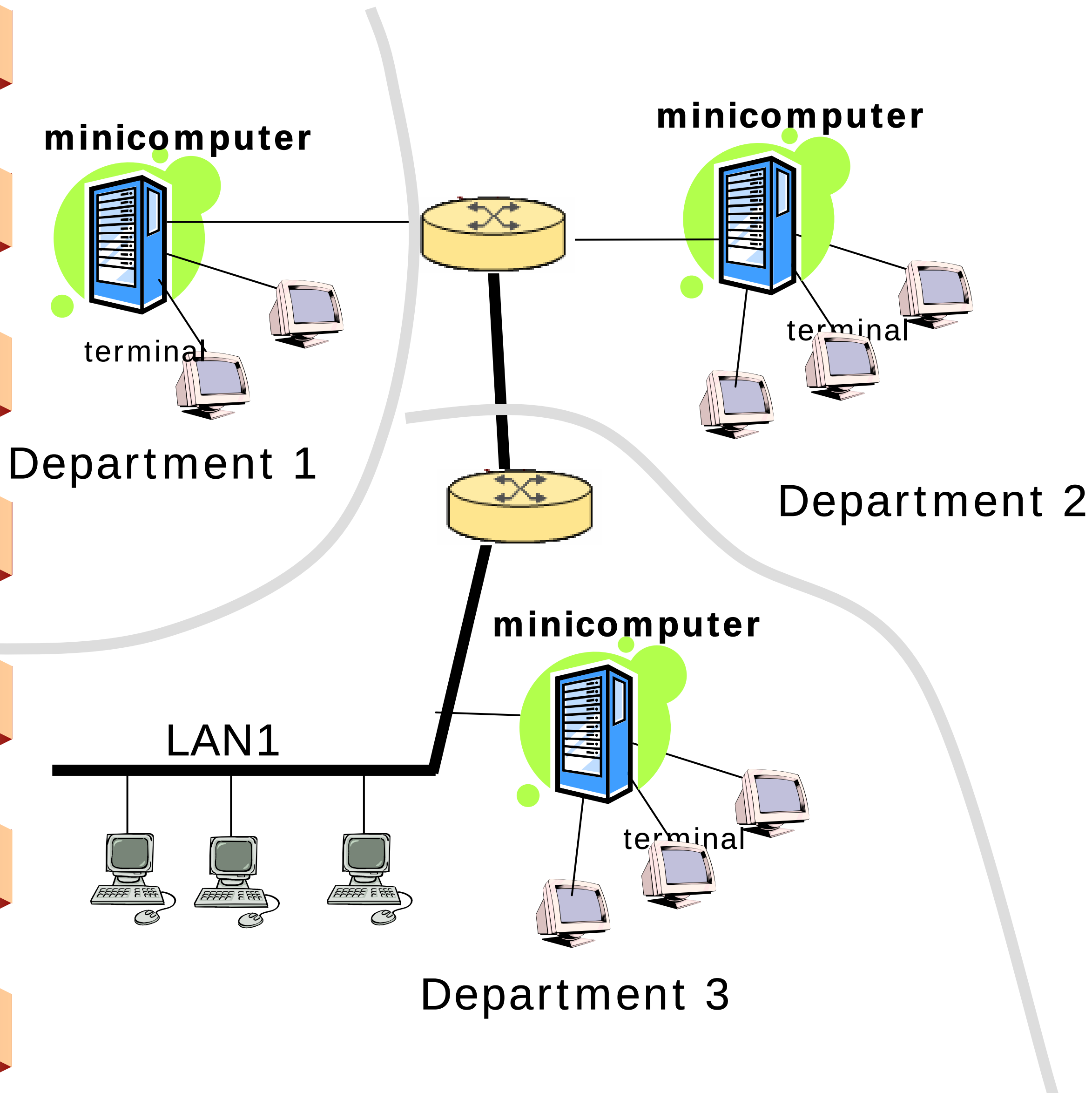
Driving forces for LANs

- Lowering cost, LSI
- Cheaper and powerful computers - PCs
- Need for better resource sharing

What is LAN?

- Groups of computers connected in a small region
- owned by an organization

Cont…



Characteristics

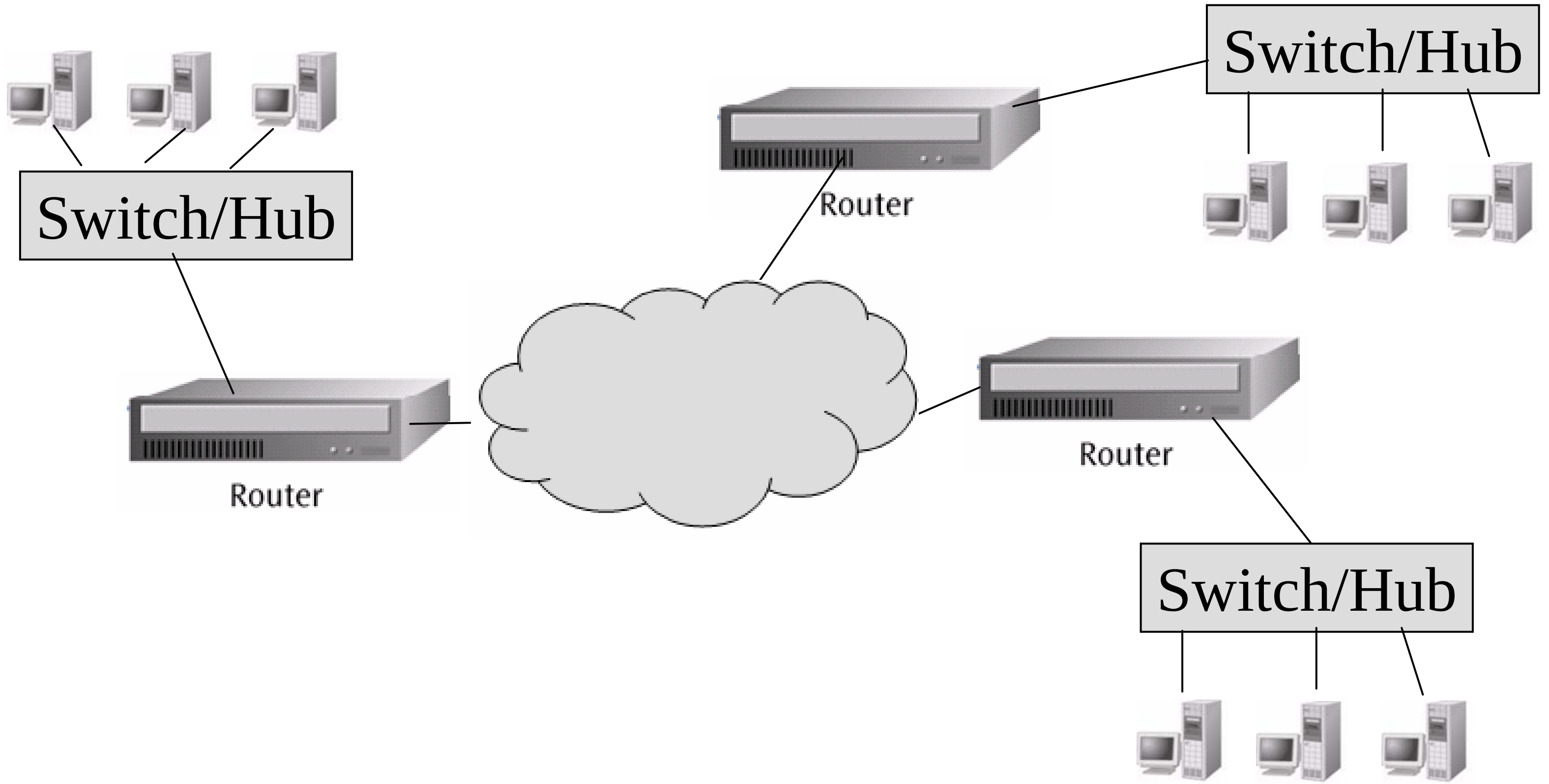
- ➢ high speed
- ➢ low delay
- ➢ Eg. Ethernet, token ring, FDDI, etc
- ➢Ethernet(10-1000 Mbps), has become the de facto LAN by late 90s

Wide Area Networks in 70's: First computer Network

- ➢**WAN connects geographically distributed computers together**
- ➢**Earlier Networks (DECNET, SNA, ARPANET) development has contributed to:**
  - ✶Layered Network architecture
  - ✶Packet switching technology
  - ✶Packet routing in heterogeneous networks
  - ✶Network OS
  - ✶TCP/ IP

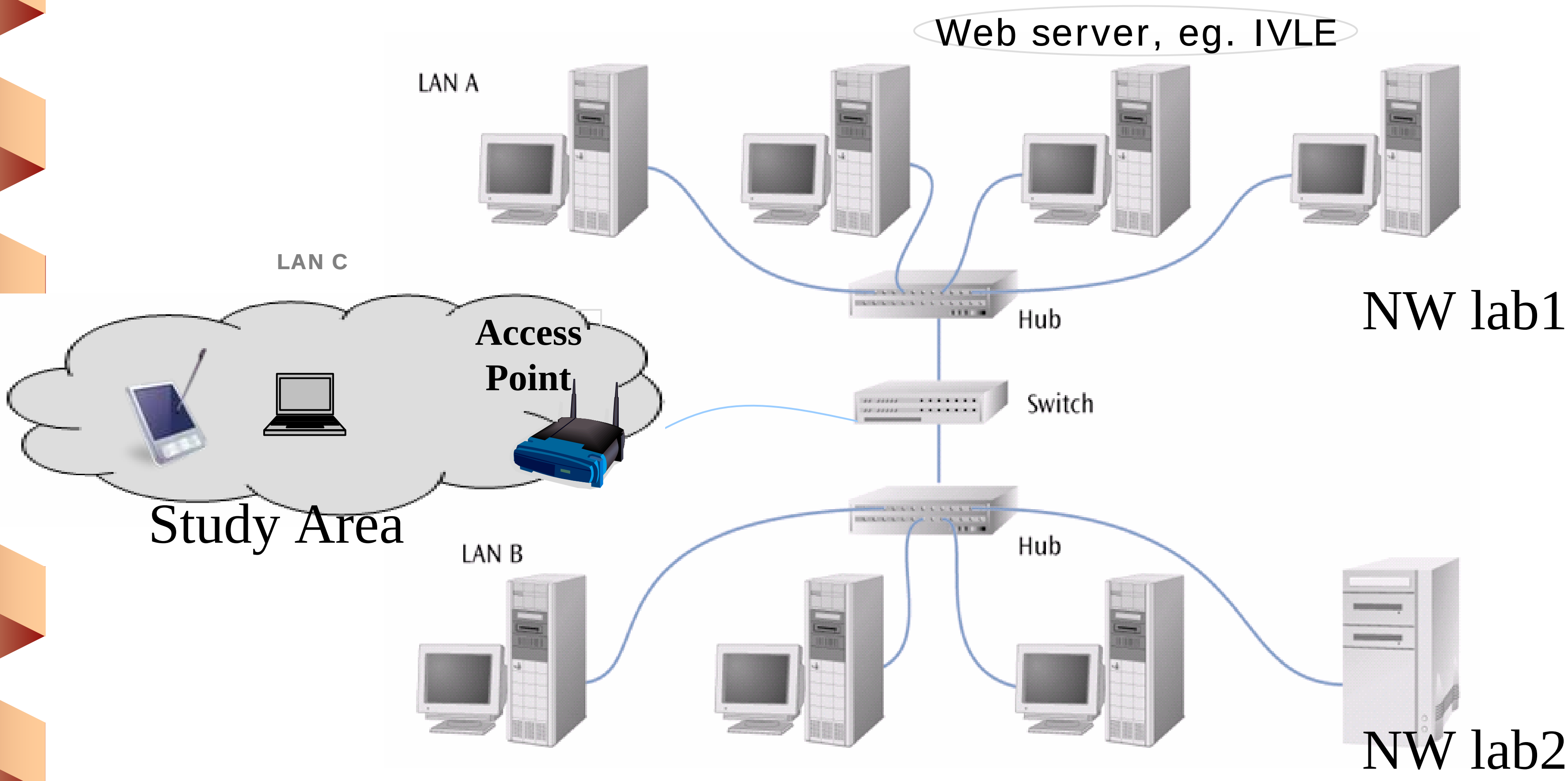
INTERNET

- WAN & IP (Internet Protocol)
  - ✶A collection of networks interconnected and function as a single worldwide network is known as INTERNET
  - ✶WAN is used for interconnection; IP is the glue



INTRANET

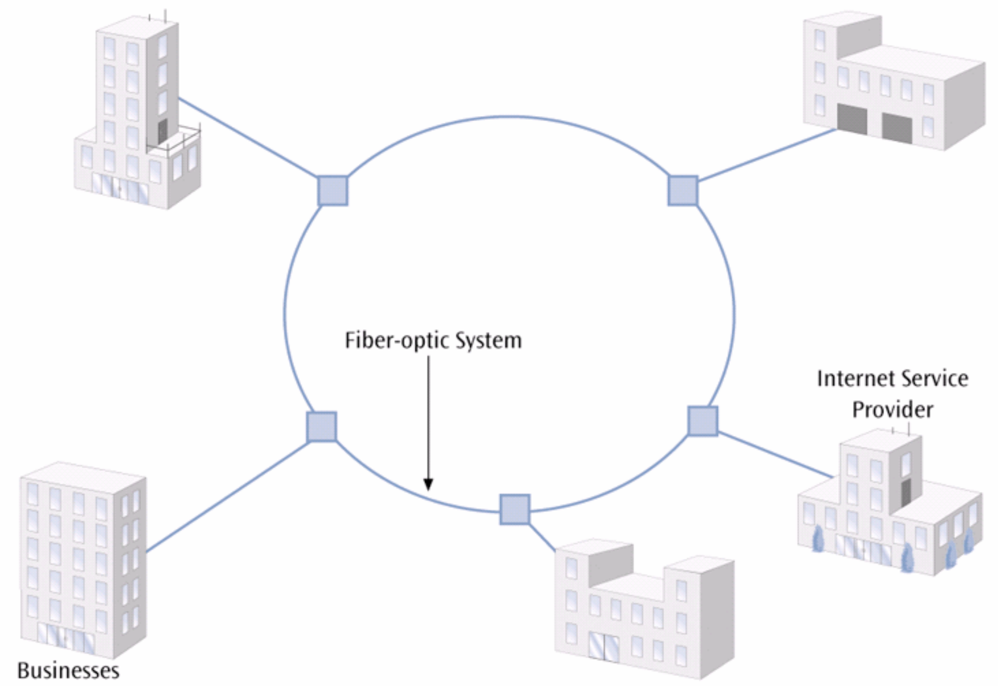
- Multiple LANs of an organization interconnected using IP protocol (i.e. WANs technology) is known as INTRANET



Metropolitan Networks (MANs)

Metropolitan Area Networks (MANs) are networks between LANs and WANs

- Higher speed than LANs (155 Mbps and above)
- Cover a larger area (such as a city)
- Mostly using fiber as the transmission media
- Connecting LANs and and LANs to WANs



Chronological of the most significant events in the history of computer networks FYORP

- 60s : First experiments with batch-processing networks – terminal oriented network
- 1962: Paul Baran at RAND proposes packet switching
- 1969: DARPA funds project on packet switching, 1st IMP at UCLA
- 1970s: Computerized switches; work on ISDN starts
- 1970s early: Large Scale IC, 1st mini-computers
- 1970s: ARPANET starts (UCLA, Utah, SRI, UCSB); its technology evolved into today's Internet
- 1972: ARPANET grew to 15 nodes
- 1972 – 80 propriety networks and internetworking growing – ALOHAnet (packet radio), Telenet (BBN commercial packet switching network), Cyclades (French), Tymnet, IBM's SNA….
- 1974: "A Protocol for Packet Network Interconnection,"V. Cerf and R. Kahn, IEEE Trans. Comm (May).
- 1974: Standardization of X.25
- 1980s early: First PC

Cont..

FYORP

- 1980s: OSI (open system interconnection) reference model
- 1983: official deployment of TCP/IP in ARPANET/MILNET
- 1986: NSFNET is created; becomes Internet backbone
- 1980-85: Standardization of LANs (Ethernet, token ring, fddi)
- 1980s late: Commercial use of internet
- 1990s: ATM evolves; does not replace IP
- 1990s: Internet: From 4 to 30M+ wired, published nodes in two decades
- 1992: WWW by Tim Berners-Lee (CERN) is released; gives a GUI to the Internet
- 1999: Gigabit Ethernet starts, simplicity wins again.
- 1990s late: Convergence of telecommunications networks and computer networks
- Early 2000 – dot com crashed.
- Wireless bloom, P2P

What will happen in the 2000s?

- Ad-hoc wireless networks; self-configuring nets
- Networked sensors and appliances
- IP voice, IP devices
- Content routing: ISPs start to be CDNs, allow clients to obtain content based on its name from the best location
- Network convergence (Telecommunication and Computer networks) → Multiservice networks : telephone, TV, video, radio, web apps, business, edutainments, healthcare
- Network-based community computing: grid computing

  ("the computer--processing and storage--is in the network")
- System-area networks ("the network is [in] the computer")

"Networked Computing is the future. Not PC!"
- Major players like, SUN, Microsoft… have admitted.

Introduction of Networked Computing*

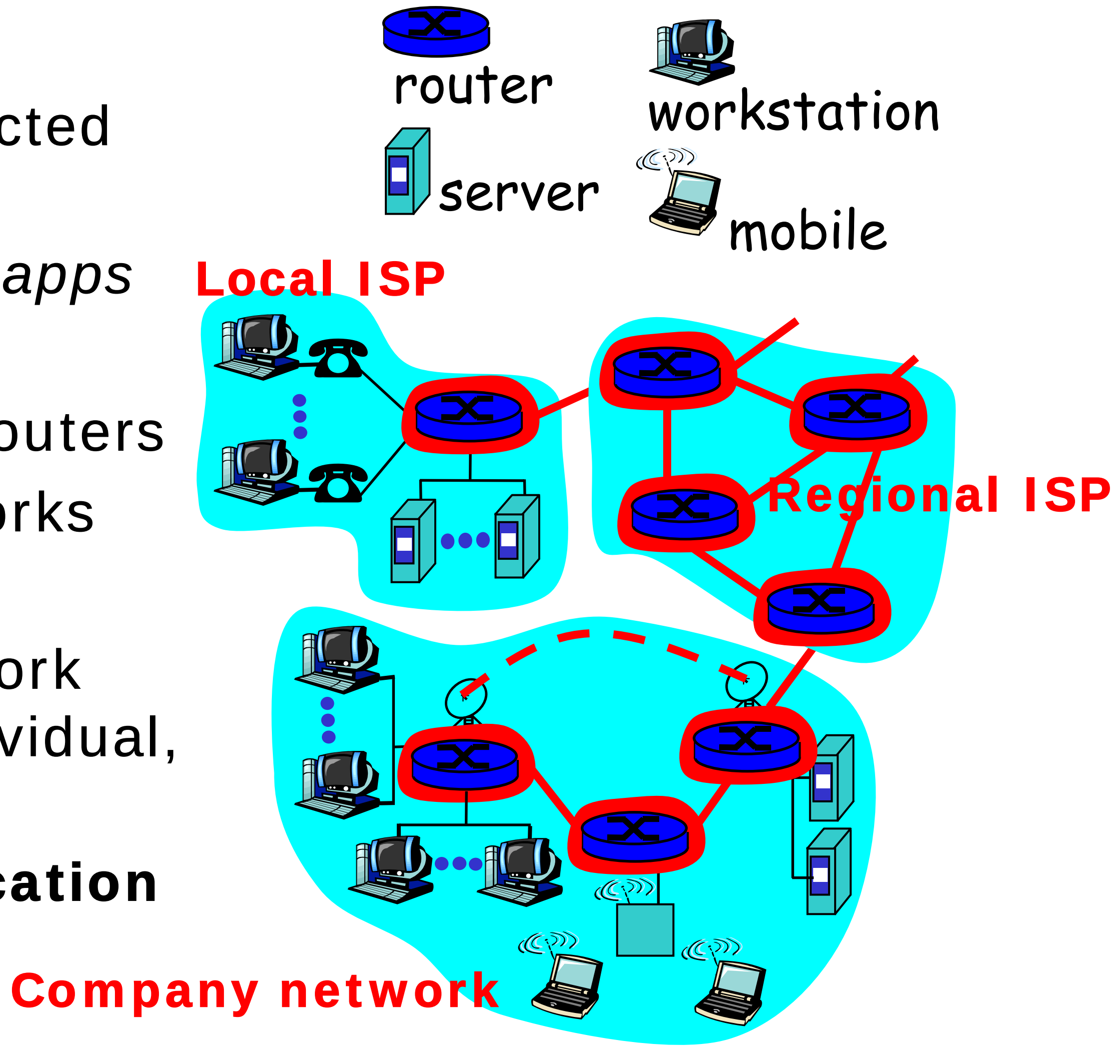
Sub-topics:

- What is computer networks?
- Evolution of computer networks
- Overview of network technologies: LAN/MAN/WAN/Internet
- Basic concepts and requirements of distributed processing, and its basic working principles: messaging, protocol and network architecture

Kurose Text Book, Chapter 1
(Some slides/images are taken from text book)

Compositions of a network: Internet as an example

- **Network edge**
  - ✶millions of connected computing device
  - ✶running *network apps*
- **Network core**
  - ✶Interconnected routers
  - ✶network of networks
- **Access networks**
  - ✶Varieties of network technology for individual, home & offices
- **Different communication links**



Internet: Service View

- Connection-Oriented Service
  - TCP
    - Reliable Transfer
    - Flow Control Service
    - Congestion Control Service
- Connectionless Service
  - UDP
    - Unreliable

A real life example of communication: Postal Service

A. Bob writes a letter

1. Puts the letter into an envelope
2. Fills up the recipient's address
3. Posts the letter
4. Postal company picks up the letters from various letter boxes, brings them to the area office for sorting
5. Sorted mails are transported to the respective destination area office
6. Postman at the various area offices deliver the letters to respective homes
7. Recipient picks up letter from his own mailbox

- The postal service is independent of the letter writing and the process of letters being pick up by the recipients
- Clearly there is a need to standardize the postal service (postage, addressing)
- There is a client and server relationship here; connectionless service.

Another real life example of communication: Telephone call

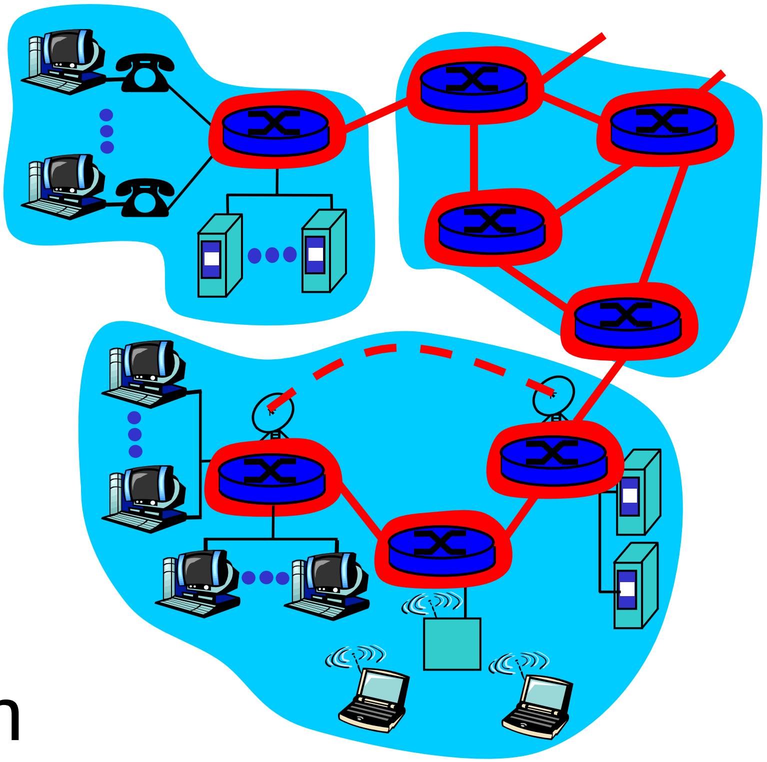
B. Bob wishes to call Alice, dials her telephone no

1. A connection request is sent to telephone network
   1. Network route the request and set up the circuit
   2. Rise a ringtone at Alice's phone
2. Alice picks up the phone (ie accept the call)
3. Network confirms the connection and the 'circuit' is maintained and dedicated for his conversation
4. Alice and Bob can then start speaking
5. Either party may terminate the call
6. Network will then release the circuit

➢ What are the differences in the processes of the postal service and the telephone service?
Connection oriented service

The Network Core

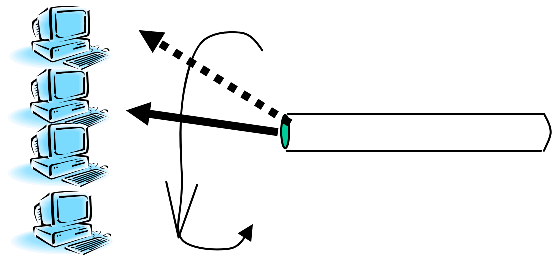
- mesh of interconnected routers
- *the* fundamental question: how is data transferred through net?
    - ✶How would the network resources be shared?
    - ✶Which path to take to delivery data between two-points in a network?



Network Core - Switching

- Circuit Switch
  - ✶ Dedicated end-to-end connection
  - ✶ Guaranteed service, (eg.guaranteed transmission rate)
  - ✶ Resources are reserved
  - ✶ Intermediate switches maintains the connection
  - ✶ Eg. Telephone network

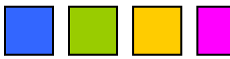
Multiplexing in Circuit Switched Networks



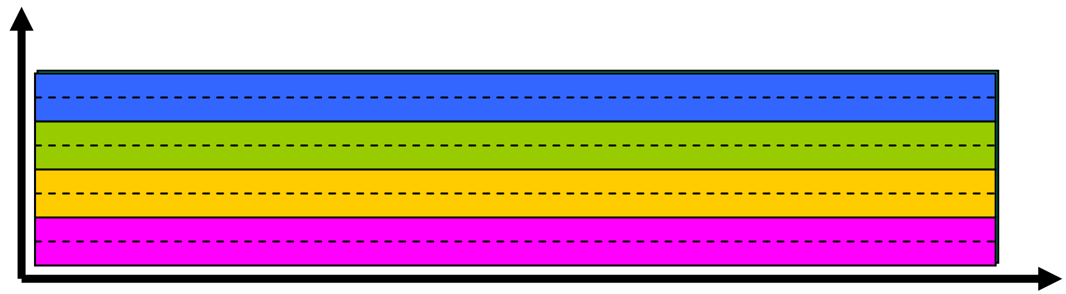
FDM

Example:

4 users



frequency

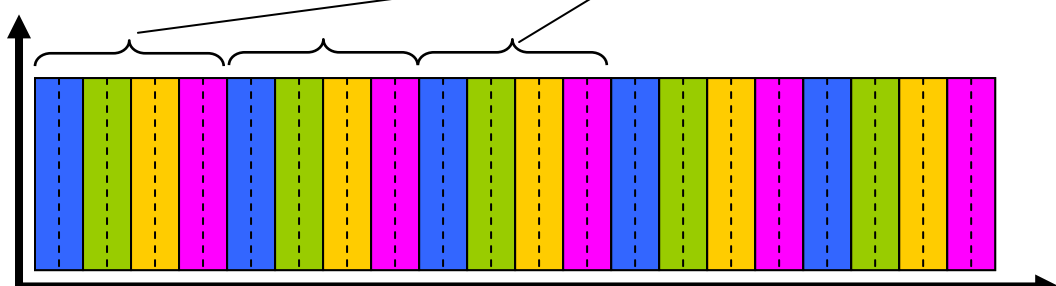


time

TDM

frames

frequency



Slots **1 2 3 4 1 2 3 4 1 2 3 4**

time

Circuit Switching: A numerical example

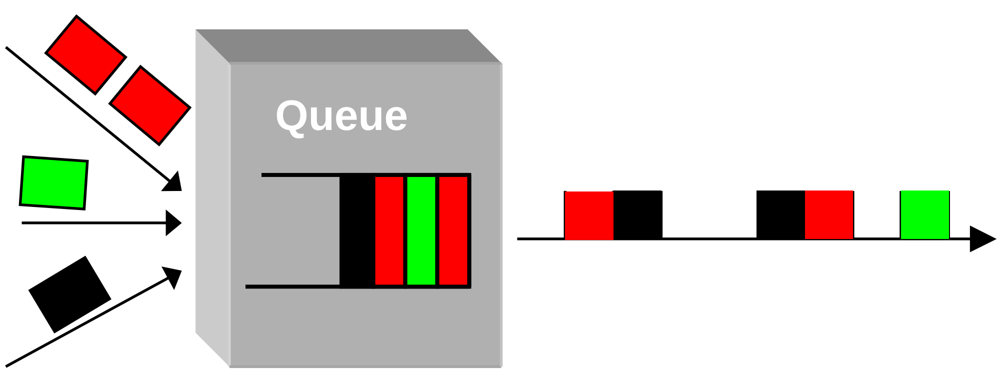
- How long does it take to send a file of 640,000 bits from host A to host B over a circuit-switched network?
  - All links are 1.536 Mbps
  - Each link uses TDM with 24 slots/sec
  - 500 msec to establish end-to-end circuit

Multiplexing in Circuit Switched Networks

- Assume link capacity is R bits/sec and TDM
- Each communication requires L bits/sec
  - How many concurrent communications are possible?
  - What if the a communication sends less than L bits/sec?
  - What if the a communication sends more than L bits/sec?
  - What if the number of concurrent communications exceeds the maximum?
  - Is Circuit Switching suitable for Internet? Why? Why not?

Network Core – Switching

- Packet Switch
  - Data is sent in **Packets** (header contains control info, e.g., source and destination addresses)
  - Per-packet routing
  - At each node the entire packet is received, stored, and then forwarded (**store-and-forward networks**)
  - No capacity is allocated, Best effort service
  - Link is allocated on demand
  - Different packets might follow different paths, reordering required
  - Eg. Internet



Best Effort Service Model

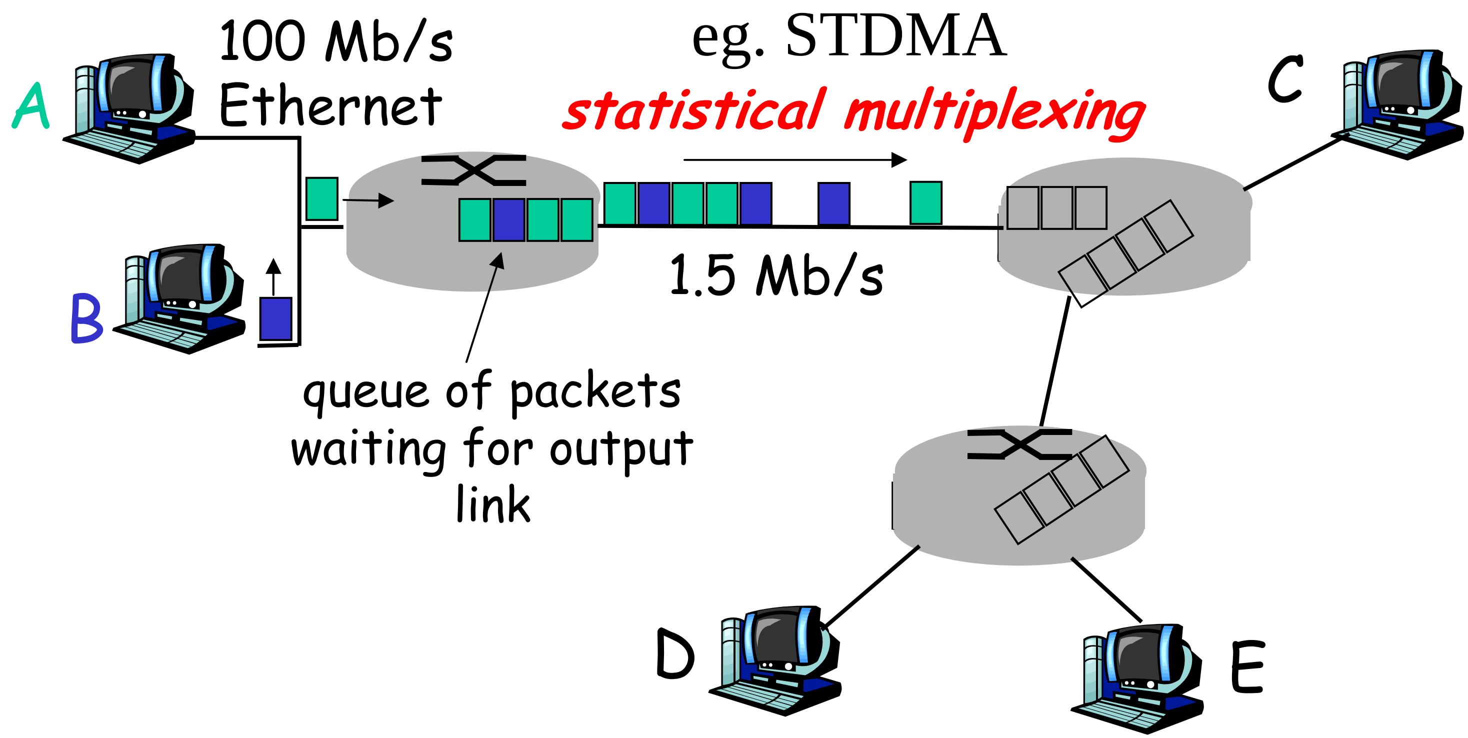
No Guarantees:

- ✶ Variable Delay (jitter)
- ✶ Variable rate
- ✶ Packet loss
- ✶ Duplicates
- ✶ Reordering

Eg. Internet

Q: Postal Service?

Multiplexing in Packet Switching



Lecture – Week 2

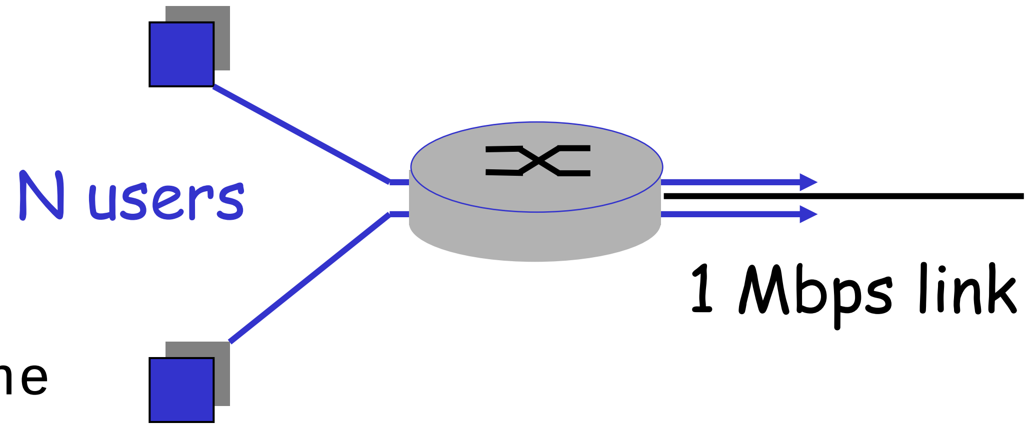
- Recap on Circuit and packet Switching

Circuit-Switching	Packet-Switching
Guaranteed transmission rate	No guarantees (best effort)
Not suitable for Internet traffic (bursty)	More suitable and efficient
Before sending data establishes a path/connection, intermediate switches maintain the connection	Send data immediately (Store-and-Forward) Forward data based on destination addr in Packet header
All data in a single flow follow one path	Different packets might follow different paths
No reordering; constant delay; no pkt drops	Packets may be reordered, delayed, or dropped

Packet switching versus circuit switching

Packet switching allows more users to use network!

- 1 Mb/s link
- each user:
  - 100 kb/s when "active"
  - active 10% of time



- circuit-switching:
  - 10 users
- packet switching:
  - with 35 users, probability => 11 active less than .0004

$$f_b(x) = \frac{n!\,p^x (1-p)^{n-x}}{x!(n-x)!}$$

$$f_b(11) = \frac{35!\,(0.1)^{11}\,(0.9)^{35-11}}{(11!)\,(24!)}$$

Q: how did we get value 0.0004?

$$f_b(>=11) = ?$$

Packet Switched Networks

- Datagram Networks
  - Destination address. Eg IP addr
  - Internet
- Virtual-Circuit Networks
  - Virtual-circuit numbers. Eg VC-ID
  - ATM, X.25, frame relay
  - Establish connection
  - Connection state information in intermediate switches
- Q: Advantages of VC networks over Datagram networks?
  - Switching is faster
  - QoS – Easy to provide differentiated services

Packet Switched Networks

- IP forwarding Table

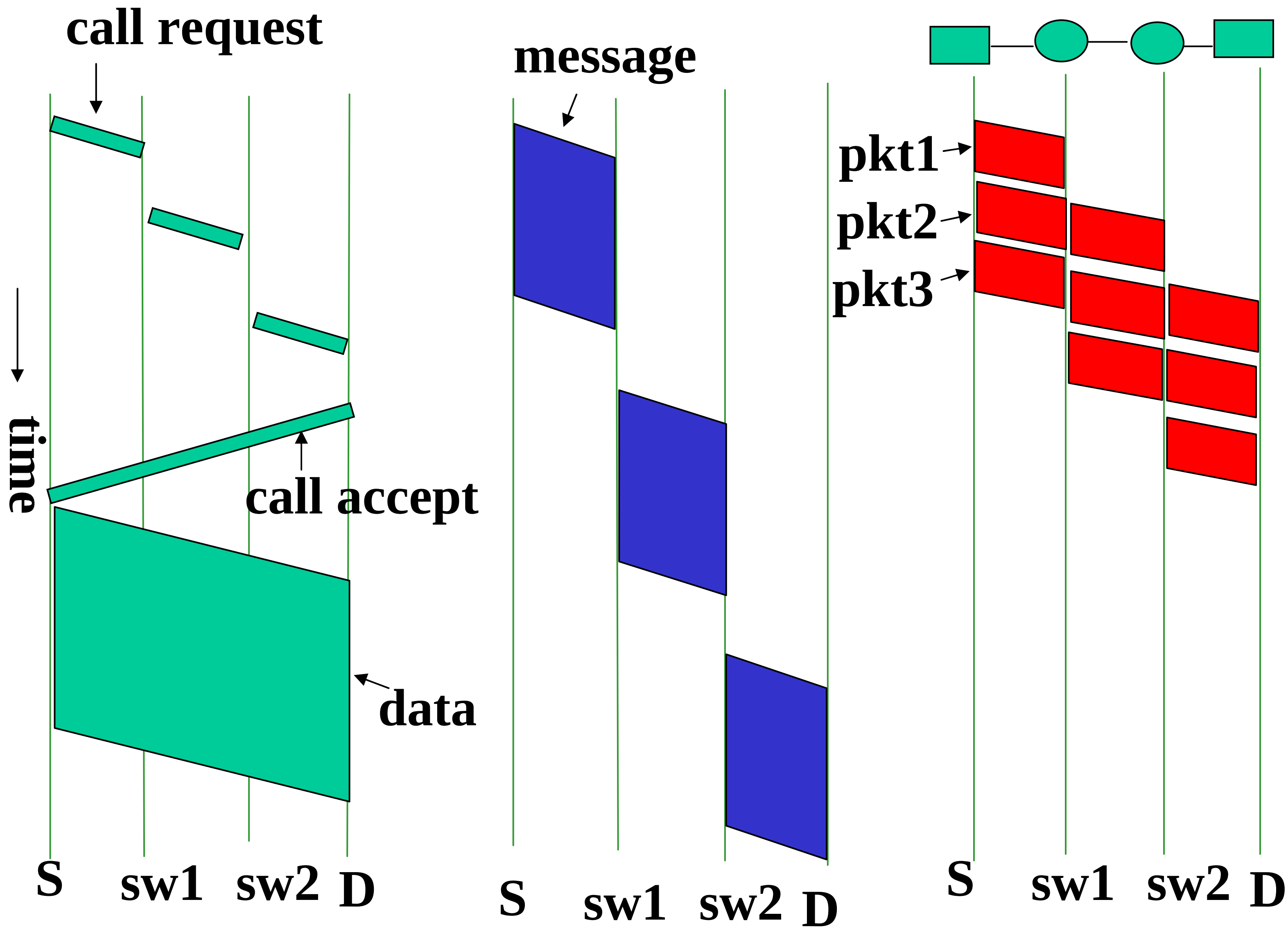
```
===========================================================================
Active Routes:
Network Destination        Netmask          Gateway       Interface  Metric
          0.0.0.0          0.0.0.0    192.168.1.254    192.168.1.64       1
        127.0.0.0        255.0.0.0        127.0.0.1       127.0.0.1       1
      192.168.1.0    255.255.255.0     192.168.1.64    192.168.1.64      25
     192.168.1.64  255.255.255.255        127.0.0.1       127.0.0.1      25
    192.168.1.255  255.255.255.255     192.168.1.64    192.168.1.64      25
        224.0.0.0        240.0.0.0     192.168.1.64    192.168.1.64      25
  255.255.255.255  255.255.255.255     192.168.1.64               3       1
  255.255.255.255  255.255.255.255     192.168.1.64               2       1
  255.255.255.255  255.255.255.255     192.168.1.64    192.168.1.64       1
Default Gateway:     192.168.1.254
===========================================================================
```

- VC forwarding table

Switch #1			
In Port	In Label	Out Port	Out Label
1	2	3	5
2	1	3	1
1	1	4	1

In Label/Out Label – VC ID

Circuit, Message, and Packet switching



Taxonomy of Telecommunication Networks

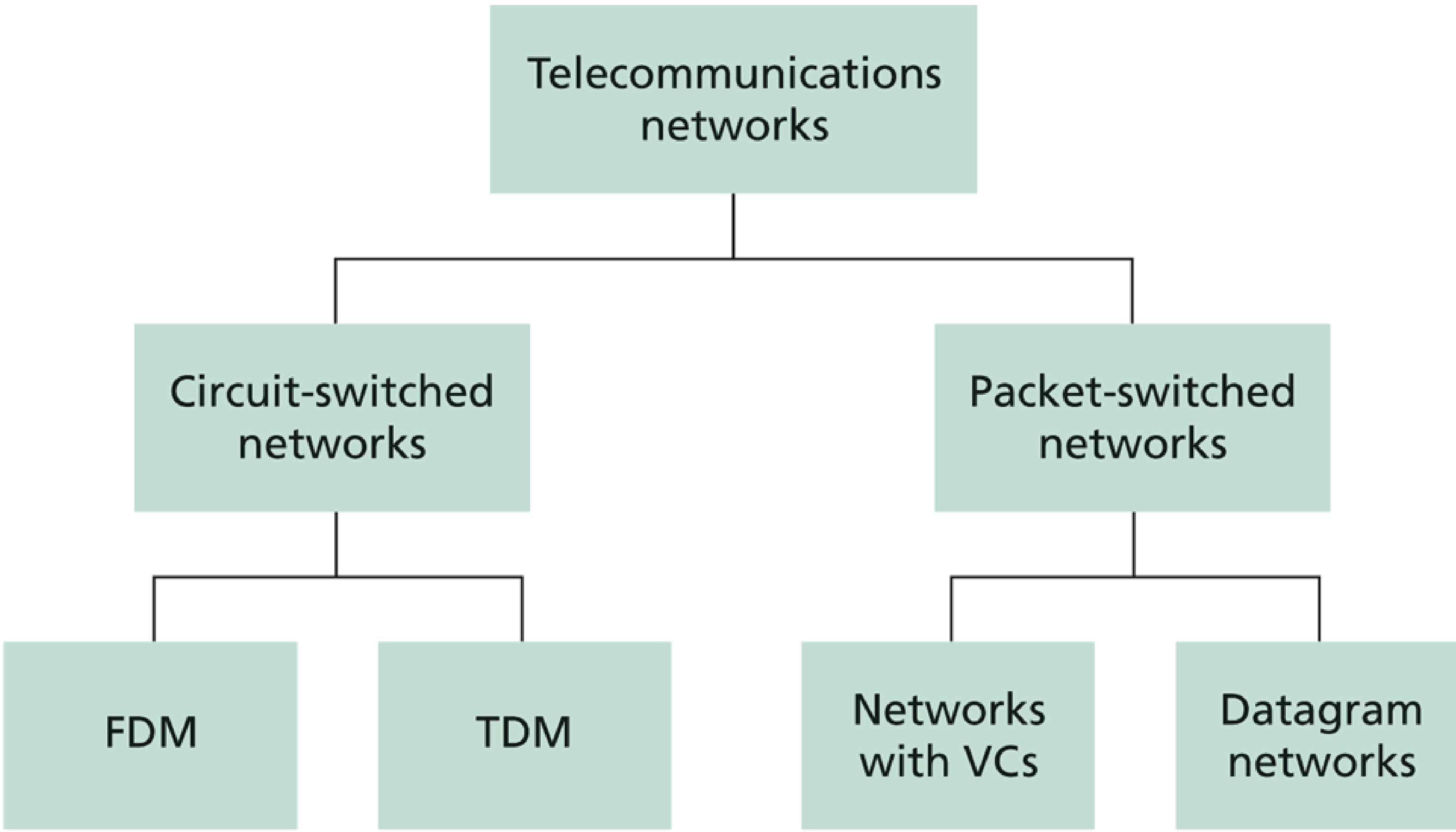
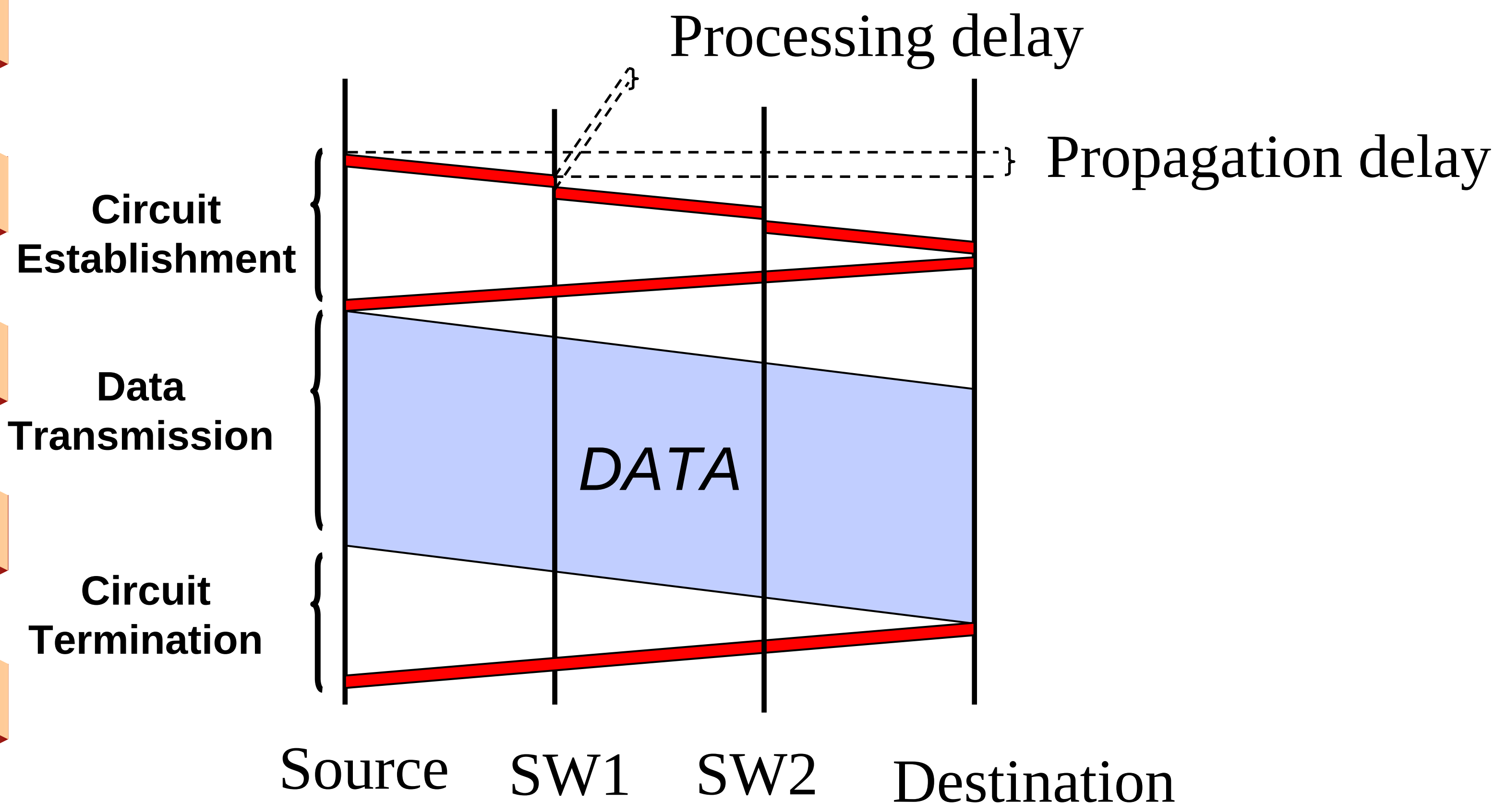


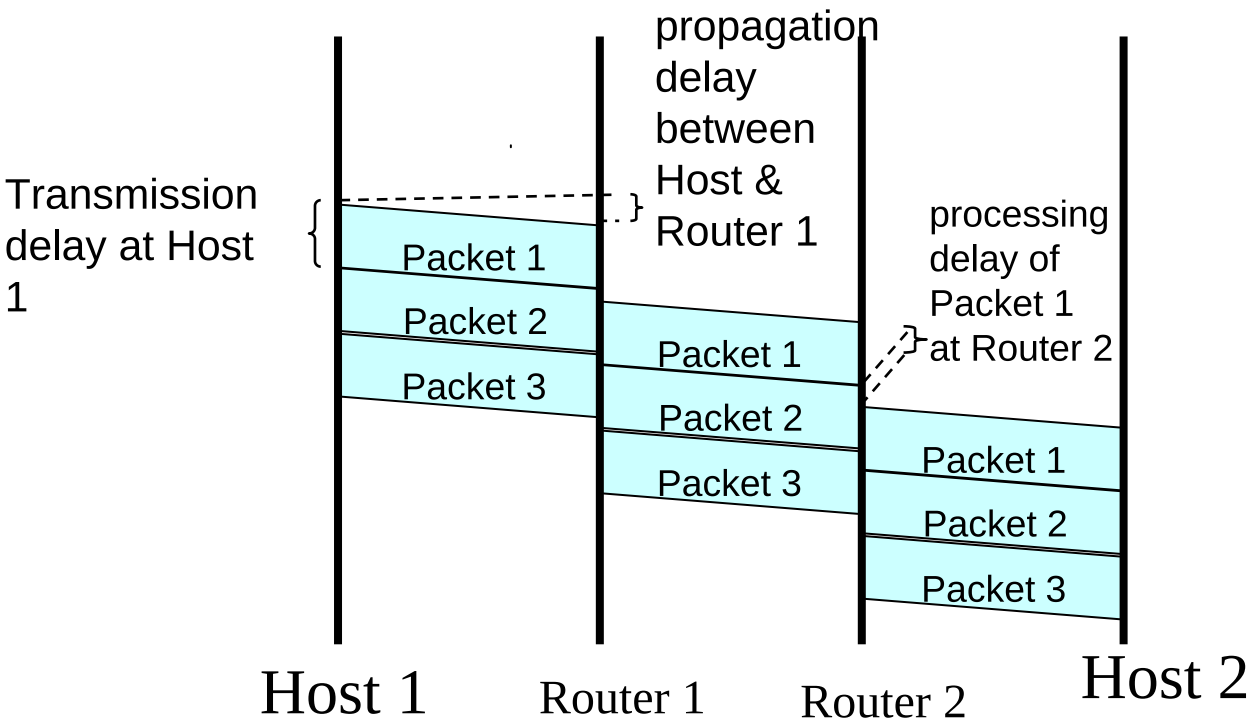
Figure 1.8 ♦ Taxonomy of telecommunication networks

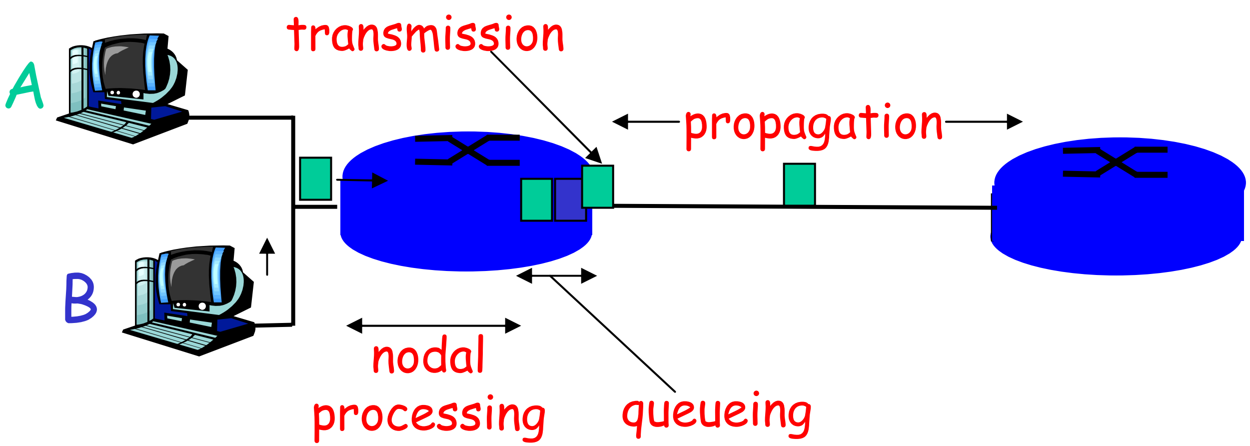
Delay in Circuit Switched Networks



Total Delay: Circuit Establishment/Termination Delay + Transmission Delay + Propagation Delay

Delay in Packet Switched Networks





Delay in Packet Switched Networks

- Nodal Delay components:
  - ✶ Processing Delay
  - ✶ Queuing Delay
  - ✶ Transmission Delay
    - – R=link bandwidth (bps)
    - – L=packet length (bits)
    - – time to send bits into link = L/R
  - ✶ 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?
- Eg: Water pipe. (Capacity vs Propagation)

Delay – CS, PS

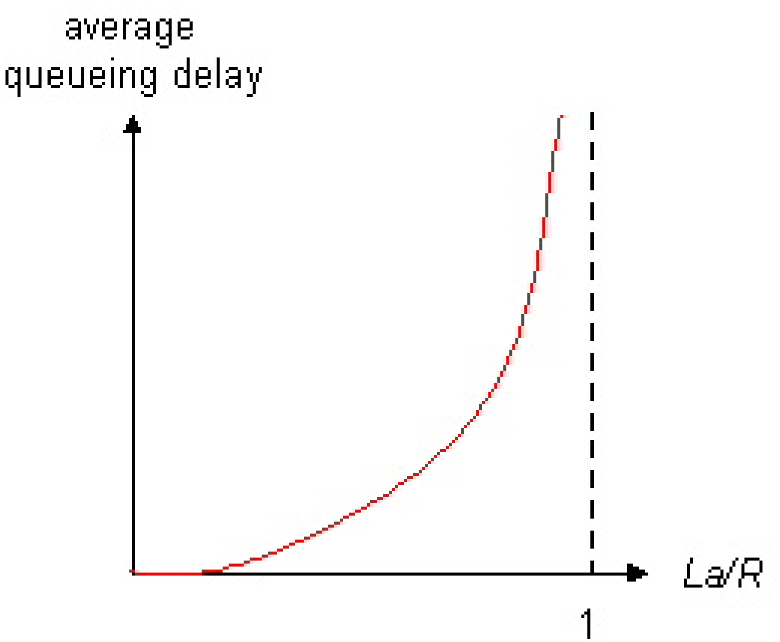
- Compare the delay in sending an m-bit message over a k-hop path in a circuit-switched network and in a (lightly load) packet-switched network. The circuit setup time is s sec, the propagation delay is d sec per hop, the packet size is p bits, and the data rate is b bps.
  - Under what conditions does the packet network have a lower delay?
  - What is the implication on the packet switched network when the load is heavy? (**Exam Qn)**

Packet switch is faster if $s > (k-1)p/b$

Queueing delay (revisited)

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

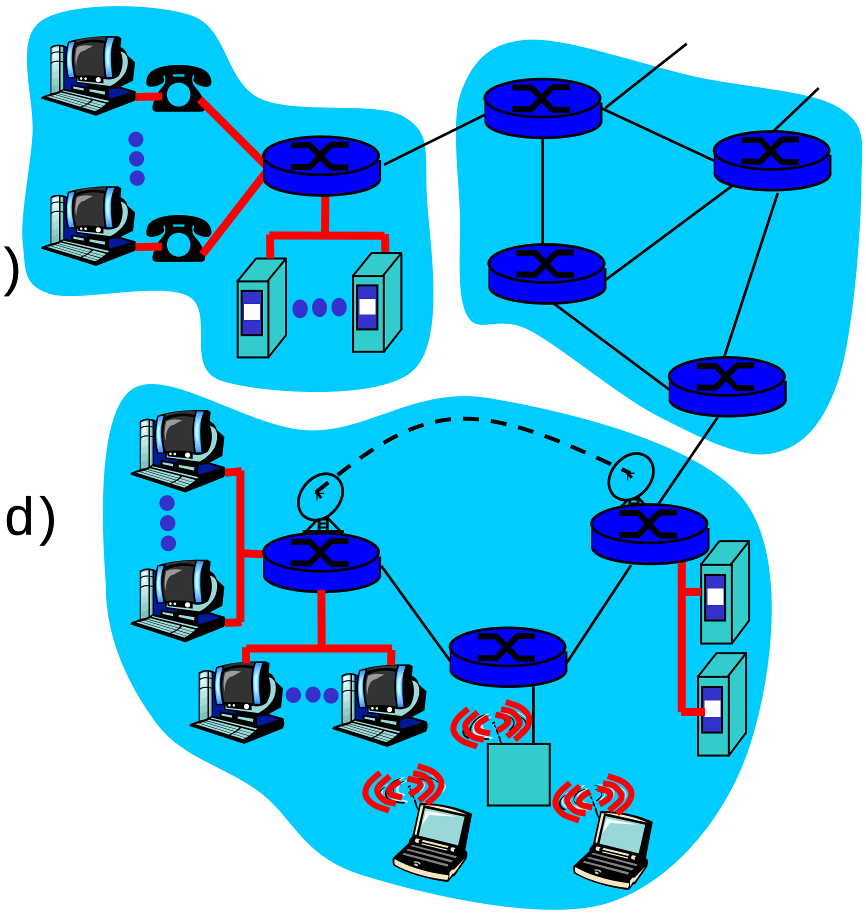
Access networks and physical media

Q: How to connect end systems to edge router?

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

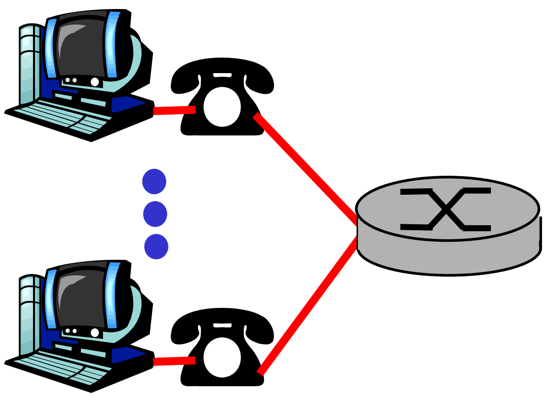
Keep in mind:

- bandwidth (bits per second) of access network?
- shared or dedicated?



Residential access: point to point access

- Dialup via modem
  - up to 56Kbps direct access to router (often less)
  - Can't surf and phone at same time: can't be "always on"



- ADSL: asymmetric digital subscriber line
  - 1 Mbps upstream (today typically < 256 kbps)
  - 10 Mbps downstream (today typically < 1 Mbps)
  - Always on
  - FDM: 50 kHz - 1 MHz for downstream

    4 kHz - 50 kHz for upstream

    0 kHz - 4 kHz for ordinary telephone

Residential access: cable modems

- HFC: hybrid fiber coax
  - asymmetric: up to 30Mbps downstream, 2 Mbps upstream
  - shared broadcast medium
- network of cable and fiber attaches homes to ISP router
  - homes share access to router
- deployment: available via cable TV companies
- Always on

Residential access: cable modems

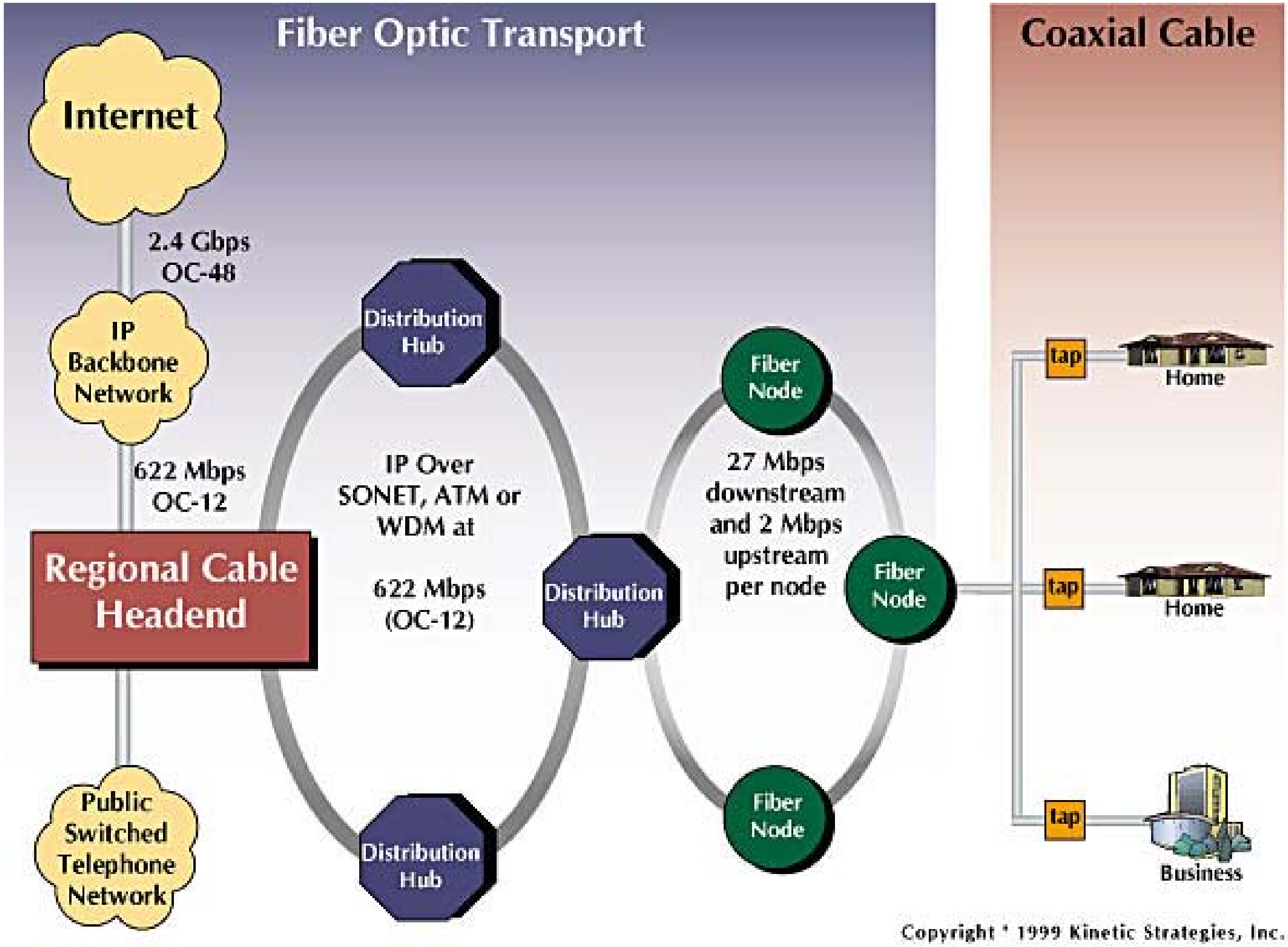
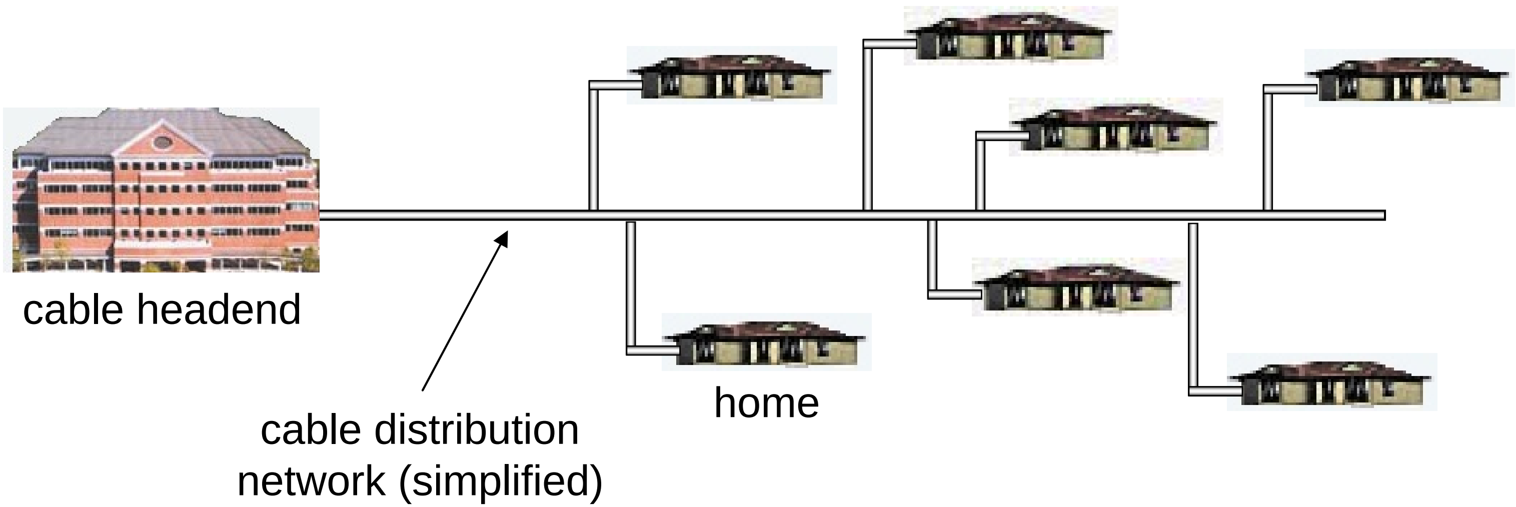


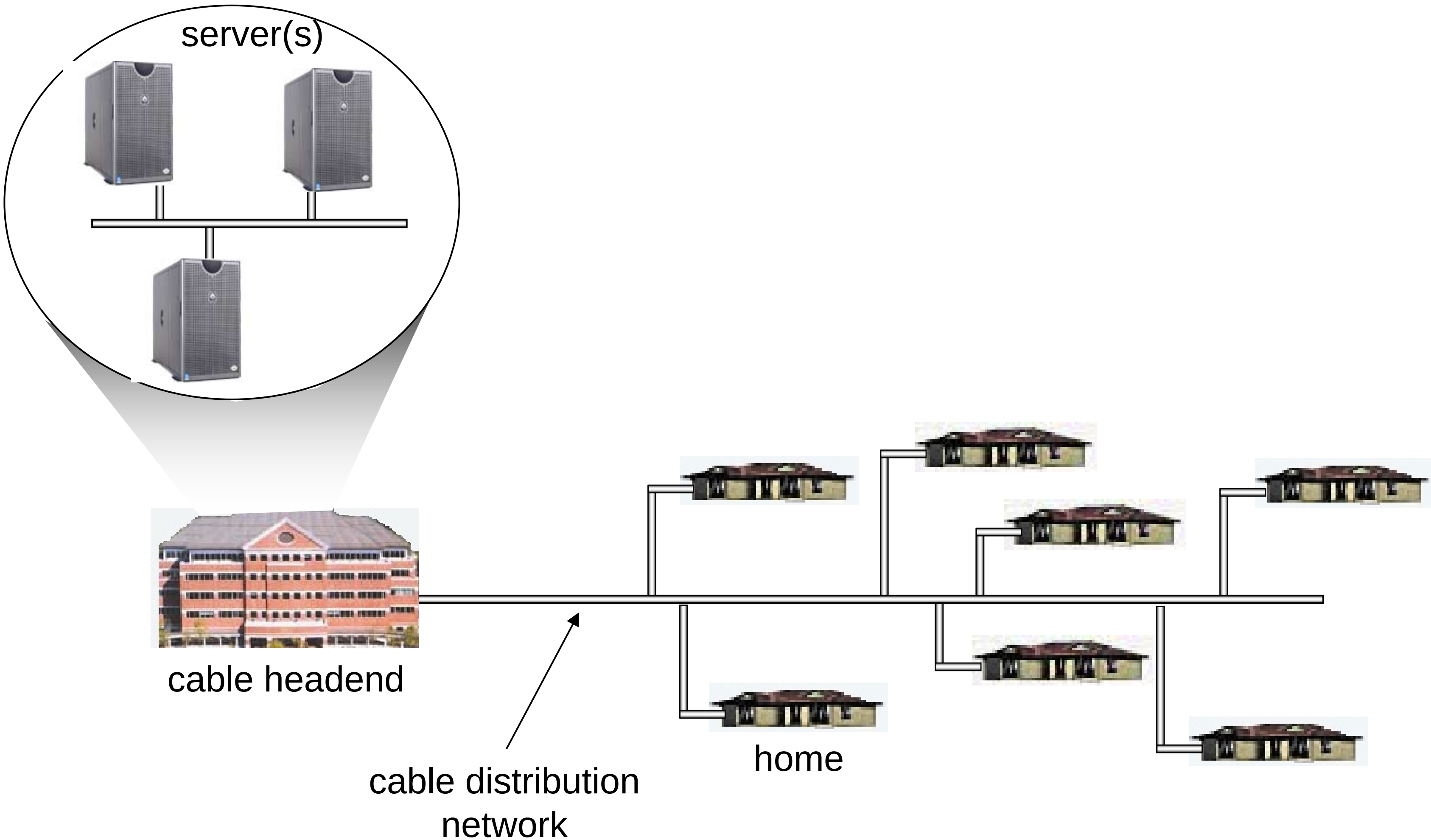
Diagram: http://www.cabledatacomnews.com/cmic/diagram.html

Cable Network Architecture: Overview

Typically 500 to 5,000 homes



Cable Network Architecture: Overview



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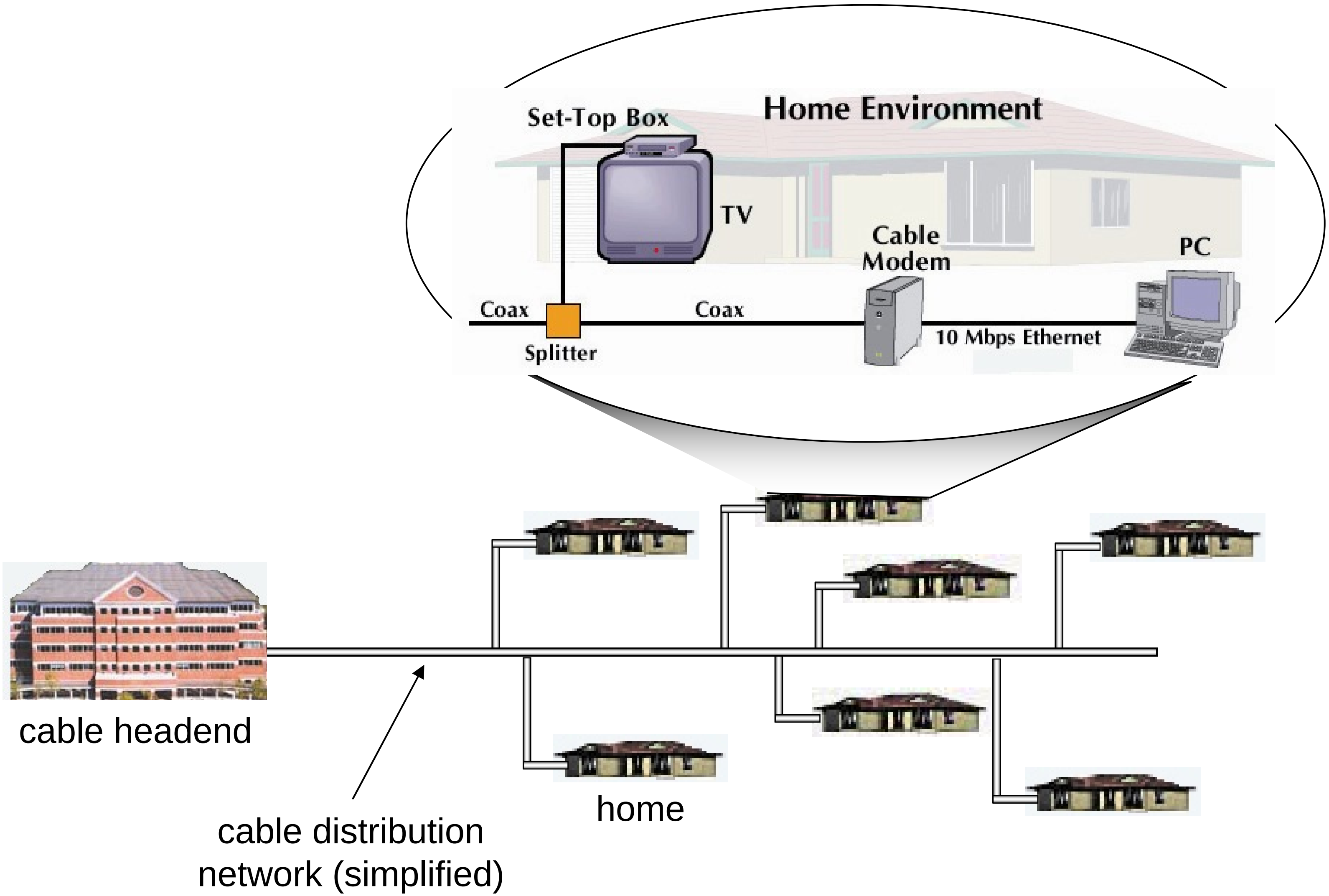
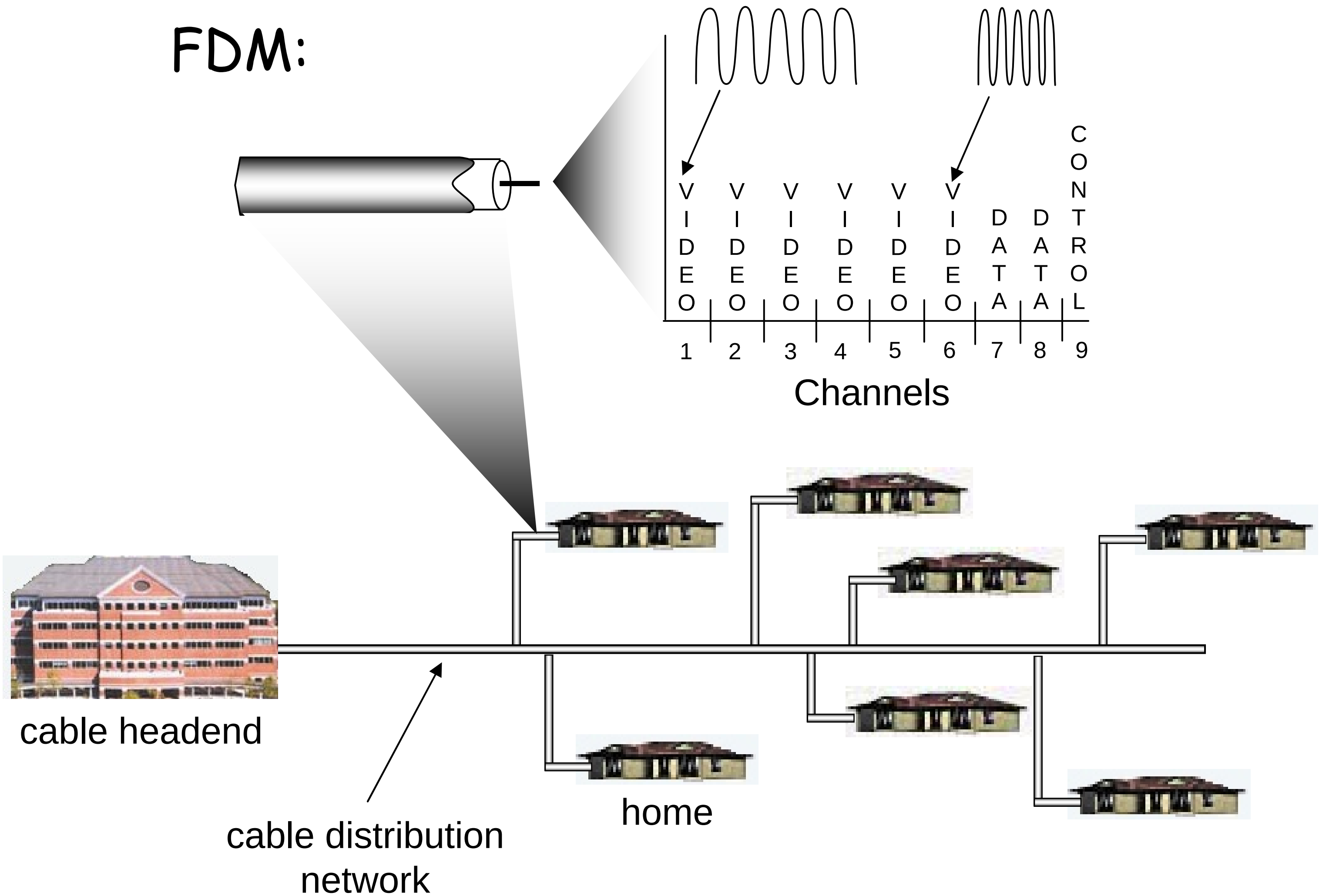


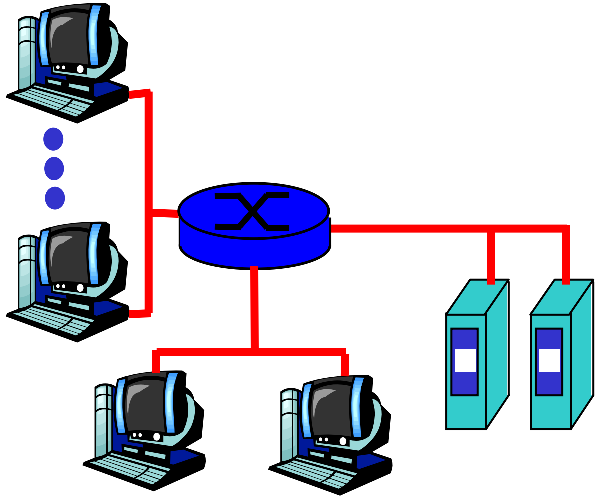
Cable Network Architecture: Overview

FDM:



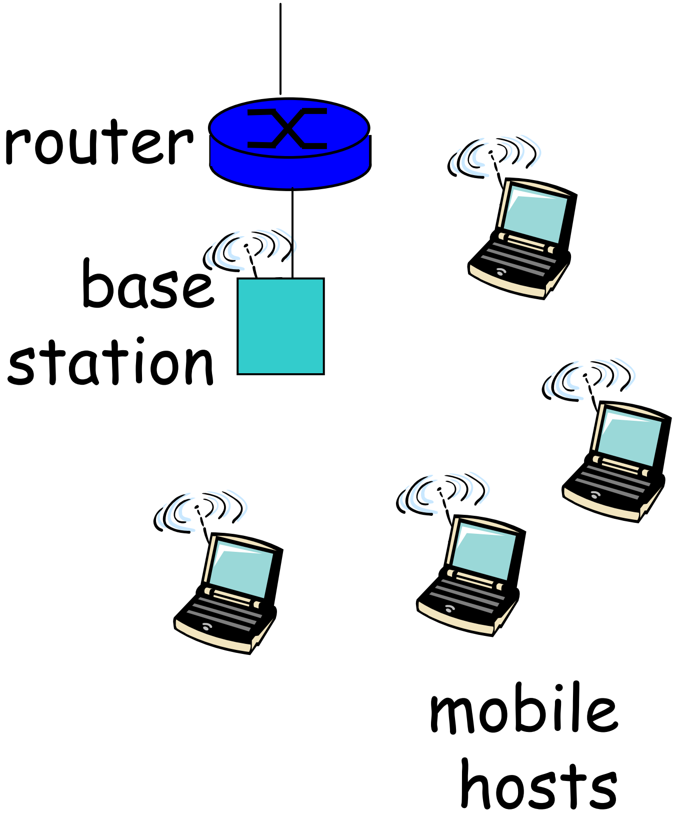
Company access: local area networks

- company/univ local area network (LAN) connects end system to edge router
- Ethernet:
  - shared or dedicated link connects end system and router
  - 10 Mbs, 100Mbps, Gigabit Ethernet
- LANs: chapter 5



Wireless access networks

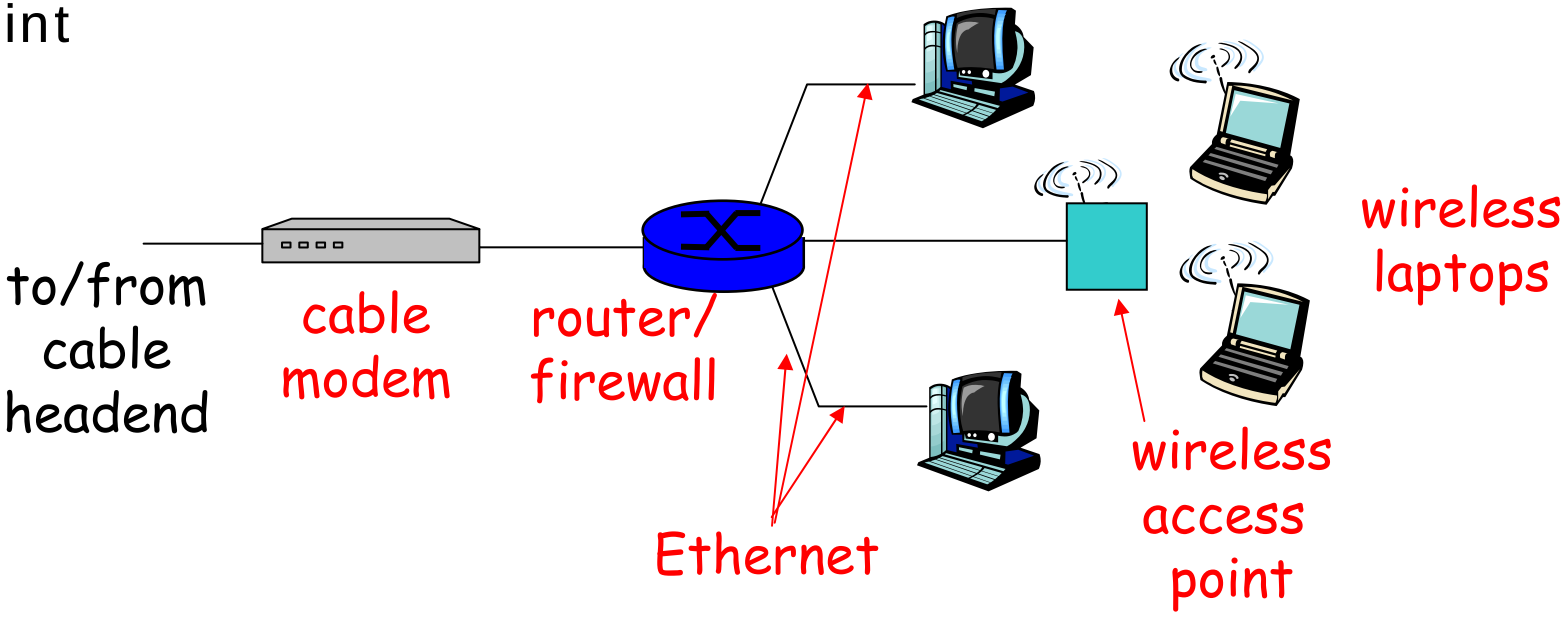
- shared *wireless* access network connects end system to router
  - via base station aka “access point”
- wireless LANs:
  - 802.11b/g (WiFi): 11 or 54 Mbps
- wider-area wireless access
  - provided by telco operator
  - 3G ~ 384 kbps
  - GPRS in Europe/US



Home networks

Typical home network components:

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



Physical Media

FYORP

- 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)

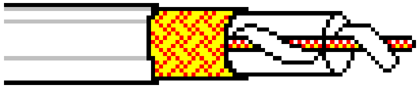
- two insulated copper wires
  - Category 3: traditional phone wires, 10 Mbps Ethernet
  - Category 5: 100Mbps Ethernet

Physical Media: coax, fiber

FYORP

Coaxial cable:

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



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

Physical media: radio

FYORP

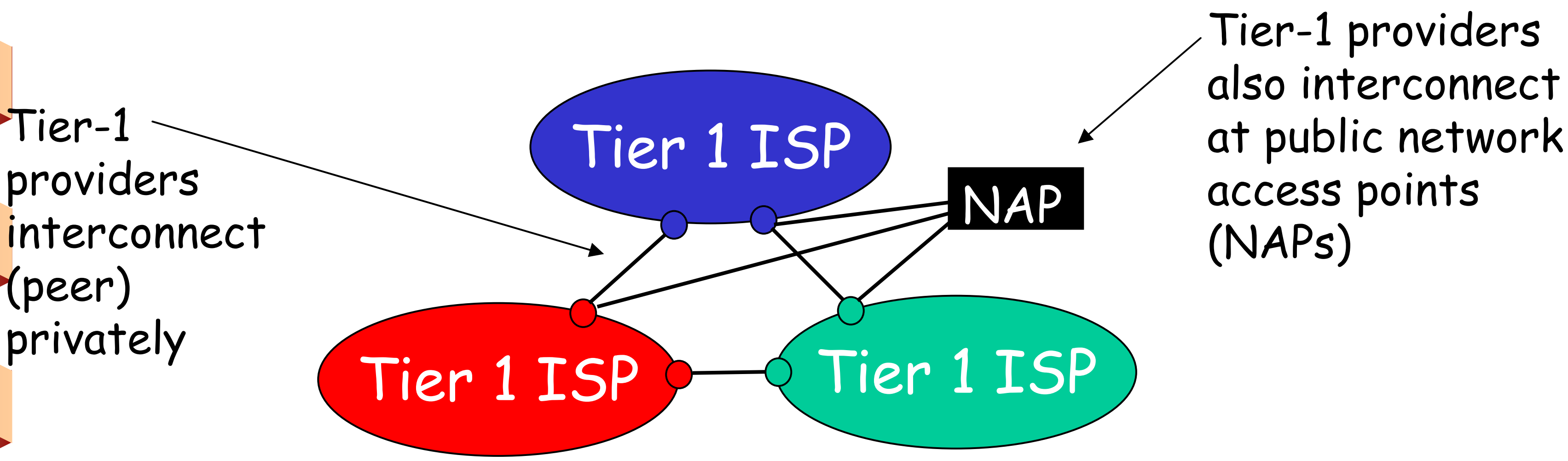
- signal carried in electromagnetic spectrum
- no physical “wire”
- bidirectional
- propagation environment effects:
  - reflection
  - obstruction by objects
  - interference

Radio link types:

- terrestrial microwave
  - e.g. up to 45 Mbps channels
- LAN (e.g., Wifi)
  - 11Mbps, 54 Mbps
- wide-area (e.g., cellular)
  - e.g. 3G: hundreds of kbps
- satellite
  - Kbps to 45Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus low altitude

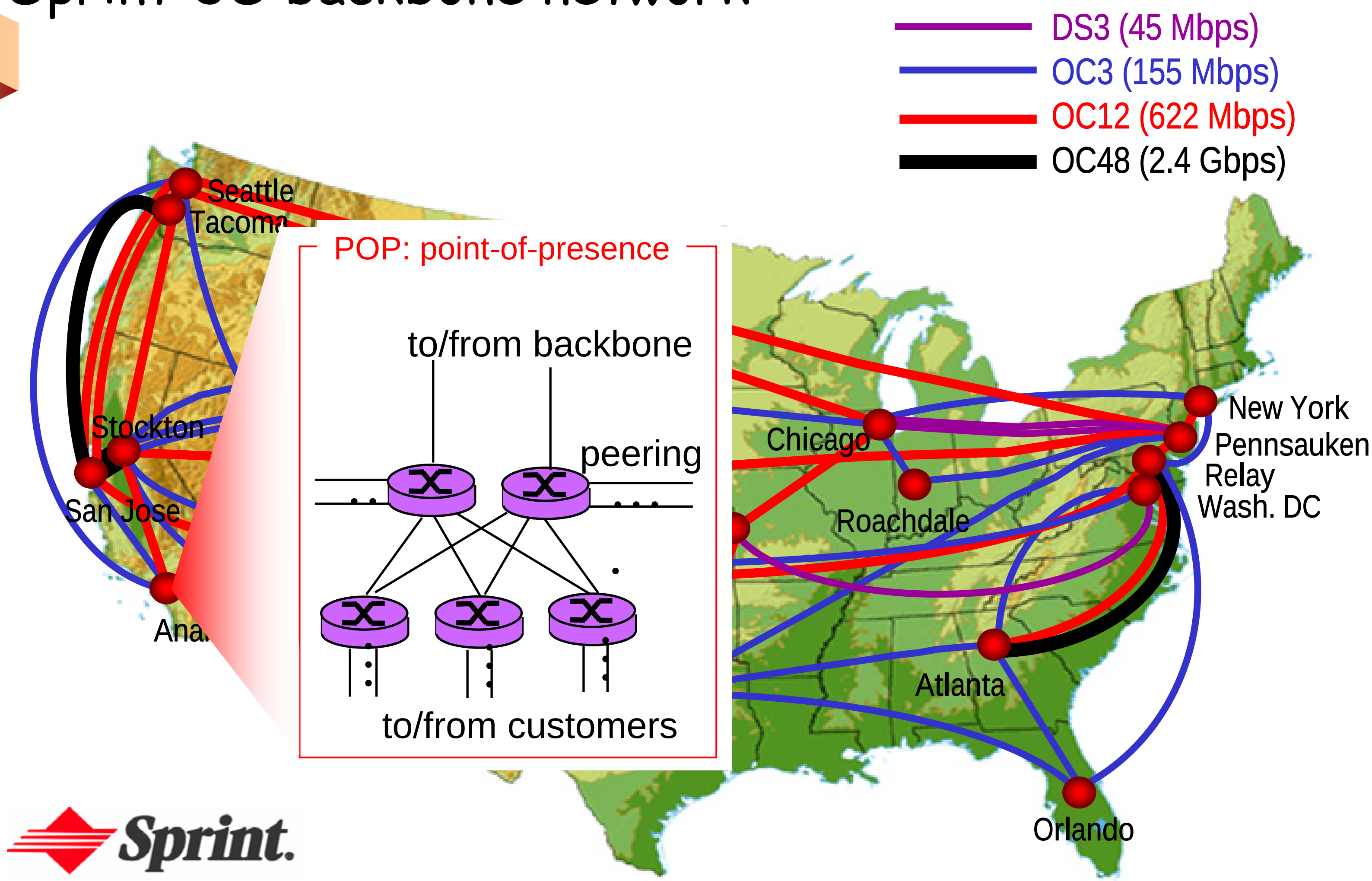
Internet structure: network of networks

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



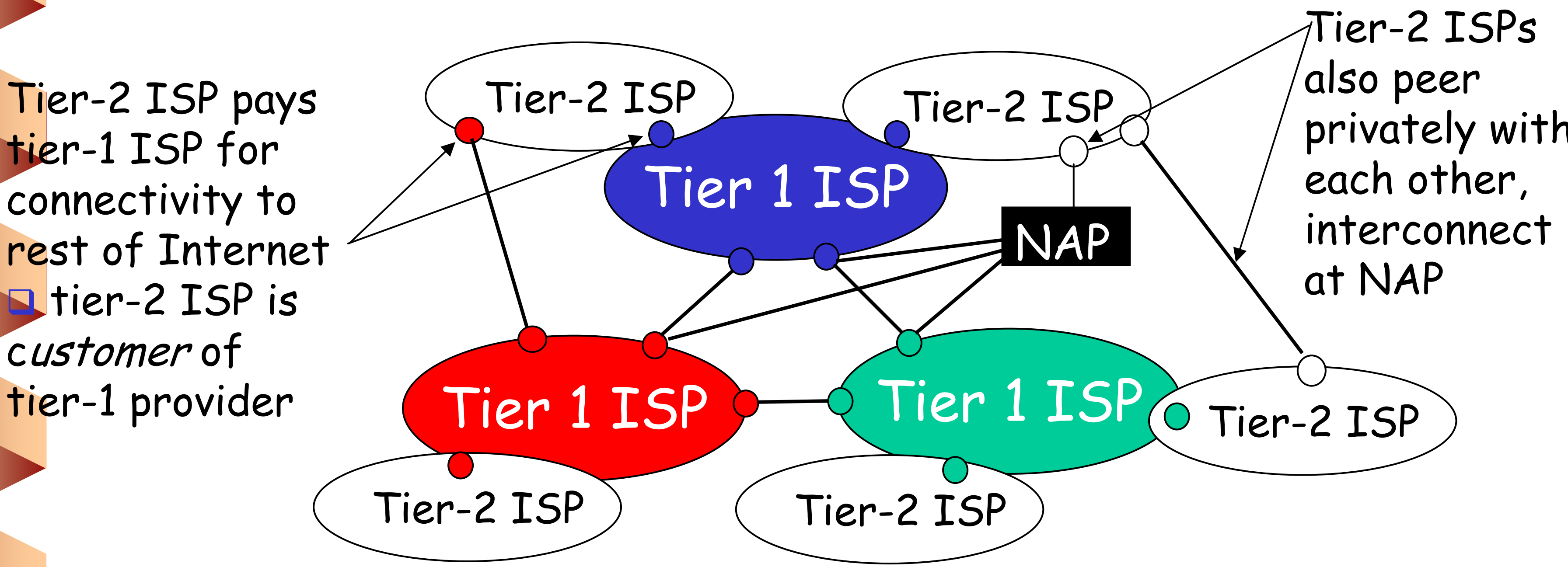
Tier-1 ISP: e.g., Sprint

Sprint US backbone network



Internet structure: network of networks

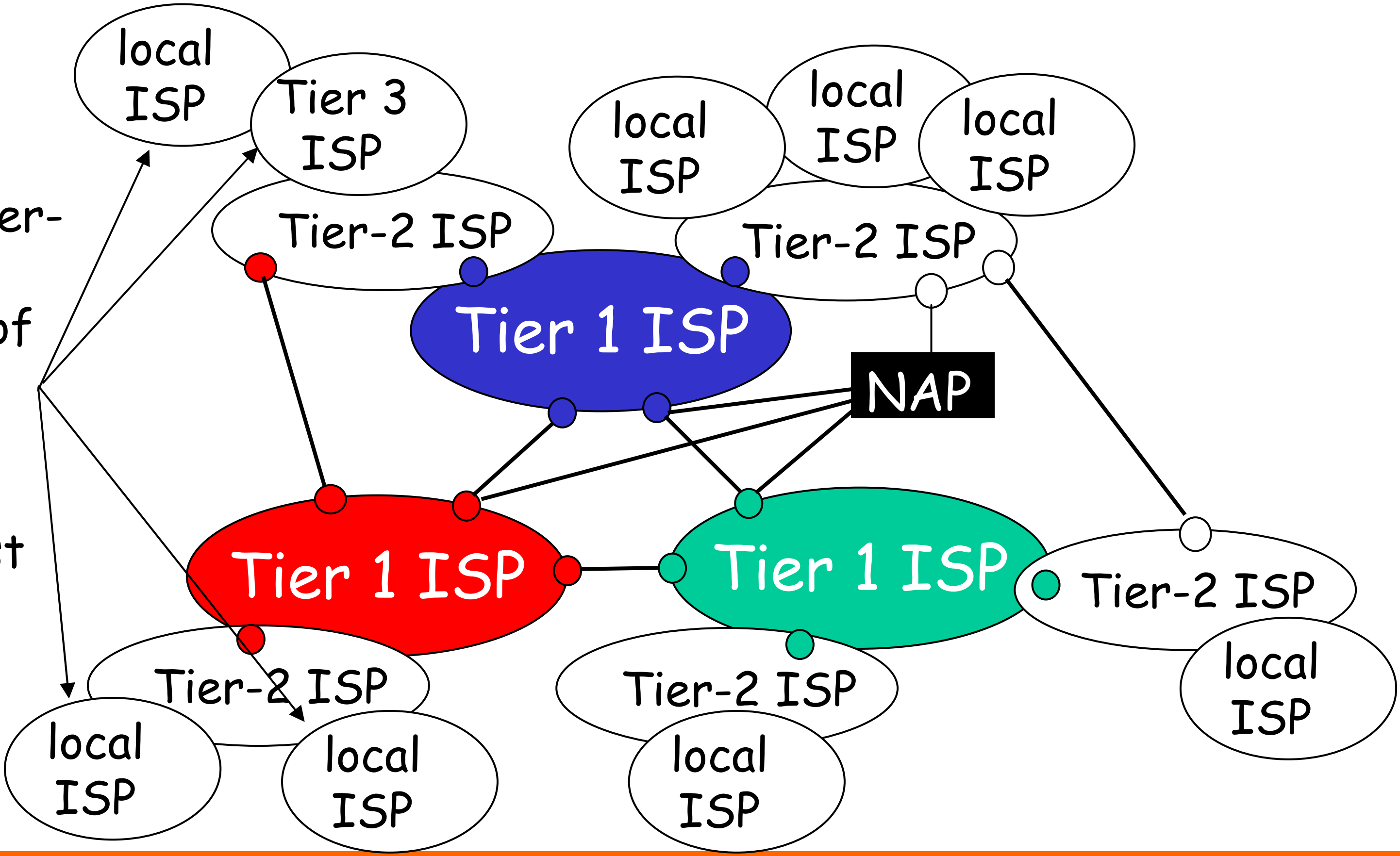
- "Tier-2" ISPs: smaller (often regional) ISPs
  - Connect to one or more tier-1 ISPs, possibly other tier-2 ISPs



Internet structure: network of networks

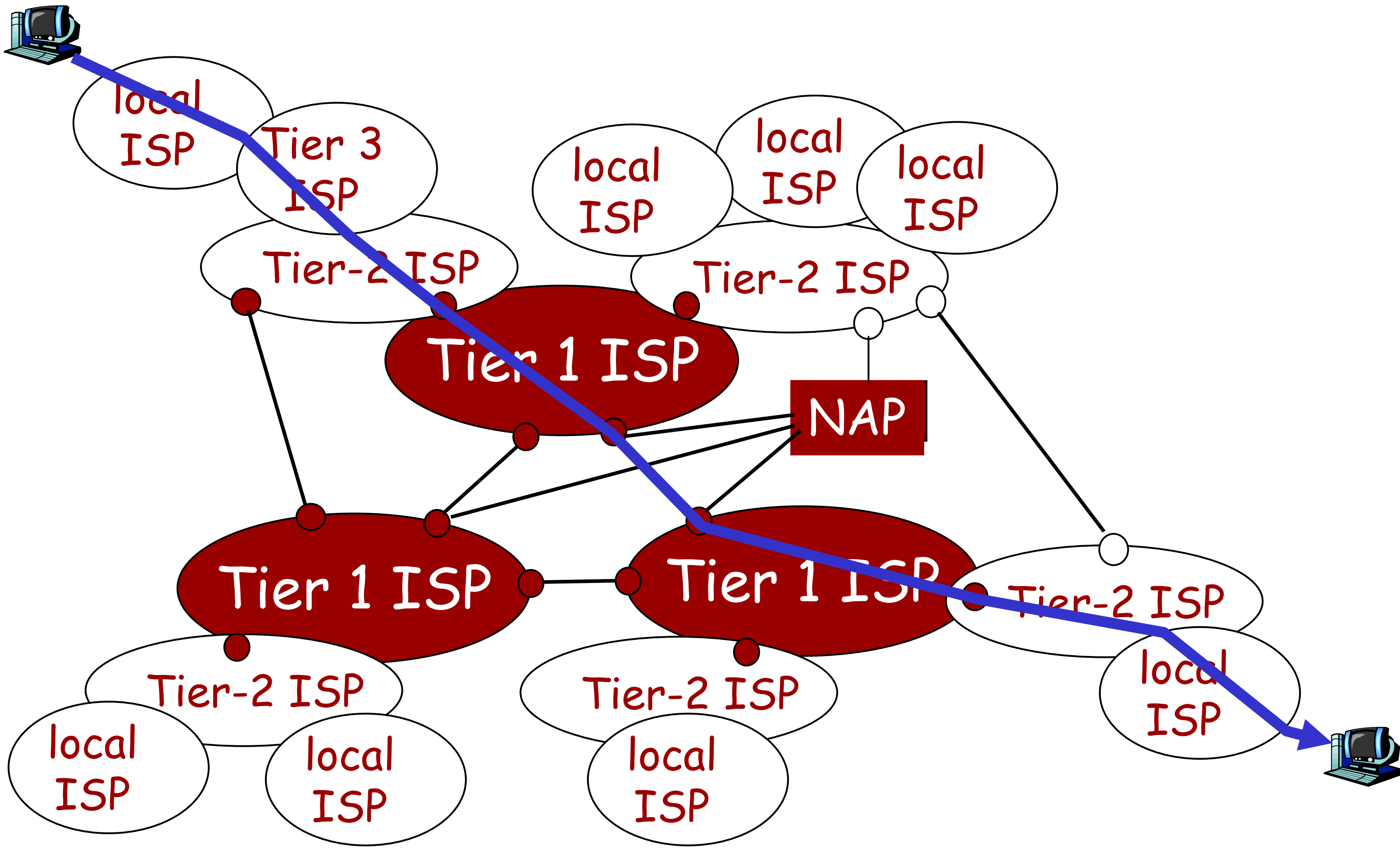
- "Tier-3" ISPs and local ISPs
  - last hop ("access") network (closest to end systems)

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



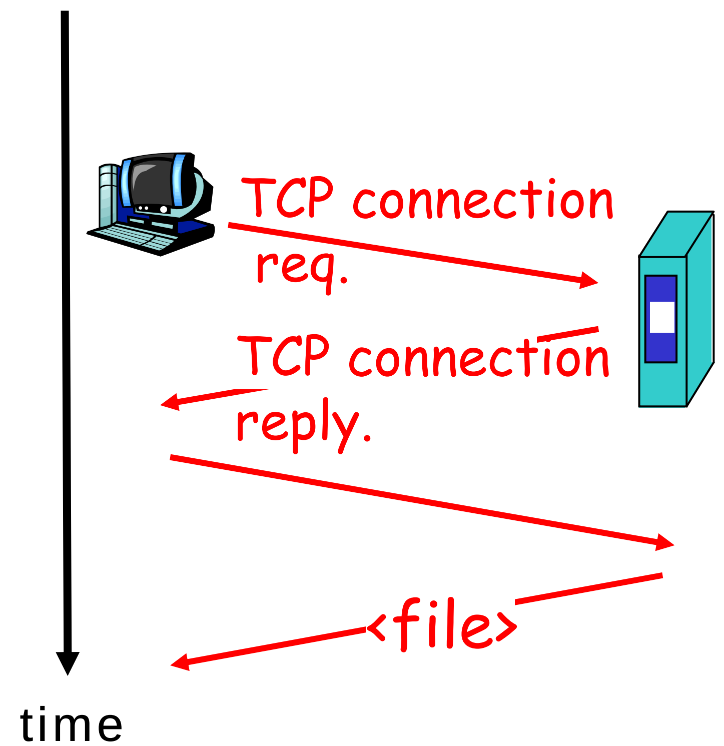
Internet structure: network of networks

- a packet passes through many networks!



Layered Architecture of Protocols

- What is protocol?
  - define format and order of messages sent and received among network entities, and actions taken on message transmission and receipt
  - Govern all communication activities in a network
    - control sending and receiving of messages
  - e.g., TCP, IP, HTTP, FTP, PPP

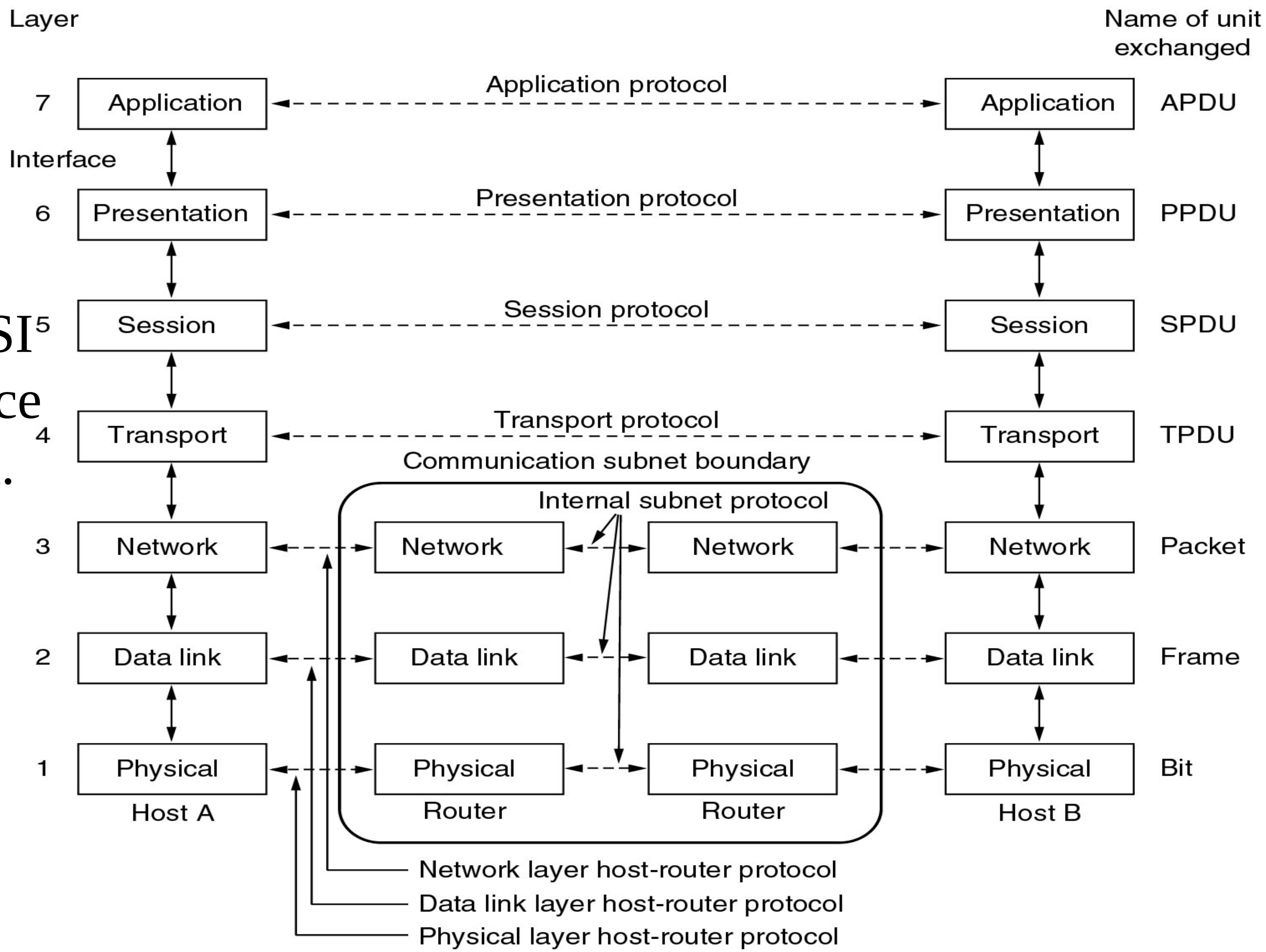


SA	DA	M_Type	data	CRC

Eg of a message format

Network architecture: ISO-OSI Reference Models

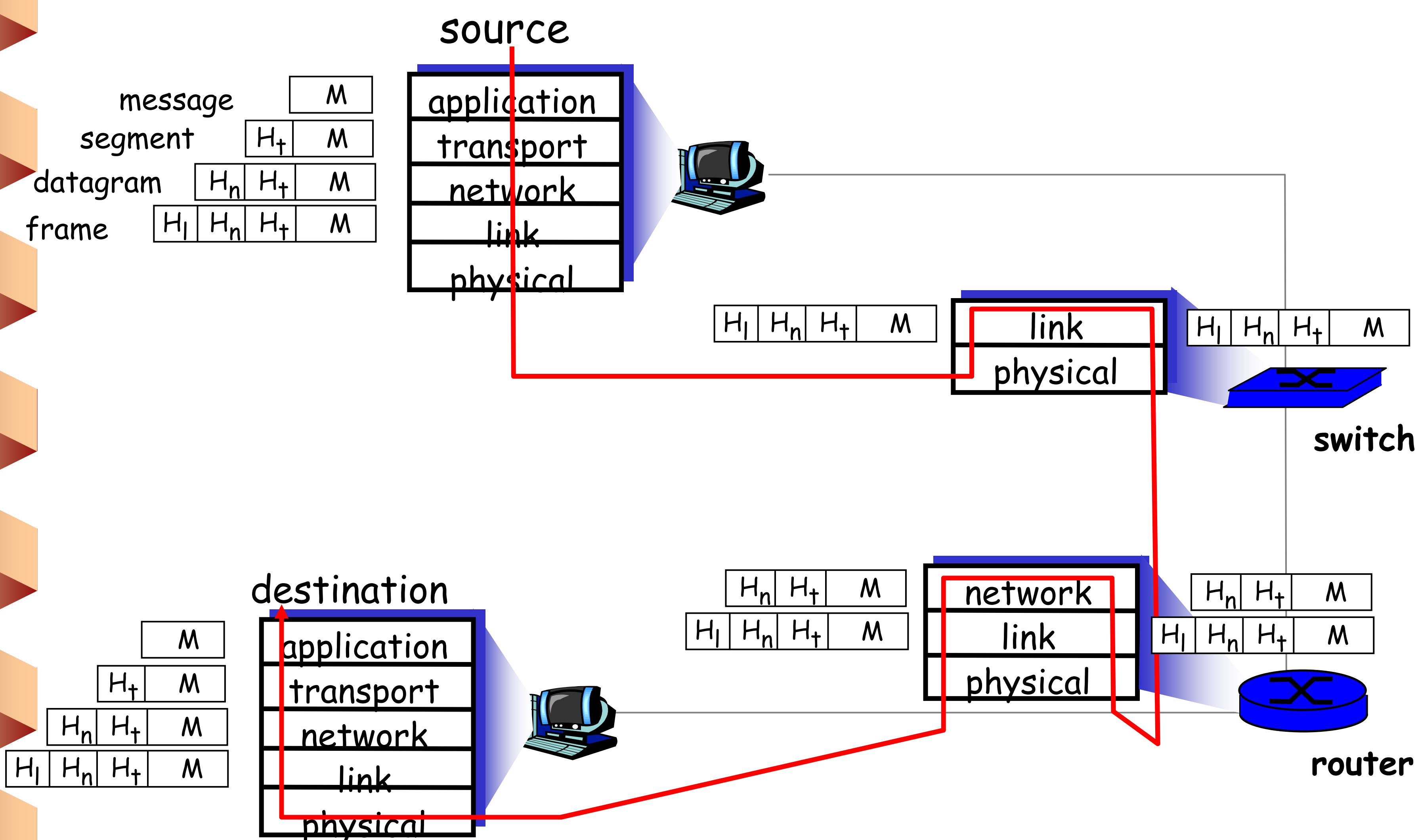
The OSI reference model.



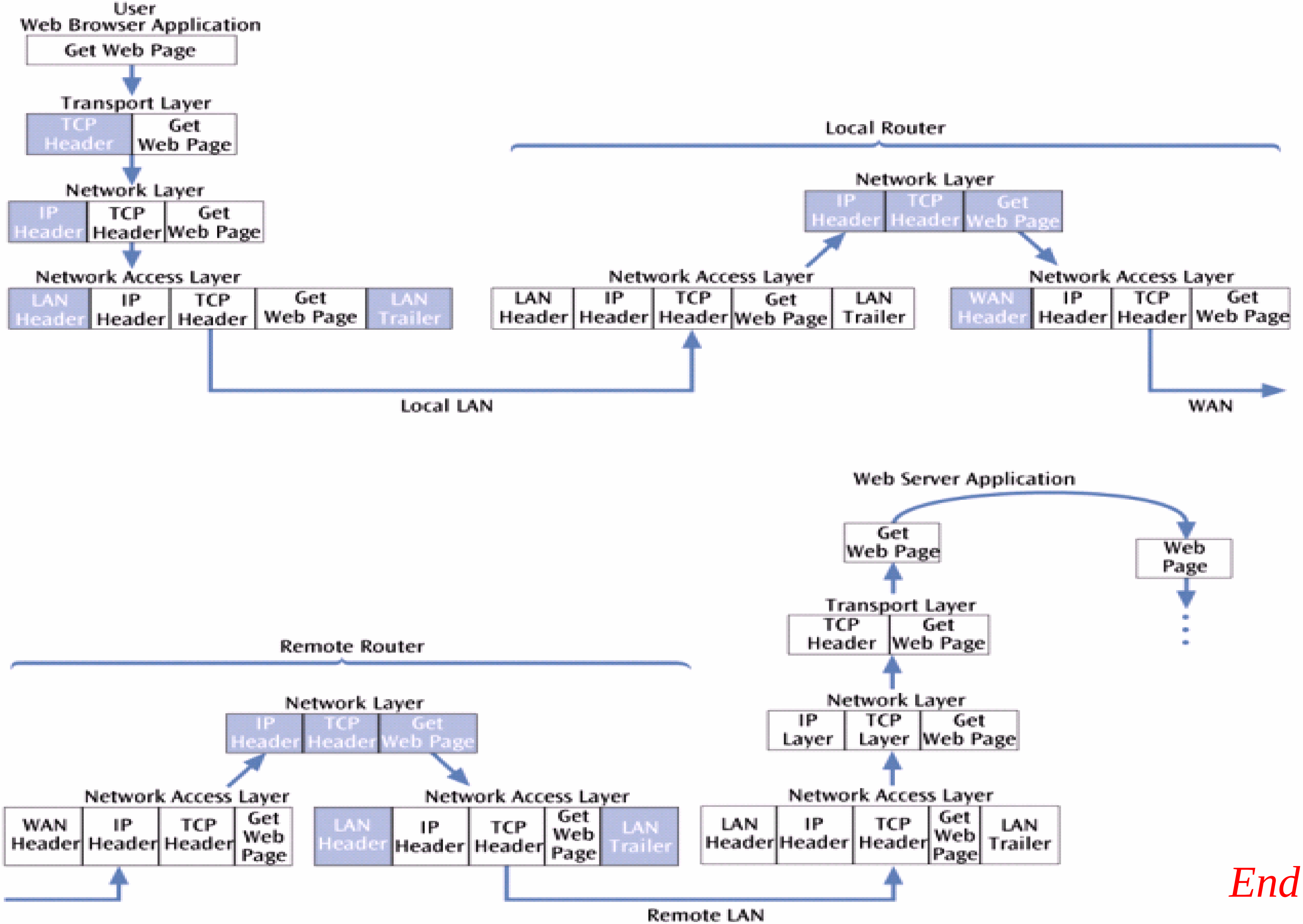
Cont..

- *Physical layer:* provides the transmission of bits over network links; defines electrical and mechanical properties.
- *Link layer:* controls the transmission of blocks of data between network nodes over a physical link; monitors and resolves errors that may occur on the physical layer.
- *Network layer*: switching, addressing and routing packets
- *Transport layer*: ensures that data from the source arrives at the destination correctly and in proper sequence.
- *Session layer*: provides the capability for cooperating applications to synchronize and manage their dialog and data exchange.
- *Presentation layer*: provides services that interpret the meaning of the information exchanged; encapsulates data, encodes, encripts and generally prepares data for representation.
- *Application layer*: directly serves the end user; supports end applications such as file transfer and database access.

Encapsulation



Example: Path of a Web page request & Encapsulation



End

Img Src: Reference book -Curt M White's book