Data Networks

UdS and IMPRS-CS

Lecture 2: Fundamental network design issues

Thanks to Eugene Ng, Rice University

History of Computer Networks

- Communication
- Telecommunication
- Telecommunication network
- Computer network
- Convergence network

Early Communication over Long Distance

- Between human beings

- Letter and messenger
  - Information carried by physical objects
  - Speed limited by transportation means: horse, bird, train, car
  - Hard disks over FedEx?
  - Bandwidth? distance? security?

- Fire
  - Early optical communication
  - Speed of light
  - Bandwidth? distance? security?

Telegraph: Communication Using Electrons

- Between human beings
- Major milestones:
  - 1827: Ohm's Law
  - 1837: "workable" telegraph invented by Samuel Morse
  - 1838: demonstration over 10 miles at 10 w.p.m.
  - 1844: Capitol Hill to Baltimore
  - 1851: Western Union founded
  - 1868: transatlantic cable laid
  - 1985: last telegraph circuit closed down
- Other important dates
  - 1869: transcontinental railway
  - 1876: Alexander Bell invented telephone

Telegraph Engineering

- Technical issues
  - How to encode information?
  - How to feed/input information to the system?
  - How to output information?
  - How to improve the distance?
  - How to improve the speed?

- Common issues faced by all telecommunication systems

Telephony

- Interactive telecommunication between people
- Analog voice
  - Transmitter/receiver continuously in contact with electronic circuit
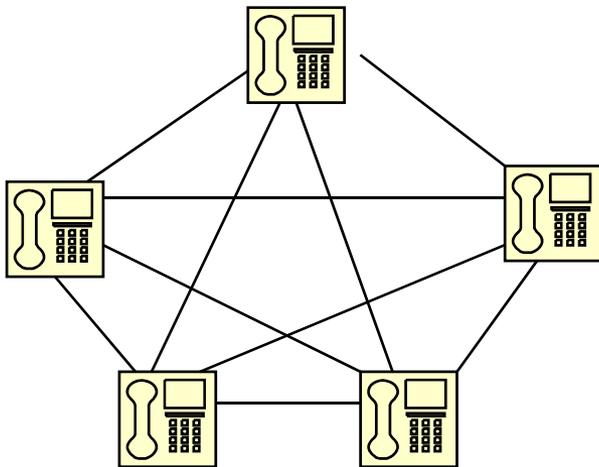 - Electric current varies with acoustic pressure

Analog/Continuous Signal

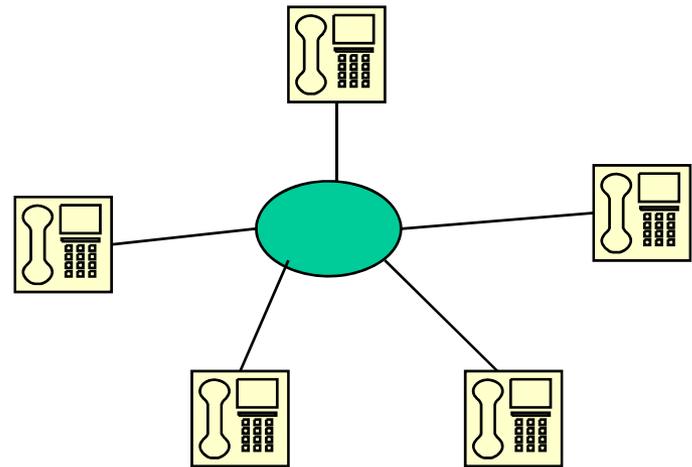**Digital/Discrete Signal**

Telephony Milestones

- 1876: Alexander Bell invented telephone
- 1878: Public switches installed at New Haven and San Francisco, public switched telephone network is born
 - People can talk without being on the same wire!

Without Switch

With Switch

Telephony Milestones

- 1878: First telephone directory; White House line
- 1881: Insulated, balanced twisted pair as local loop
- 1885: AT&T formed
- 1892: First automatic commercial telephone switch
- 1903: 3 million telephones in U.S.
- 1915: First transcontinental telephone line
- 1927: First commercial transatlantic commercial service

Telephony Milestones

- 1937: Multiplexing introduced for inter-city calls
  - One link carries multiple conversations
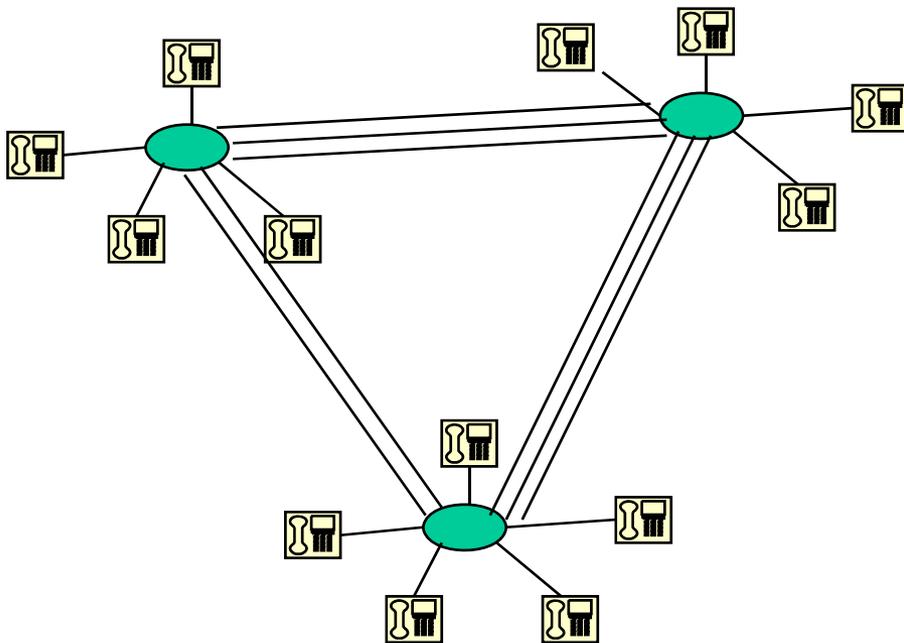
Without Multiplexing
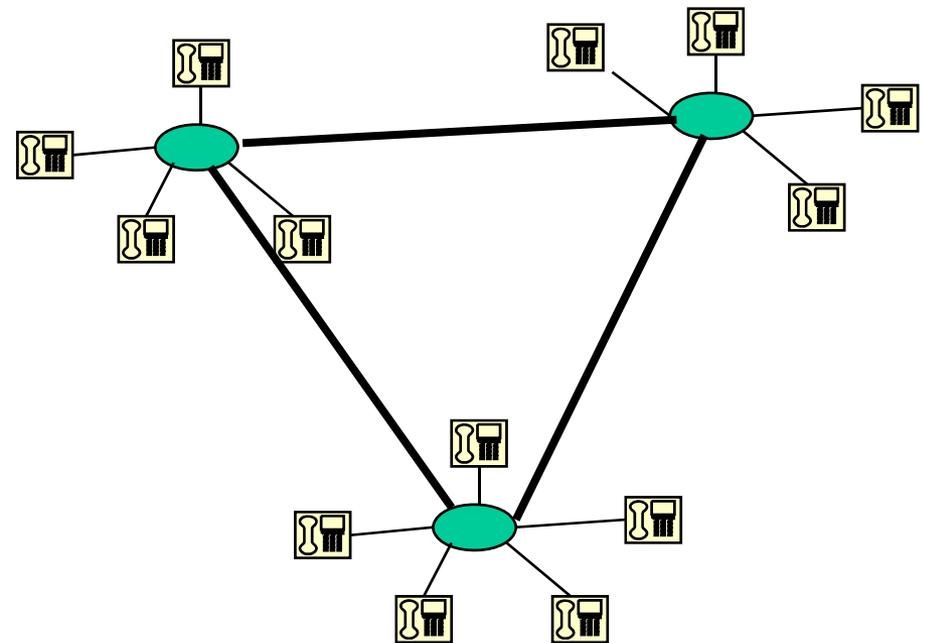
With Multiplexing

Summary

- Communication came long before computer
- Evolutions of modern communication and computer intertwined
- Important concepts
  - Switching
  - Multiplexing
  - Analog vs. Digital
  - Bandwidth
  - Latency

Data or Computer Networks

- Networks designed for computers to computers or devices
  - vs. communication between human beings
- Digital information
  - vs. analog voice

What is a Communication Network? (from end-system point of view)

- Network offers a service: move information
  - Bird, fire, messenger, truck, telegraph, telephone, Internet …
- What distinguish different types of networks?
  - The services they provide
- What distinguish the services?
  - Latency
  - Bandwidth
  - Loss rate
  - Number of end systems
  - Service interface
  - Other details
    - Reliability, unicast vs. multicast, real-time, message vs. byte ...

# What is a Communication Network? (Infrastructure Centric View)

- Communication medium: electron, photon
- Network components:
  - Links – carry bits from one place to another (or maybe multiple places): fiber, copper, satellite, …
  - Interfaces – attach devices to links
  - Switches/routers – interconnect links: electronic/optic, crossbar/Banyan
  - Hosts – communication endpoints: workstations, PDAs, cell phones, toasters
- Protocols – rules governing communication between nodes
  - TCP/IP, ATM, MPLS, SONET, Ethernet, X.25
- Applications: Web browser, X Windows, FTP, ...

Network Components (Examples)

Links

Fibers
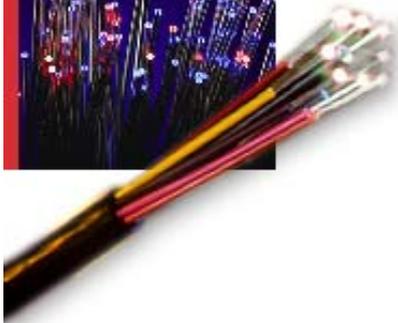
Coaxial Cable

Interfaces

Ethernet card

Wireless card

Switches/routers

Large router

Telephone switch

Juniper Routers

M160 Router

M40 Router

M20 Router

M10 Router

M5 Router

Types of Networks

- Geographical distance
  - Local Area Networks (LAN): Ethernet, Token ring, FDDI
  - Metropolitan Area Networks (MAN): DQDB, SMDS
  - Wide Area Networks (WAN): X.25, ATM, frame relay
- Information type
  - Data networks vs. telecommunication networks
- Application type
  - Special purpose networks: airline reservation network, banking network, credit card network, telephony
  - General purpose network: Internet, telecommunication networks

Types of Networks

- Right to use
  - Private: enterprise networks
  - Public: telephony network, Internet
- Ownership of protocols
  - Proprietary: SNA
  - Open: IP
- Technologies
  - Terrestrial vs. satellite
  - Wired vs. wireless
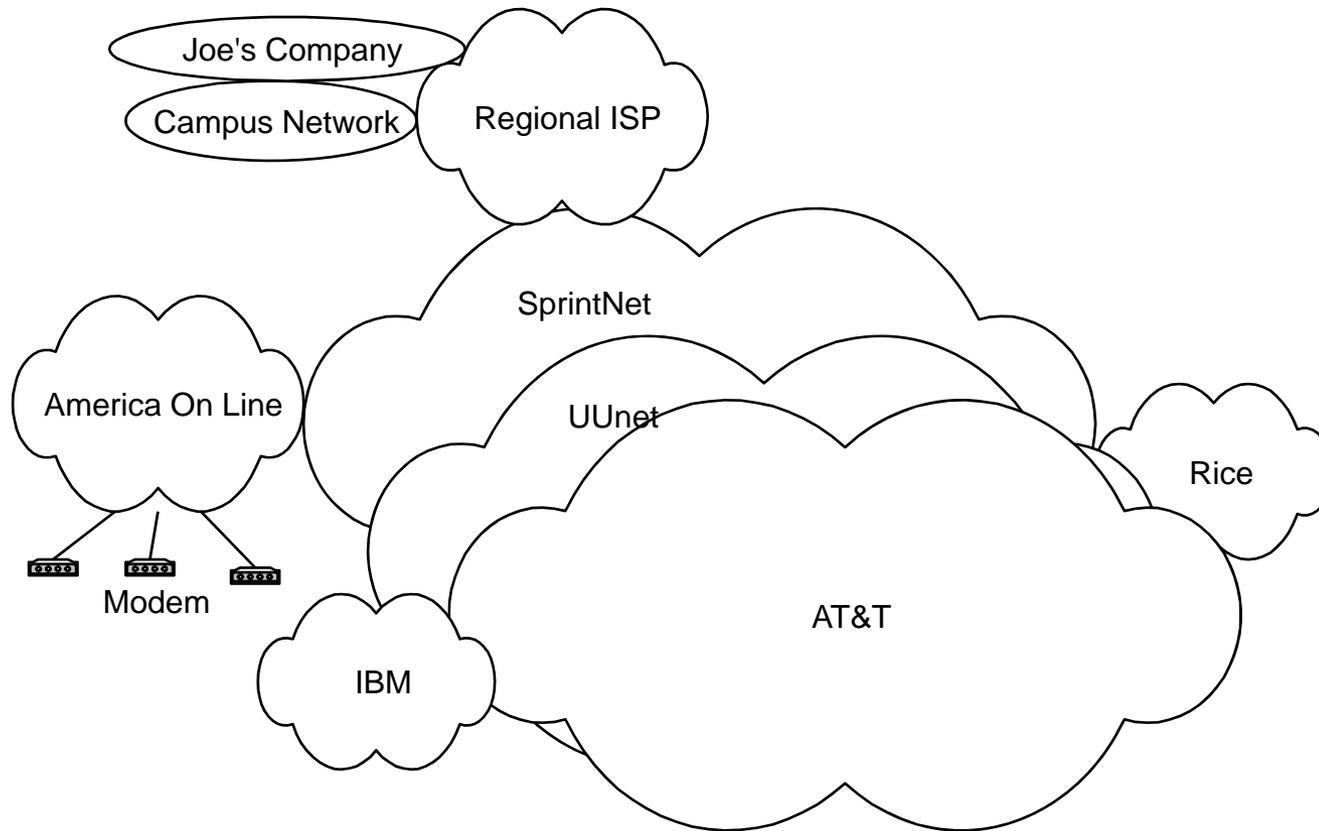- Protocols
  - IP, ATM, X.25, AppleTalk, SNA

The Internet

- Global scale, general purpose, heterogeneous-technologies, public, computer network

- Internet Protocol
  - Open standard: Internet Engineering Task Force (IETF) as standard body (http://www.ietf.org)

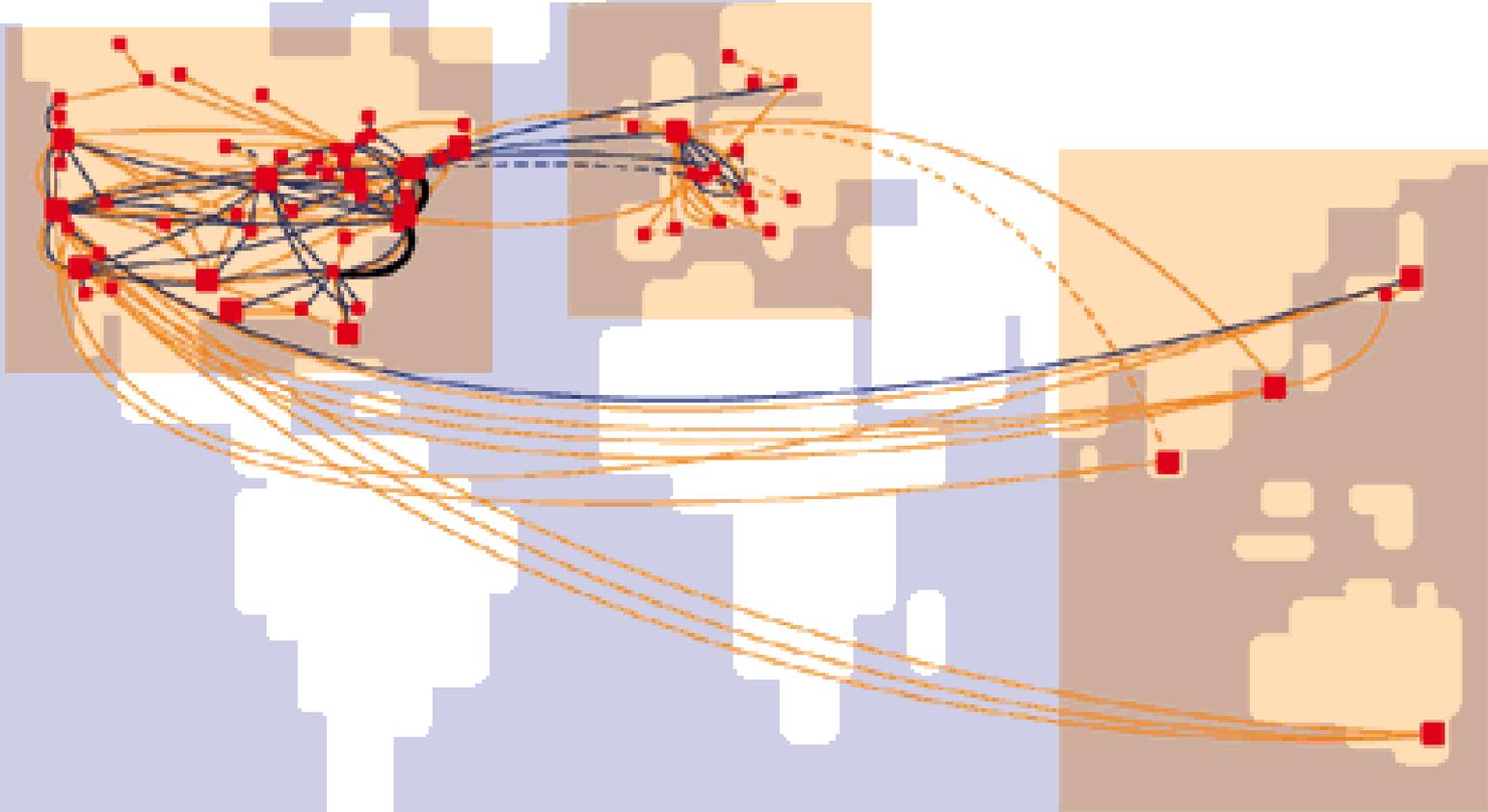- Development strongly influenced by the research community

History of the Internet

- 70's: started as a research project, 56 kbps, < 100 computers
- 80-83: ARPANET and MILNET split
- 85-86: NSF builds NSFNET as backbone, links 6 Supercomputer centers, 1.5 Mbps, 10,000 computers
- 87-90: link regional networks, NSI (NASA), ESNet(DOE), DARTnet, TWBNet (DARPA), 100,000 computers
- 90-92: NSFNET moves to 45 Mbps, 16 mid-level networks
- 94: NSF backbone dismantled, multiple private backbones
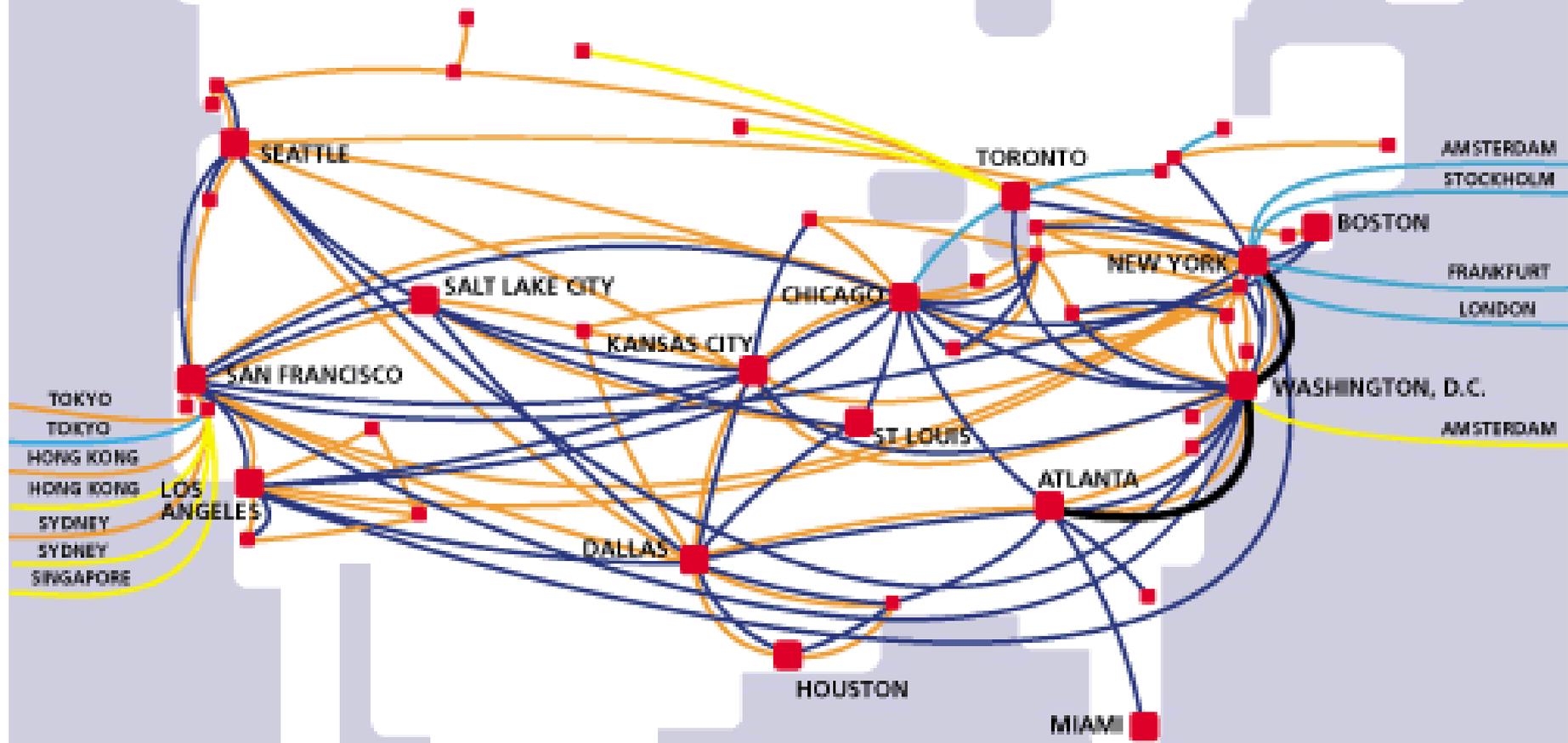- Today: backbones run at 10 Gbps, 200 millions computers in 150 countries

Commercial Internet after 1994

Joe's Company

Campus Network

Regional ISP

SprintNet

America On Line

UUnet

Rice

Modem

AT&T

IBM
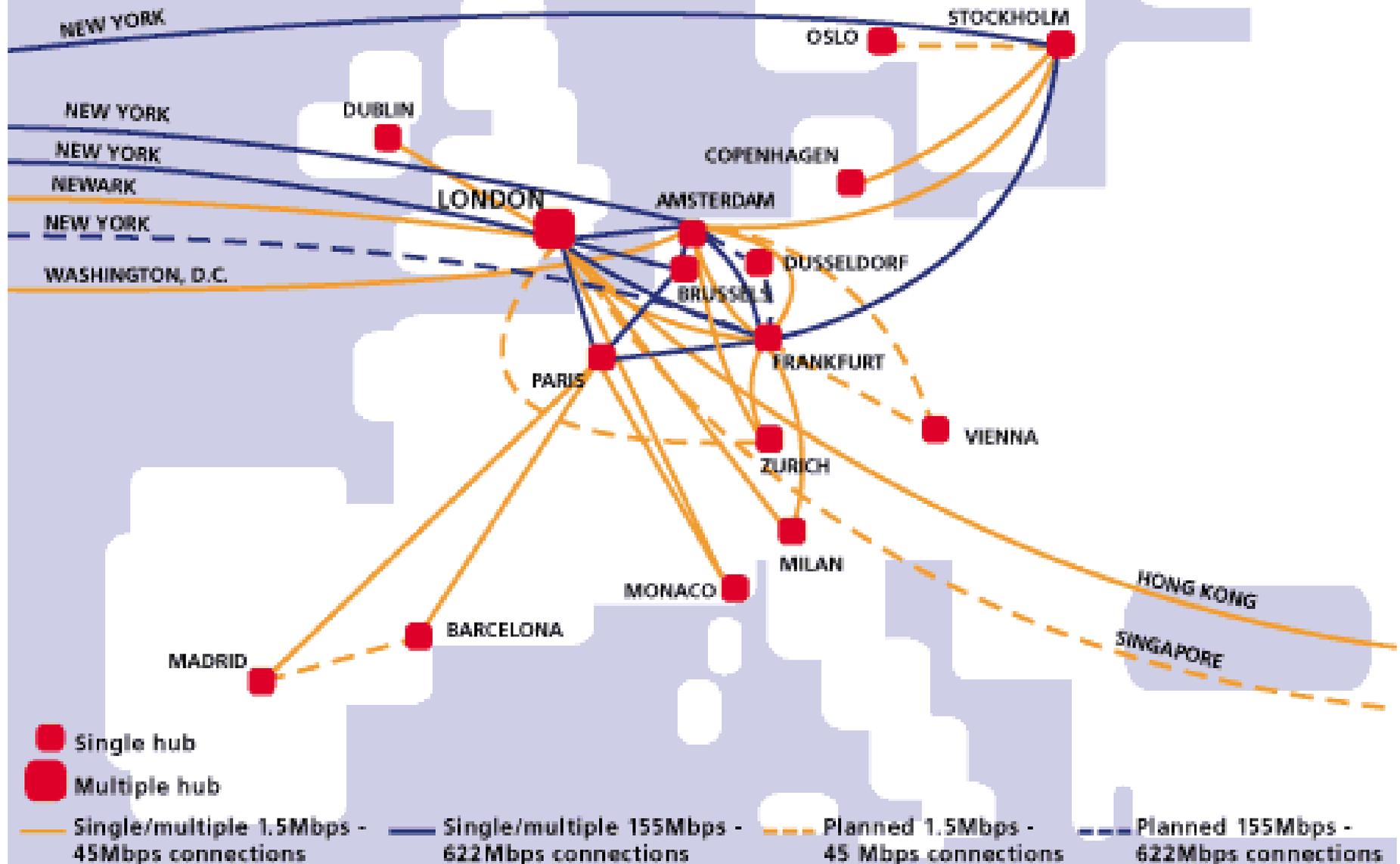
UUNET's Global Internet Backbone

UUNET'S North American Internet Backbone

- ■ Single hub
- ■ Multiple hub

- Single/multiple DS - 1 (1.54Mbps)
- Single/multiple DS - 3 (45Mbps)

- Single/multiple OC - 3 (155Mbps)
- Single/multiple OC -12 (622Mbps)

- Single OC - 48 (2.45Gpbs)

N.B. not all intra-state links are shown
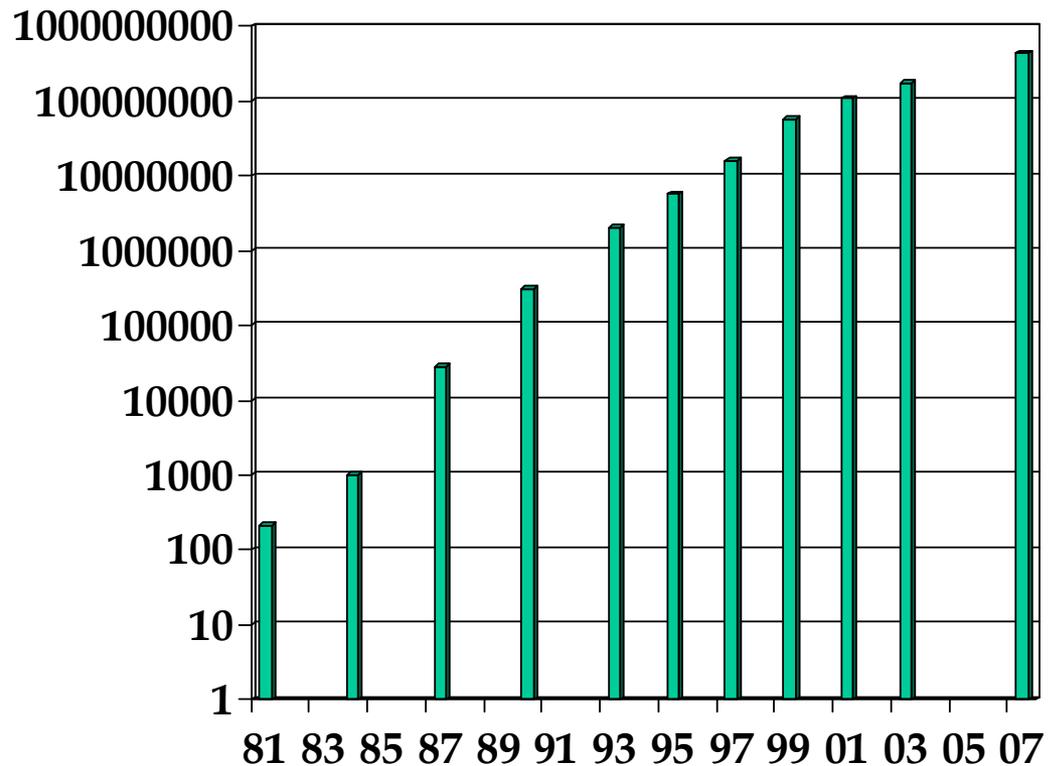
UUNET'S European Internet Backbone

Growth of the Internet

- **Number of Hosts on the Internet:**

Aug. 1981	213
Oct. 1984	1,024
Dec. 1987	28,174
Oct. 1990	313,000
Oct. 1993	2,056,000
Apr. 1995	5,706,000
Jan. 1997	16,146,000
Jan. 1999	56,218,000
Jan. 2001	109,374,000
Jan 2003	171,638,297
Jan 2007	433,193,199

Data available at: http://www.isc.org/

Internet Applications

- Shared access to computing resources
  - telnet (1970's)
- Shared access to data/files
  - FTP, NFS, AFS (1980's)
- Communication medium over which people interact
  - email (1980's), on-line chat rooms, instant messaging (1990's)
  - audio, video (when?)
- A medium for information dissemination
  - USENET (1980's)
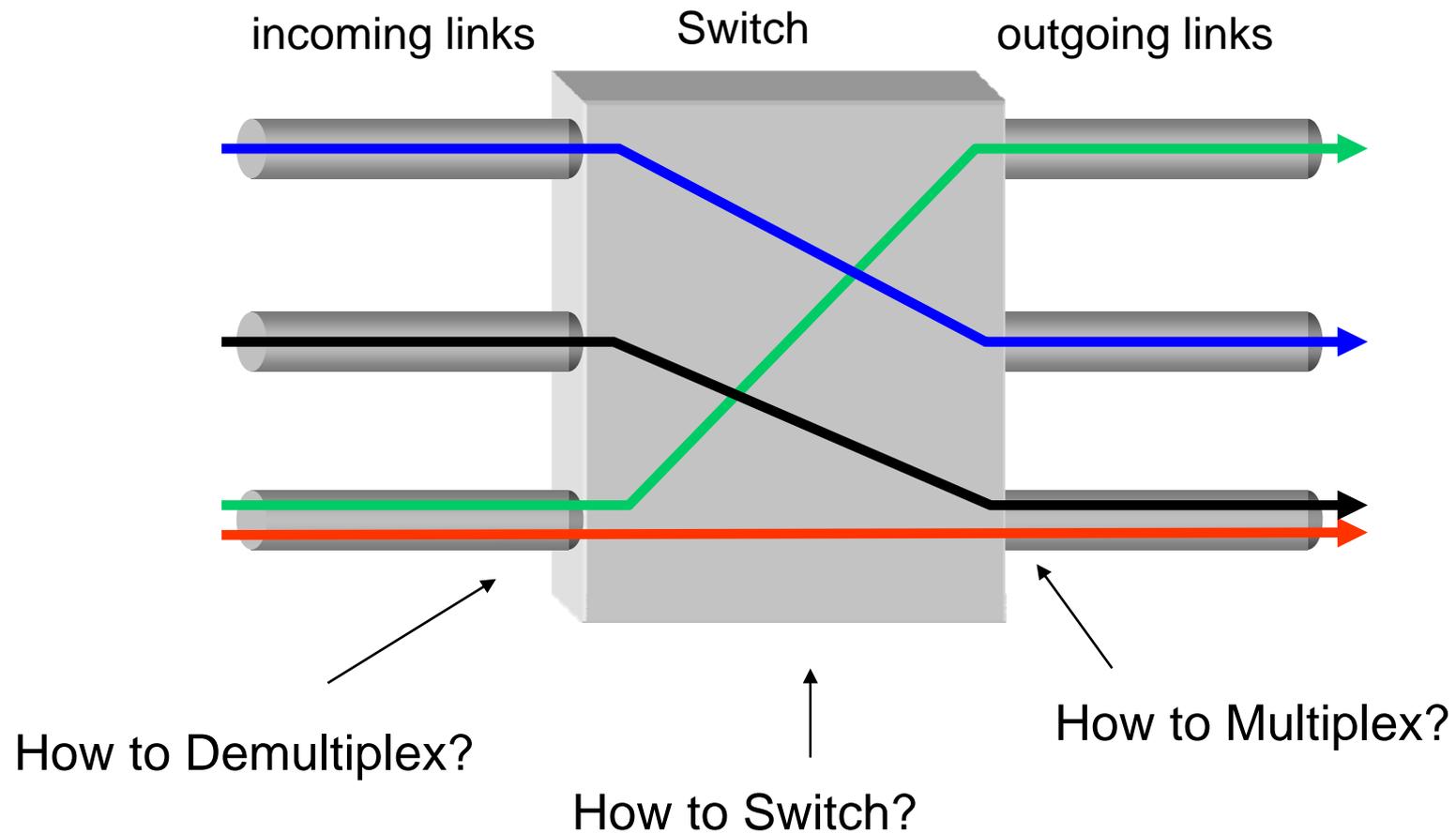 - WWW (1990's)
  - File swapping (2000)

Today's Vision

- Everything is digital: voice, video, music, pictures, live events
- Everything is on-line: bank statement, medical record, books, airline schedule, weather, highway traffic, toaster, refrigerator …
- Everyone is connected: doctor, teacher, broker, mother, son, friends, enemies
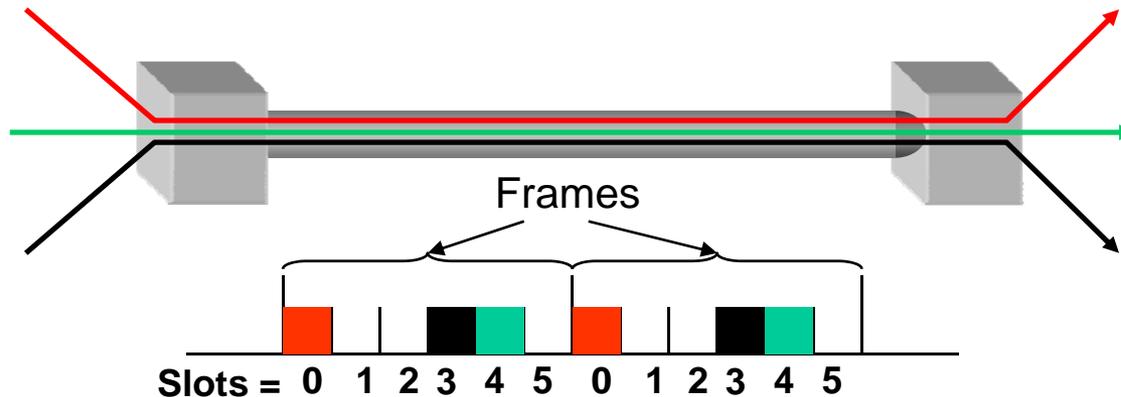
What is Next?

- Electronic commerce
  - virtual enterprise
- Internet entertainment
  - interactive sitcom
- World as a small village
  - community organized according to interests
  - enhanced understanding among diverse groups
- Electronic democracy
  - little people can publish (opinion,content) to the whole world
  - little people can coordinate their actions
  - bridge the gap between information have's and have not's
- Electronic terrorism
  - hacker can bring the whole world to its knee

A Generic Switch

incoming links   Switch   outgoing links

How to Demultiplex?

How to Switch?

How to Multiplex?

Circuit Switching: Multiplexing/Demultiplexing

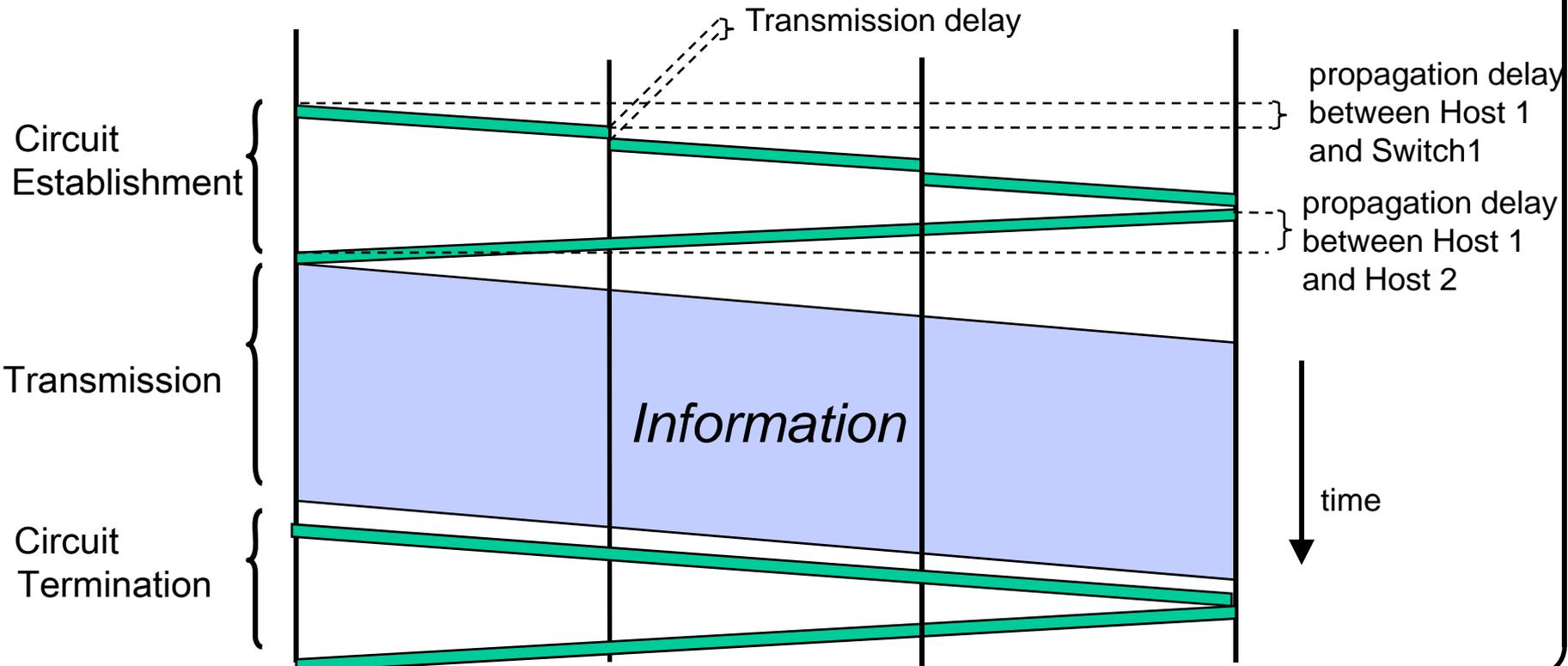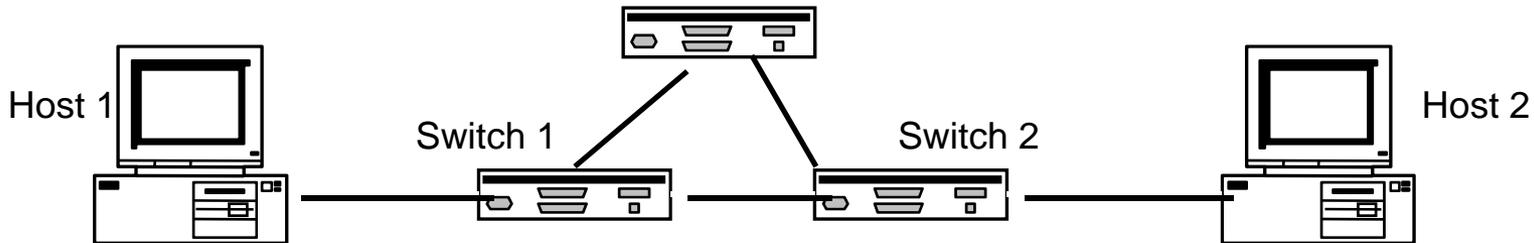
Frames

Slots = 0 1 2 3 4 5 0 1 2 3 4 5

- Time divided in frames and frames divided in slots
- Relative slot position inside a frame determines which conversation the data belongs to
  - E.g., slot 0 belongs to red conversation
- Needs synchronization between sender and receiver
- In case of non-permanent conversations
  - Needs to dynamic bind a slot to a conservation
  - How to do this?
- If a conversation does not use its circuit the capacity is lost!
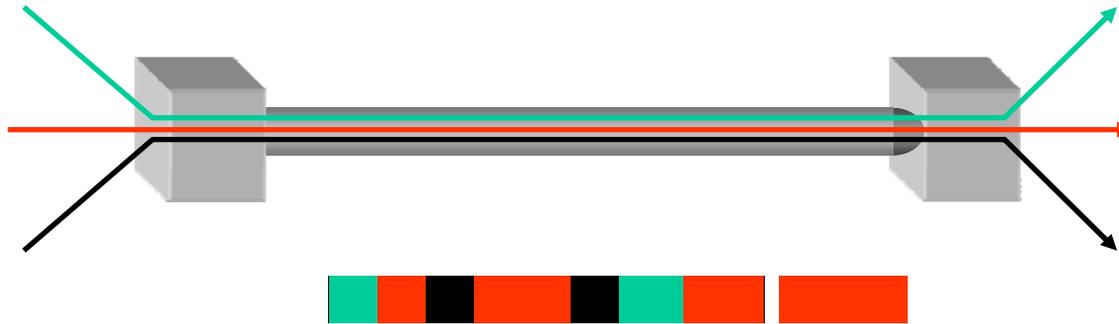
Circuit Switching

- Three phases
    1. circuit establishment
    2. data transfer
    3. circuit termination
- If circuit not available: busy
- Examples
    - Telephone networks
    - ISDN (Integrated Services Digital Networks)

Timing in Circuit Switching

Host 1

Switch 1

Switch 2

Host 2

Transmission delay

propagation delay between Host 1 and Switch1

Circuit Establishment

propagation delay between Host 1 and Host 2

Transmission

Information

time

Circuit Termination

Packet Switching: Multiplexing/Demultiplexing

- Data from any conversation can be transmitted at any given time
  - A single conversation can use the entire link capacity if it is alone
- How to demultiplex?
 - Use meta-data (header) to describe data

Packet Switching

- Data are sent as formatted bit-sequences, so-called packets.
- Packets have the following structure:

| Header	Data	Trailer
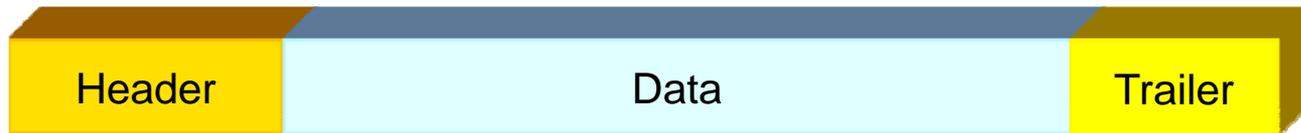
  - Header and Trailer carry control information (e.g., destination address, check sum)
- At each node the entire packet is received, stored briefly, and then forwarded to the next node based on the header information (**Store-and-Forward Networks**)
- Allows statistical multiplexing

Packet Switch

incoming links   Node   outgoing links

Memory
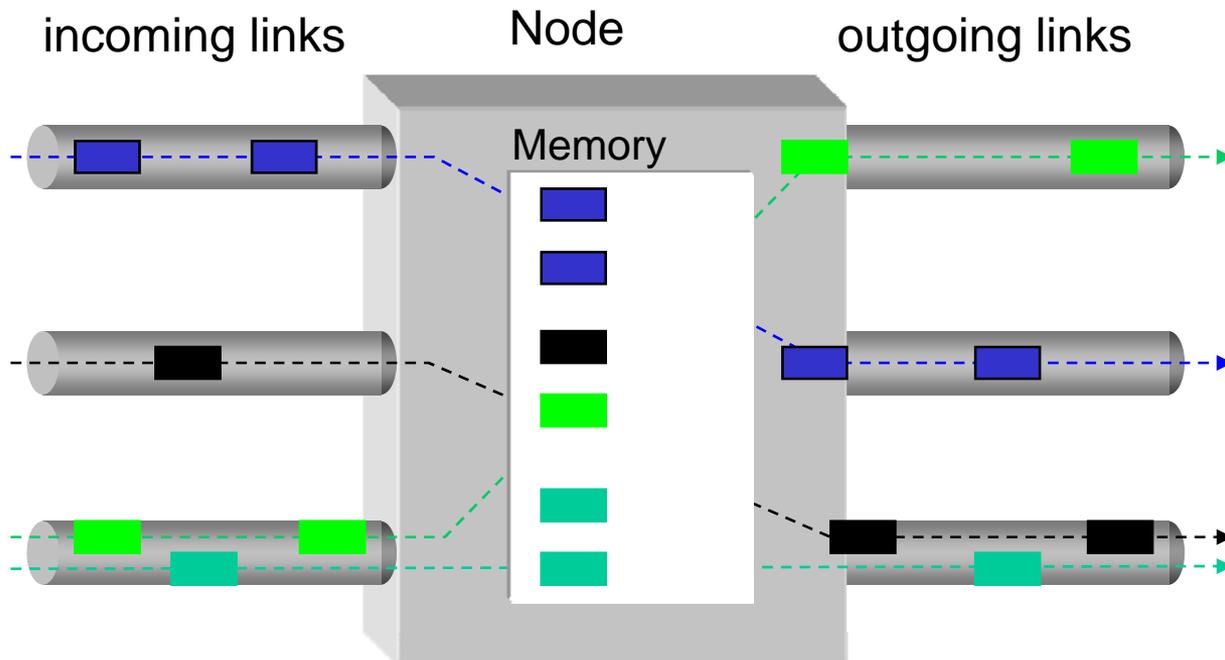
Datagram Packet Switching
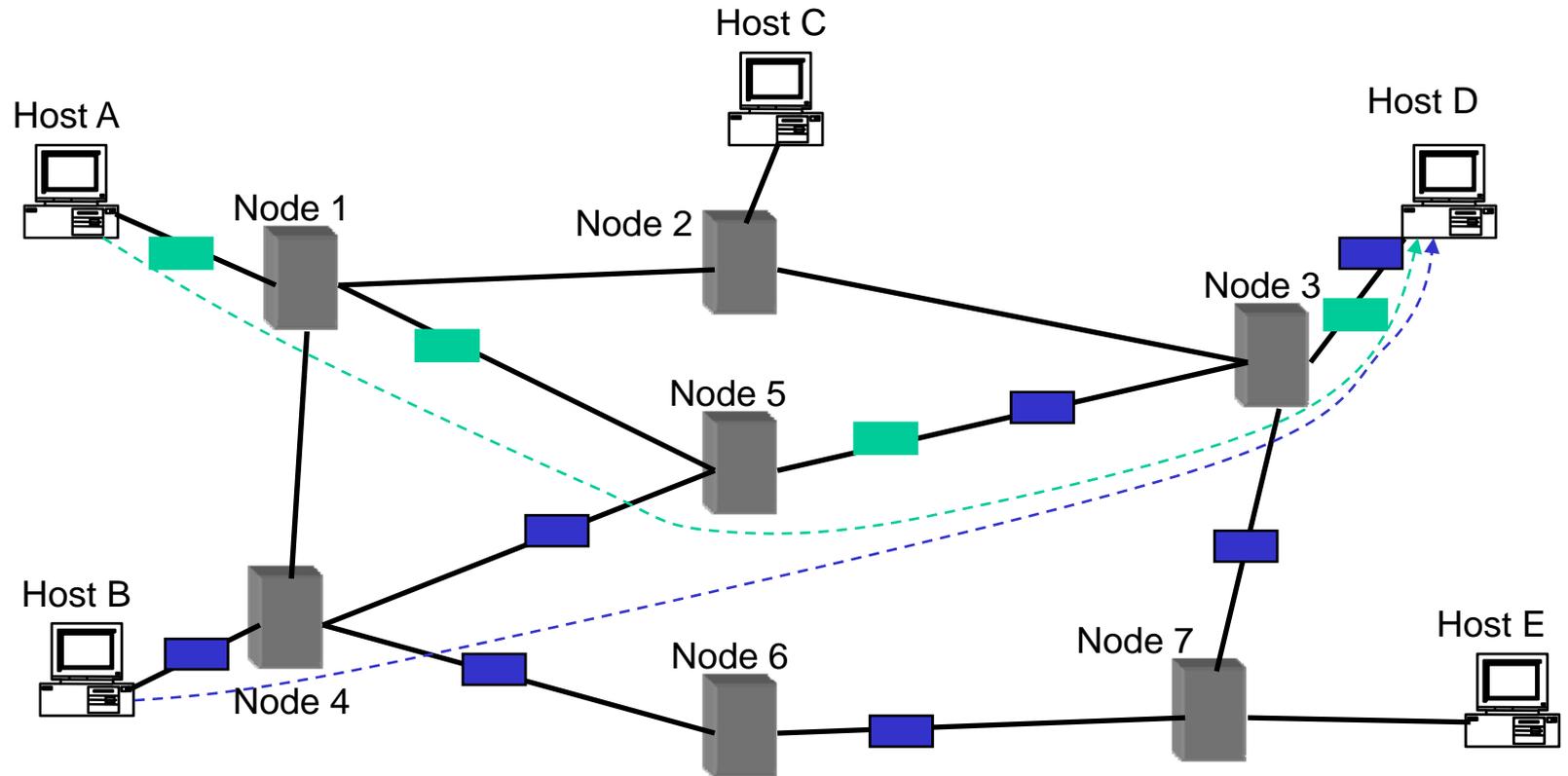
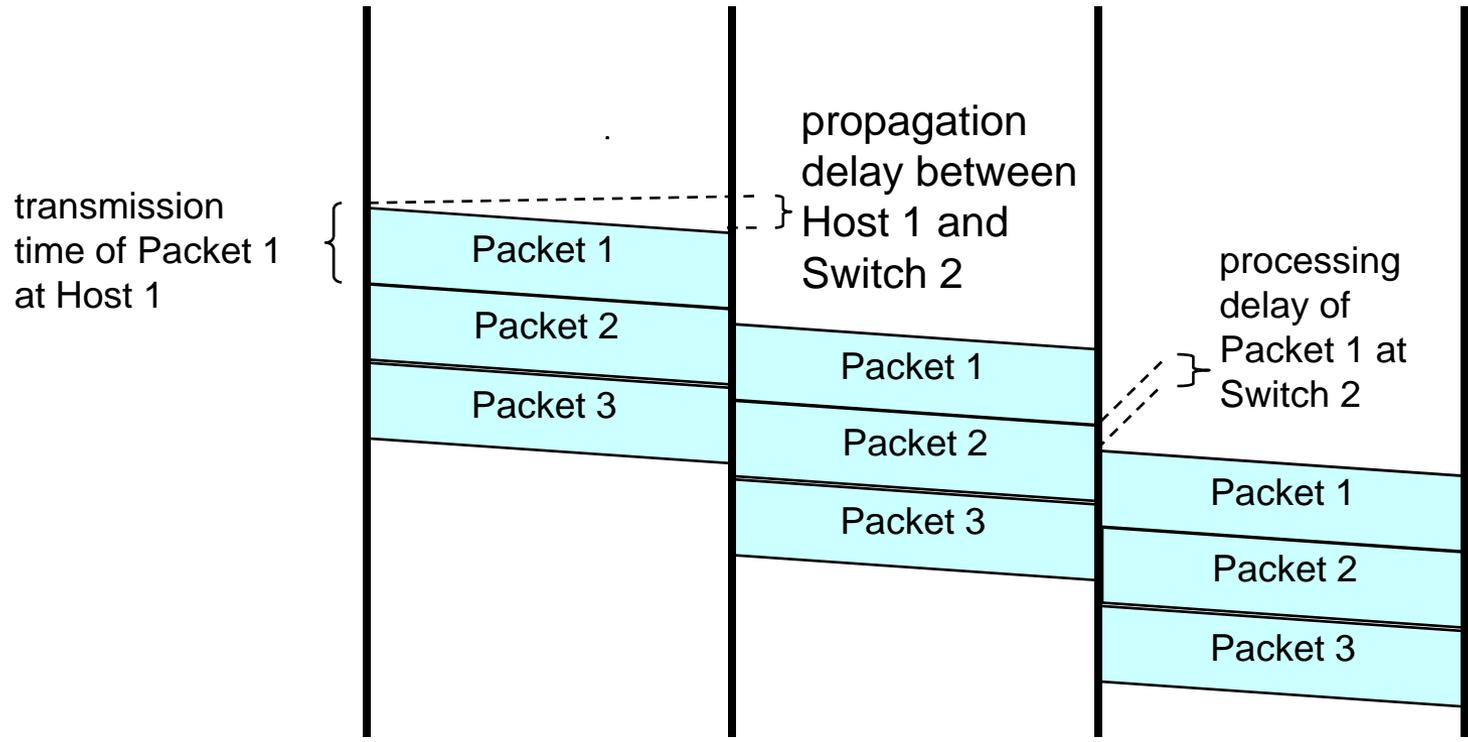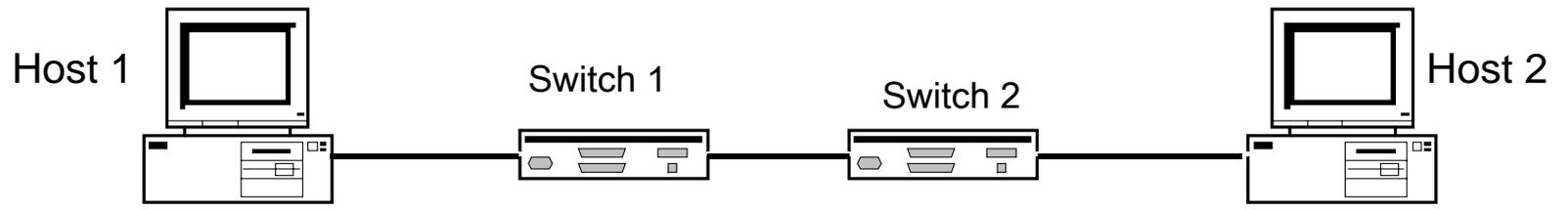- Each packet is independently switched
  - Each packet header contains destination address

Timing of Datagram Packet Switching

Host 1   Switch 1   Switch 2   Host 2

propagation
delay between
Host 1 and
Switch 2

transmission
time of Packet 1
at Host 1

Packet 1

processing
delay of
Packet 1 at
Switch 2

Packet 2

Packet 1

Packet 3

Packet 2

Packet 1

Packet 3

Packet 2

Packet 3
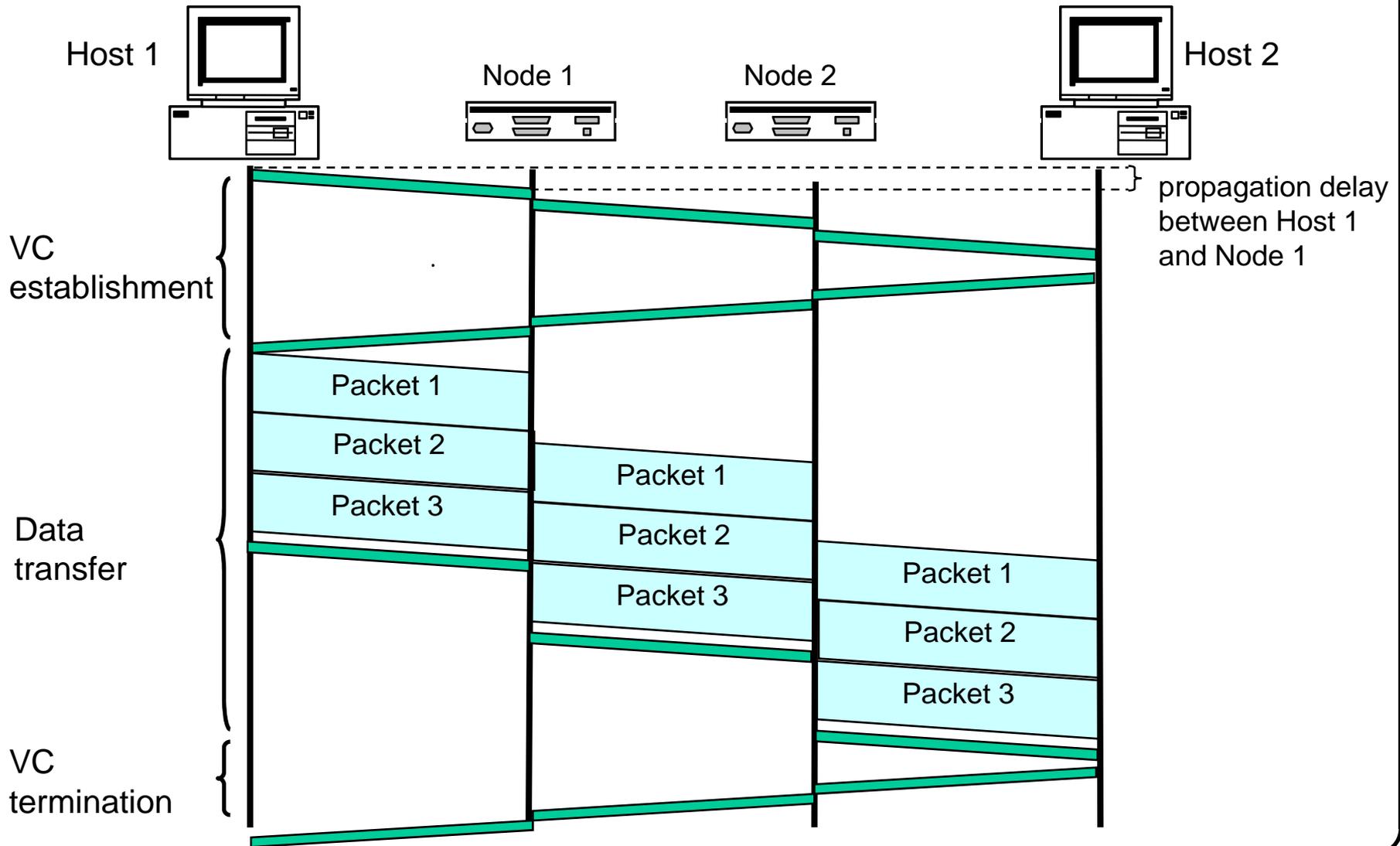
Virtual-Circuit Packet Switching

- Hybrid of circuit switching and packet switching
- Data is transmitted as packets
- All packets from one packet stream are sent along a pre-established path (=virtual circuit)
- Packet header only contains local virtual circuit identifier (VCI)
- Demultiplexing and switching based on VCI
- Guarantees in-sequence delivery of packets
- Example: ATM networks

Virtual-Circuit Packet Switching

- Communication with virtual circuits takes place in three phases
    1. VC establishment
    2. data transfer
    3. VC disconnect

- Note: packet headers don't need to contain the full destination address of the packet

Timing of Virtual-Circuit Packet Switching

Host 1

Node 1

Node 2

Host 2

propagation delay
between Host 1
and Node 1

VC
establishment

Packet 1

Packet 2

Packet 3

Packet 1

Packet 2

Packet 1

Packet 3

Data
transfer

Packet 2

Packet 3

VC
termination

Virtual Circuit Switching
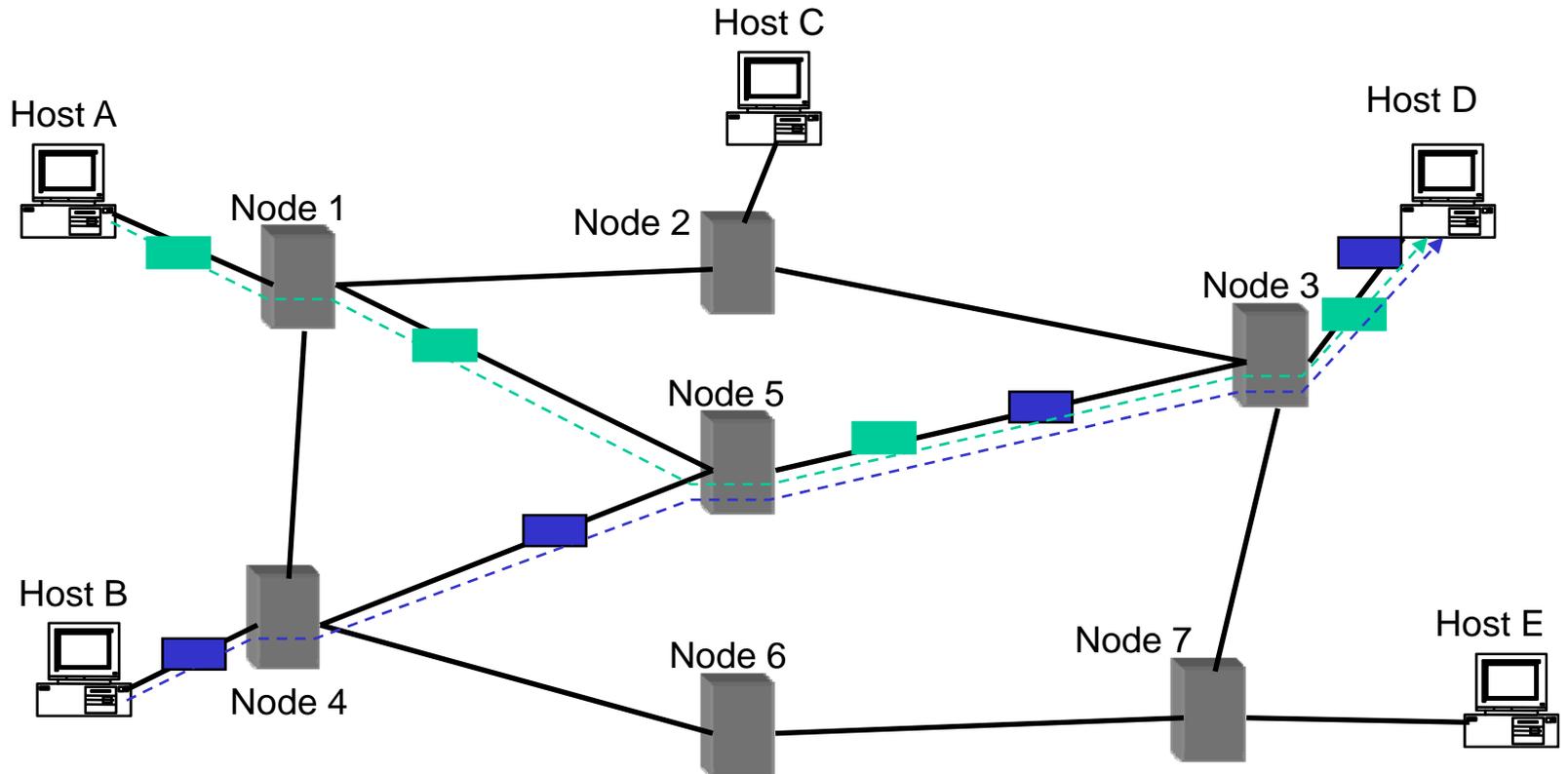
A Taxonomy of Communication Networks

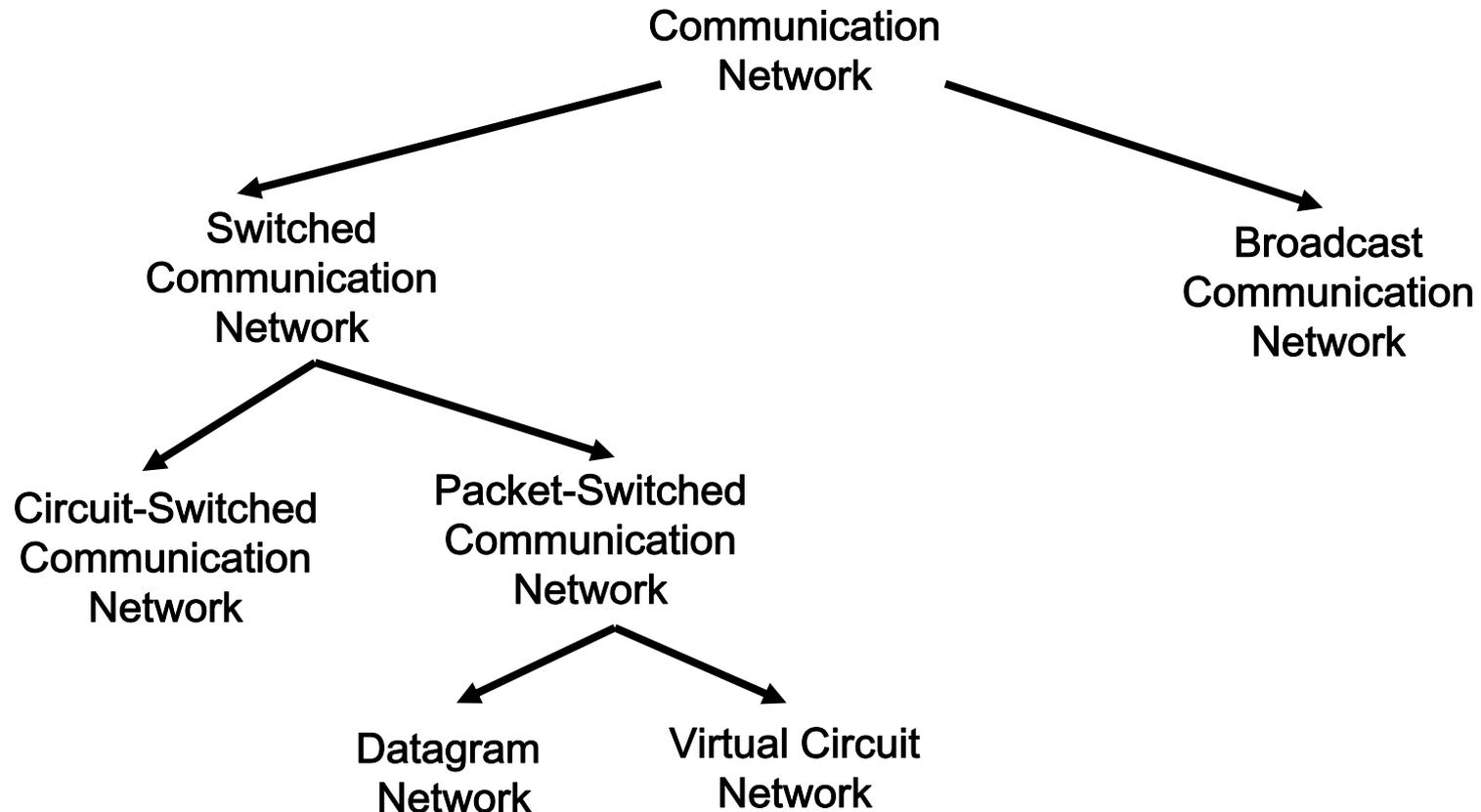- Communication networks can be classified based on the way in which the nodes exchange information:

```
                        Communication
                           Network
                    ↙                    ↘
      Switched                              Broadcast
   Communication                         Communication
      Network                               Network
       ↙      ↘
Circuit-Switched    Packet-Switched
 Communication       Communication
    Network            Network
                       ↙        ↘
                  Datagram    Virtual Circuit
                  Network        Network
```

Packet-Switching vs. Circuit-Switching

- Most important advantage of packet-switching over circuit switching: ability to exploit statistical multiplexing

    - More efficient bandwidth usage

- However, packet-switching needs to buffer and deal with congestion

    - More complex switches

    - Harder to provide good network services (e.g., delay and bandwidth guarantees)