# CS 552 Computer Networks

Fall 2005

Rich Martin

# Course Description

- Graduate course on computer networking
  - Undergraduate knowledge of networking assumed
    - Packets,routing (DV,link-state), layering and encapsulation, protocol stacks,  congestion control …
- Goals:
  - Learn about computer networking research
  - Gain skills needed to perform research
    - Problem selection
    - Solution and research methodologies
    - Presentation, “marketing”

# Overview

- Administrative
- Course Topics
- Overview and history of the Internet
- A Taxonomy of Communication Networks

# Administrative

- Instructor: Richard Martin
- TA: Robert Moore
- Course web page:

  http://www.cs.rutgers.edu./~rmartin/teaching/fall05/cs553/
- Check web page for
  - Readings, assignments, due dates, announcements

# Expected work

- Readings and discussion
  - No write-ups
- Two assignments
  - Experiments Measuring Wide Area Internet properties
- Position paper
  - Defend a position related to computer networks
- Reviews of other student's papers
- Revised position paper
- Project
  - A small research project

# Class format

- Short lecture on readings for the week
  - 3-4 readings for the week
  - I will present some basic material + context
- Discussion
  - Strengths and weaknesses of the papers
    - E.g, readability,problem, methodologies, results, contribution, applicability.
  - Older papers: did the results stand up?

# Course Topics

- Routing:
  - paradigms
  - IP routing
  - router design
- Queuing theory and traffic analysis
- Network tomography
- Reliable transmission
- Quality of service
- Dependability
- Security
- Peer-to-Peer
- Wireless

# Routing Paradigms

- What does a destination address mean?
  - Not all networks use “node centric” routing
- Explore networking address spaces
- Node-centric
  - packet and circuit switched
- Geometric
  - position-centric routing
- Application Data
  - Publish/subscribe routing

# IP Routing

- Global Internet uses:
  - node-centric routing
  - IP address space
- How to route within this address space?
  - How to pick paths between a source and destination?
- Implications of routing choices
  - Performance, security, reliability, economics

# Router Design

- Routing vs. Forwarding
  - Routing: which path
  - Forwarding: getting the packet from the input to the right output(s)
- Forwarding design has wide ranging impacts:
  - Latency, bandwidth, jitter
  - Security, tomography, billing (who pays)
- Router design internals are driven by forwarding

# Network Tomography

- No central authority
  - Network built from the “bottom up”
  - A user’s data crosses many “black boxes”
- How to figure out state of the interior by observations at the edges?
  - Analysis of results of probing network

# Queuing theory/traffic analysis

- How to mathematically describe data motion in computer networks?
- Probabilistic, stochastic analysis
- Queuing theory
  - Single queues
  - Interconnected queues
- Traffic analysis
  - Higher-level traffic descriptions

# Reliable transmission

- Huge interconnected system
  - No central point of control!
  - No central design authority!
  - Failures, delays common
- How to insure data arrives as intended?
  - Forward error correction
  - Backward error detection/retransmission
- Sum of individual decisions has huge impact
  - Fairness, efficiency, performance

# Quality of Service

- Reliability is the 0th order quality metric
- Do all applications require same network performance?
  - Bandwidth? Latency? Jitter?
- Describe what is “quality”
- Networks that deliver different levels of quality

# Dependability

- Old world:
  - E-mail, news, telnet, FTP
- New World:
  - E-commerce, “all daily activities”, (no network -> can’t function?), emergency response?
- Robustness beyond packet loss
  - Human faults (e.g. misconfigurations)
  - Disasters (e.g. fire in Baltimore tunnel)
  - Bugs
  - Active Attacks

# Security

- Old Internet: world of good guys
  - Problems due to bugs, bad algorithms
- Today: real world has bad guys

  Hucksters (sellers), crackers, vandals, terrorists, thieves, governments …
- How can we make the network robust to bad guys?
  - Trust, encryption, authentication, non-repudiation

# Peer-to-Peer

- Biggest application in last 5 years
- Huge percentage of the traffic
- Issues in P2P systems:
  - Legal
  - Scalability
  - Search and retrieval
  - Performance
  - Reliability

# Wireless

- Old internet: all machines wired
- New Internet: many wireless devices
- What are the impacts on:
  - Mobility?
  - Performance?
  - Security?
  - Economics?

# Break

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# What is a Communication Network? (End-system Centric View)

- Network offers one basic service: move information
  - Bird, fire, messenger, truck, telegraph, telephone, Internet …
  - Another example, transportation service: move objects
    - Horse, train, truck, airplane ...
- What distinguish different types of networks?
  - The services they provide
- What distinguish services?
  - Latency
  - Bandwidth
  - Loss rate
  - Number of end systems
  - Service interface (how to invoke the service?)
  - Others
    - Reliability, unicast vs. multicast, real-time...

# 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 – attache 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, ...

# Types of Networks

- Geographical distance
  - System Area Networks (SAN): Myrinet, Infiniband
  - Local Area Networks (LAN): Ethernet, Token ring, FDDI
  - Metropolitan Area Networks (MAN): DQDB, SMDS
  - Wide Area Networks (WAN): X.25, ATM, frame relay
  - Caveat: SAN, LAN, MAN, WAN may mean different things
    - Service, network technology, networks
- Information type
  - Data networks vs. telecommunication networks vs. internal computer networks
- Application type
  - Special purpose networks: Sensing, airline reservation network, banking network, credit card network, telephony
  - General purpose network: Internet

# 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, AppleTalk, SNA

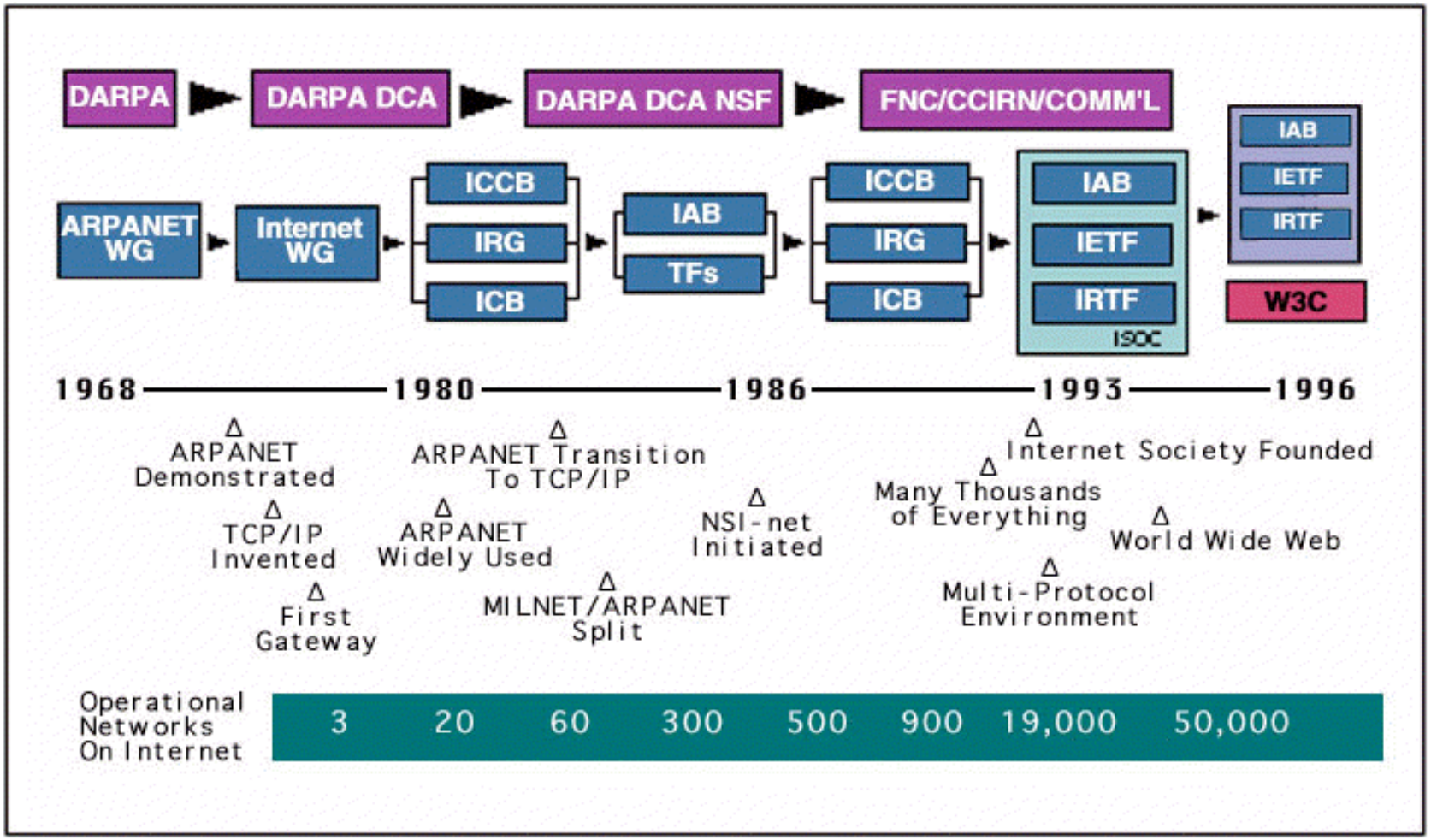
# The Internet (cont'd)

- 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 )
  - Technical basis for other types of networks
    - Intranet: enterprise IP network
- Developed 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, 10s millions computers in 150 countries

# Time Line of the Internet

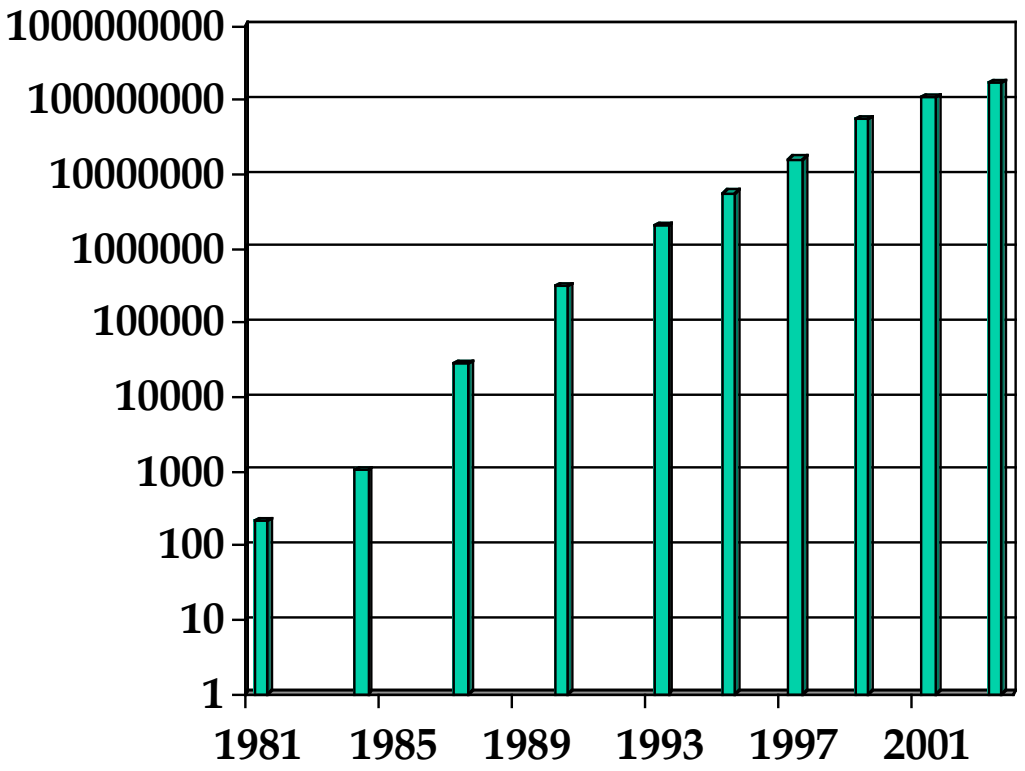



•*Source: Internet Society*

# 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 |




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

# Internet Standardization Process

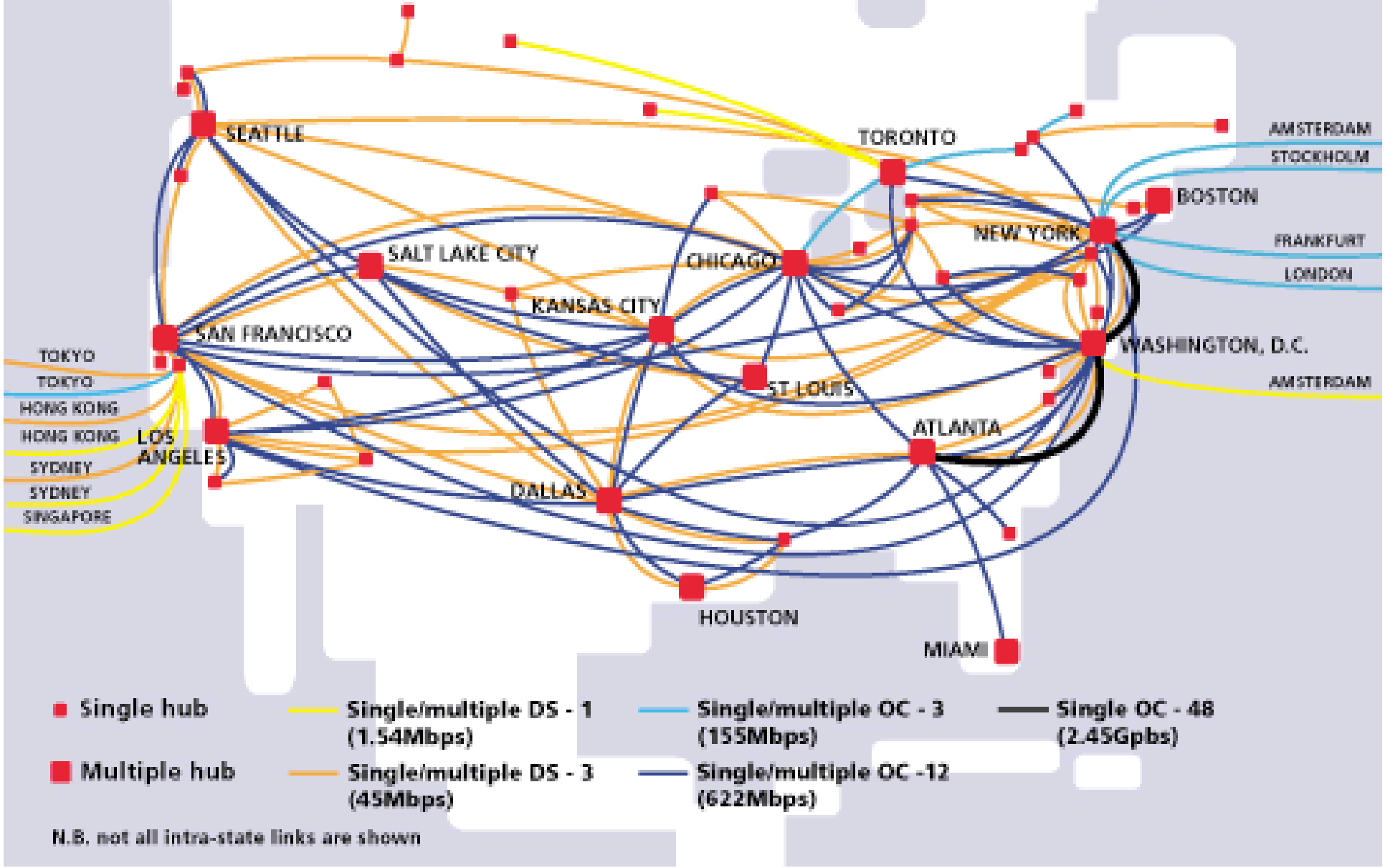
- All standards of the Internet are published as RFC (Request for Comments). But not all RFCs are Internet Standards
  - available: http://www.ietf.org
- A typical (but not only) way of standardization is:
  - Internet Drafts
  - RFC
  - Proposed Standard
  - Draft Standard (requires 2 working implementation)
  - Internet Standard (declared by IAB)

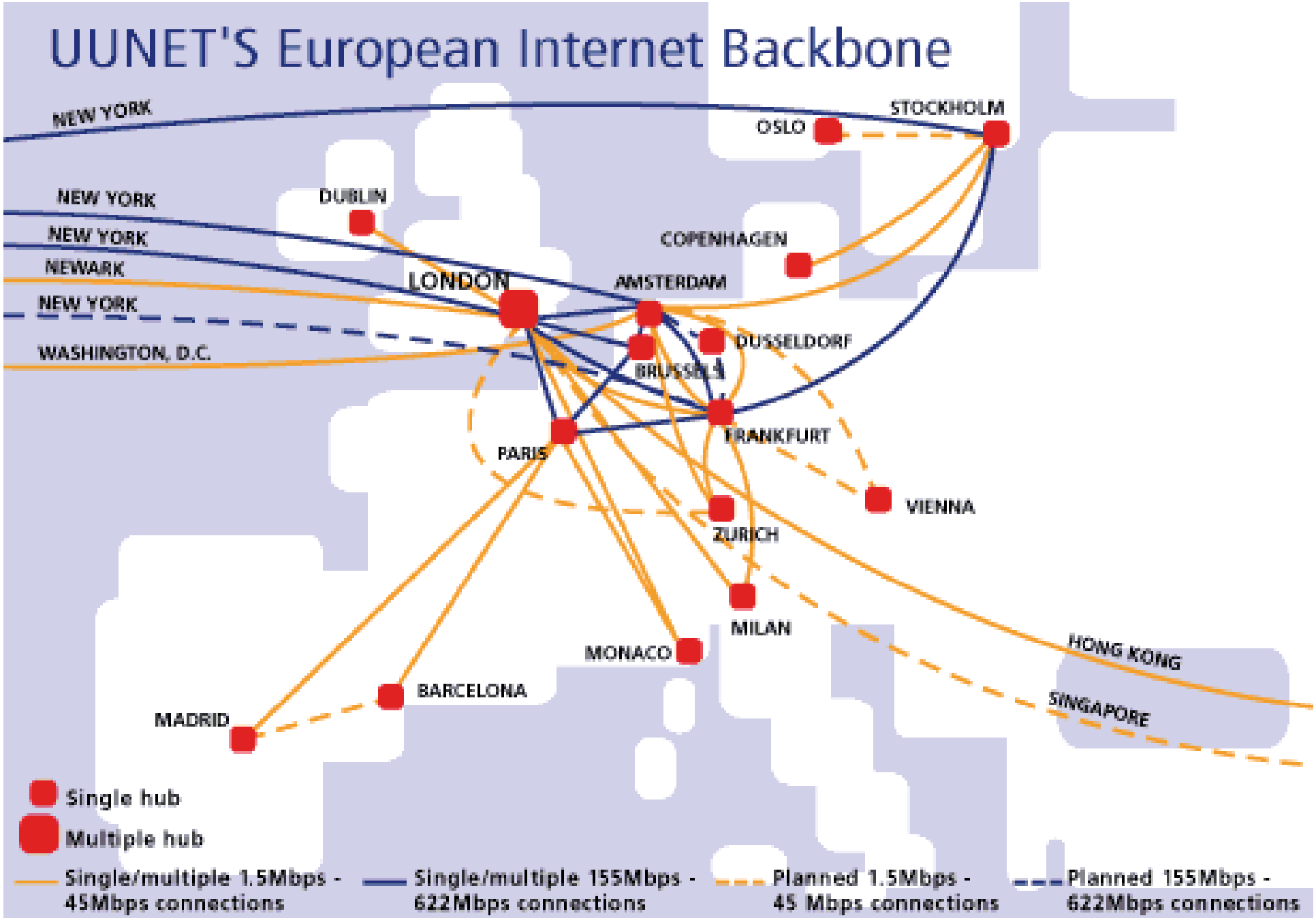
- David Clark, MIT, 1992: "We reject: kings, presidents, and voting. We believe in: rough consensus and running code."

# Services Provided by the Internet

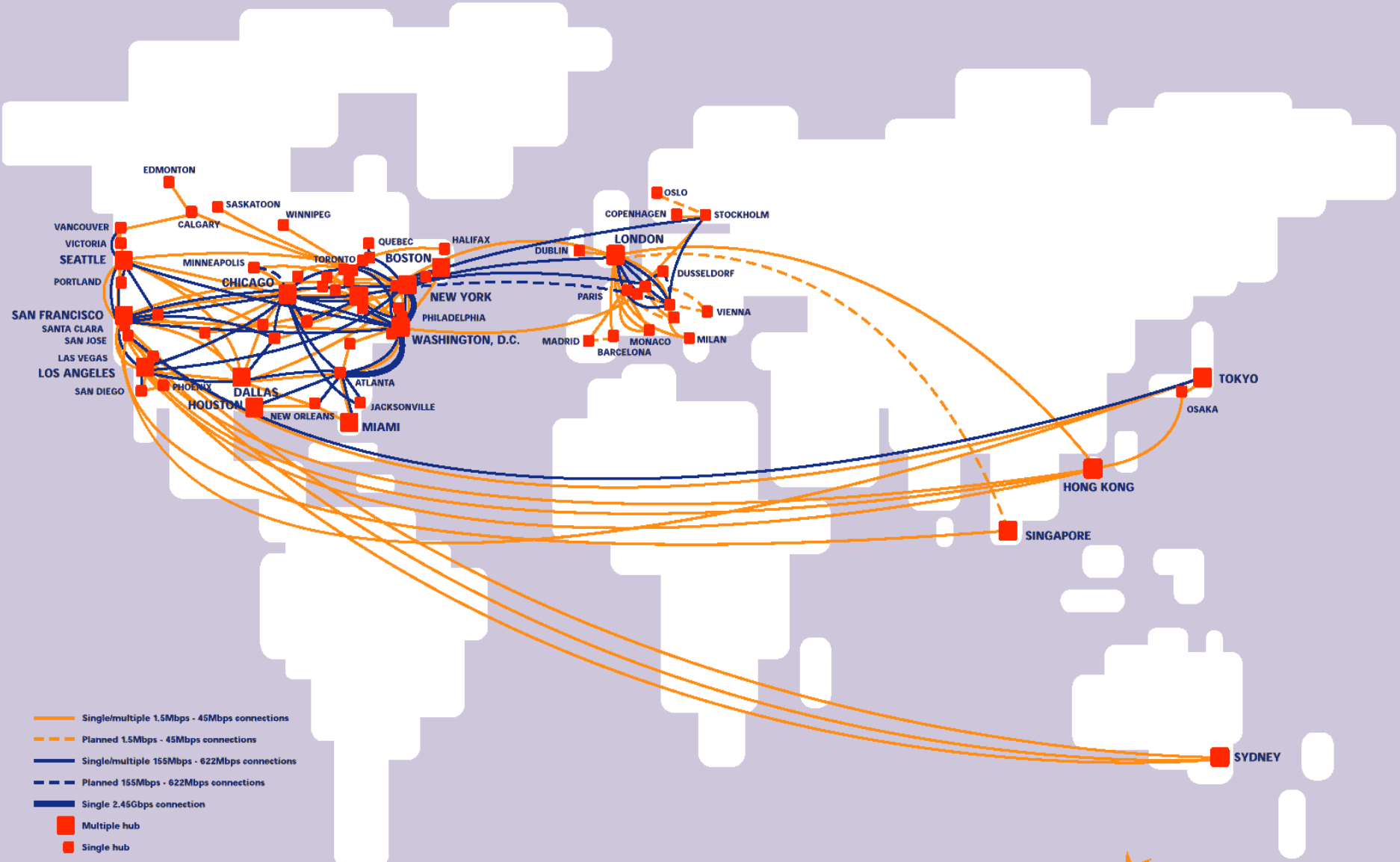
- Shared access to computing resources
  - Telnet (1970's)
- Shared access to data/files
  - FTP, NFS, AFS (1980's)
- Communication medium over which people interact
  - Email (1980's), on-line chat rooms (1990's)
  - Instant messaging, IP Telephony (2000's)
- A medium for information dissemination
  - USENET (1980's)
  - WWW (1990's)
    - Replacing newspaper, magazine?
  - Audio, video (2000's)
    - Replacing radio, CD, TV…

# UUNET'S North American Internet Backbone




UUNET'S European Internet Backbone
NEW YORK
STOCKHOLM
OSLO
NEW YORK
DUBLIN
NEW YORK
COPENHAGEN
NEWARK
LONDON
AMSTERDAM
NEW YORK
DUSSELDORF
WASHINGTON, D.C.
BRUSSELS
FRANKFURT
PARIS
VIENNA
ZURICH
MILAN
MONACO
HONG KONG
BARCELONA
SINGAPORE
MADRID
Single hub
Multiple hub
Single/multiple 1.5Mbps - 45Mbps connections
Single/multiple 155Mbps - 622Mbps connections
Planned 1.5Mbps - 45 Mbps connections
Planned 155Mbps - 622Mbps connections

# UUNET's Global Internet Backbone




For more information visit www.uu.net

NB: With the exception of North America, Spain & Germany, all major 'in-country' links have been excluded from this map. 'In-state' links within the USA have also been excluded.

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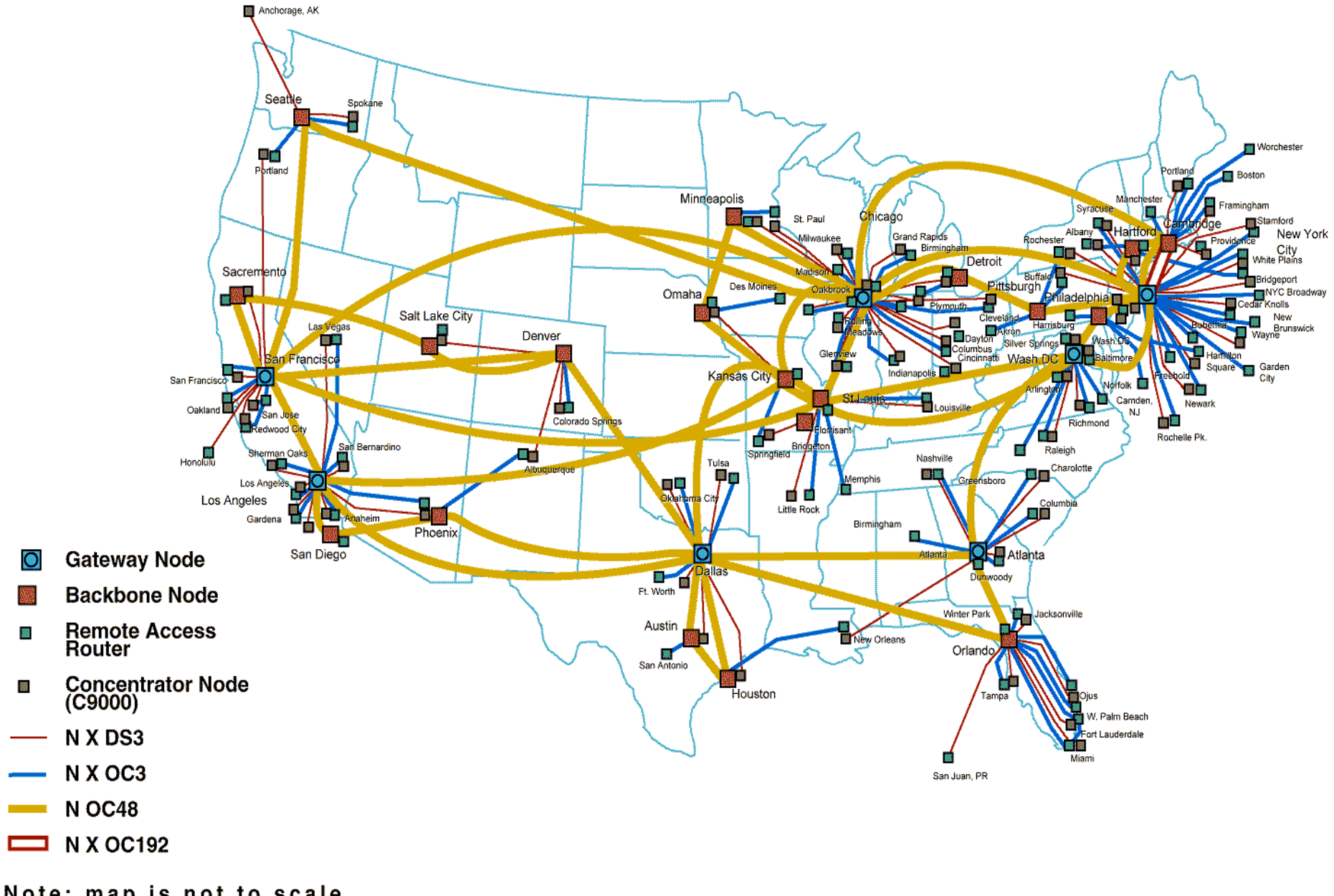


Note: map is not to scale.

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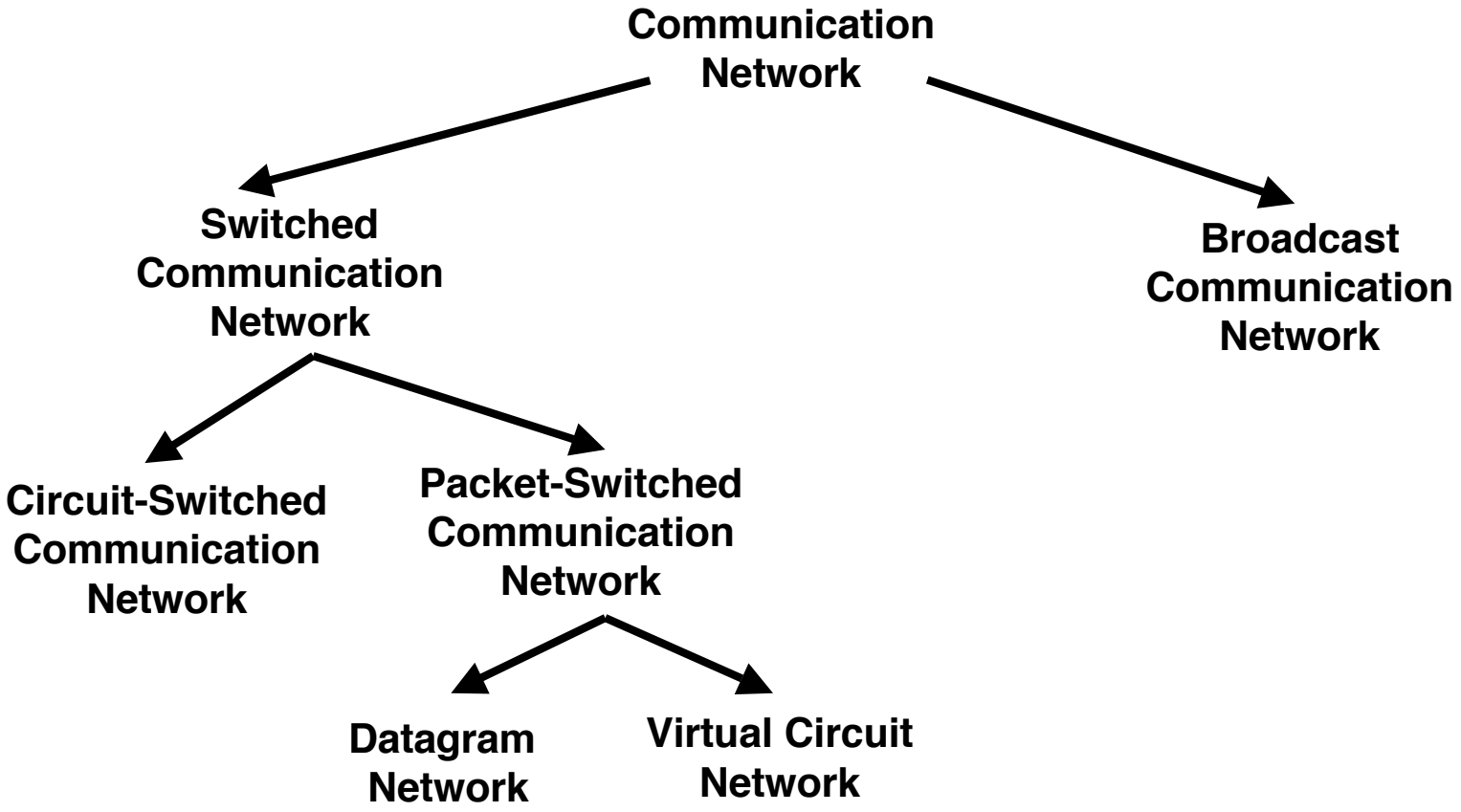
# A Taxonomy of Communication Networks

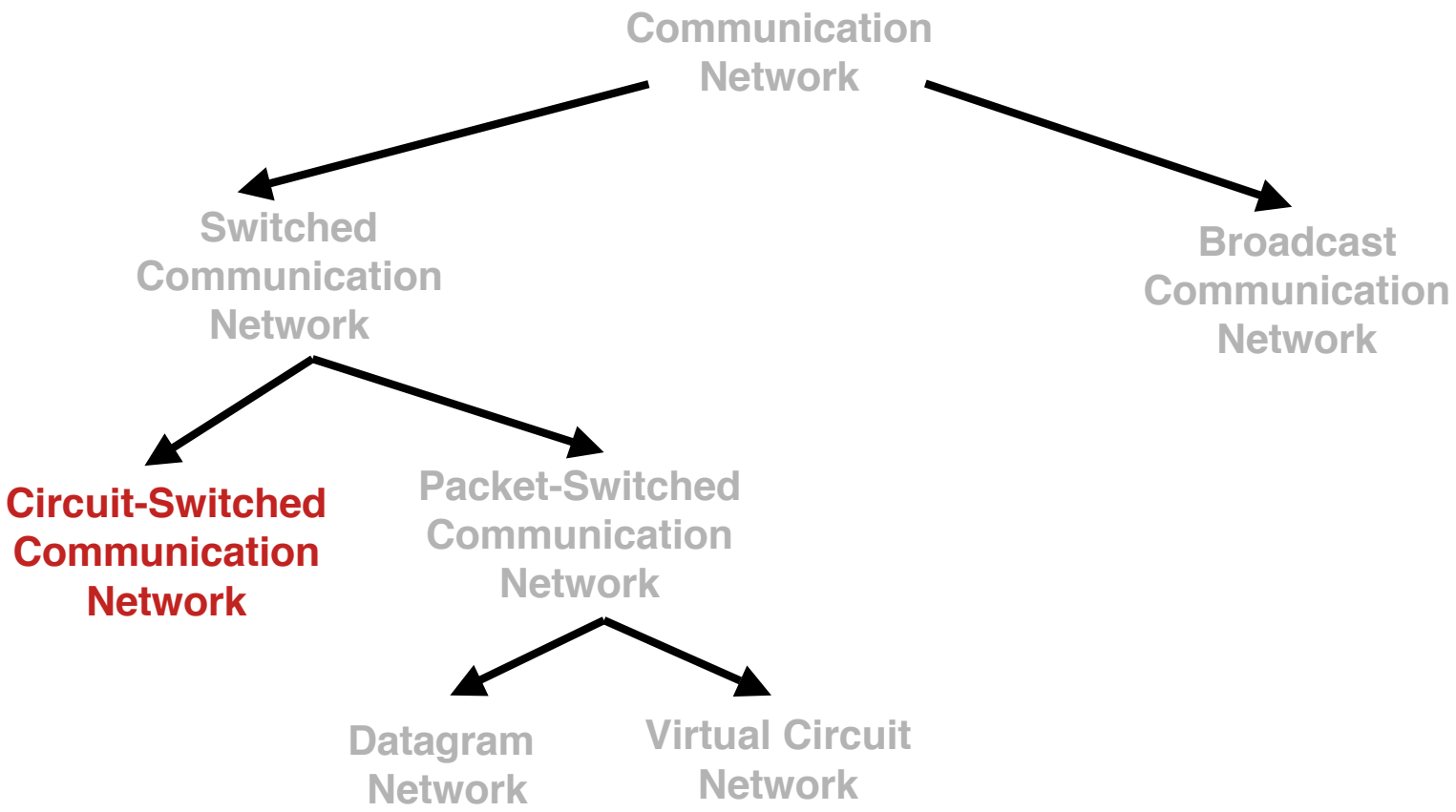
- Communication networks can be classified based on the way in which the nodes exchange information:



# Broadcast vs. Switched Communication Networks

- Broadcast communication networks
  - Information transmitted by any node is received by every other node in the network
    - E.g., LANs (Ethernet, Wavelan)
  - Problem: coordinate the access of all nodes to the shared communication medium (Multiple Access Problem)
- Switched communication networks
  - Information is transmitted to a sub-set of designated nodes
    - E.g., WANs (Telephony Network, Internet)
  - Problem: how to forward information to intended node(s)
    - Done by special nodes (e.g., routers, switches) running routing protocols

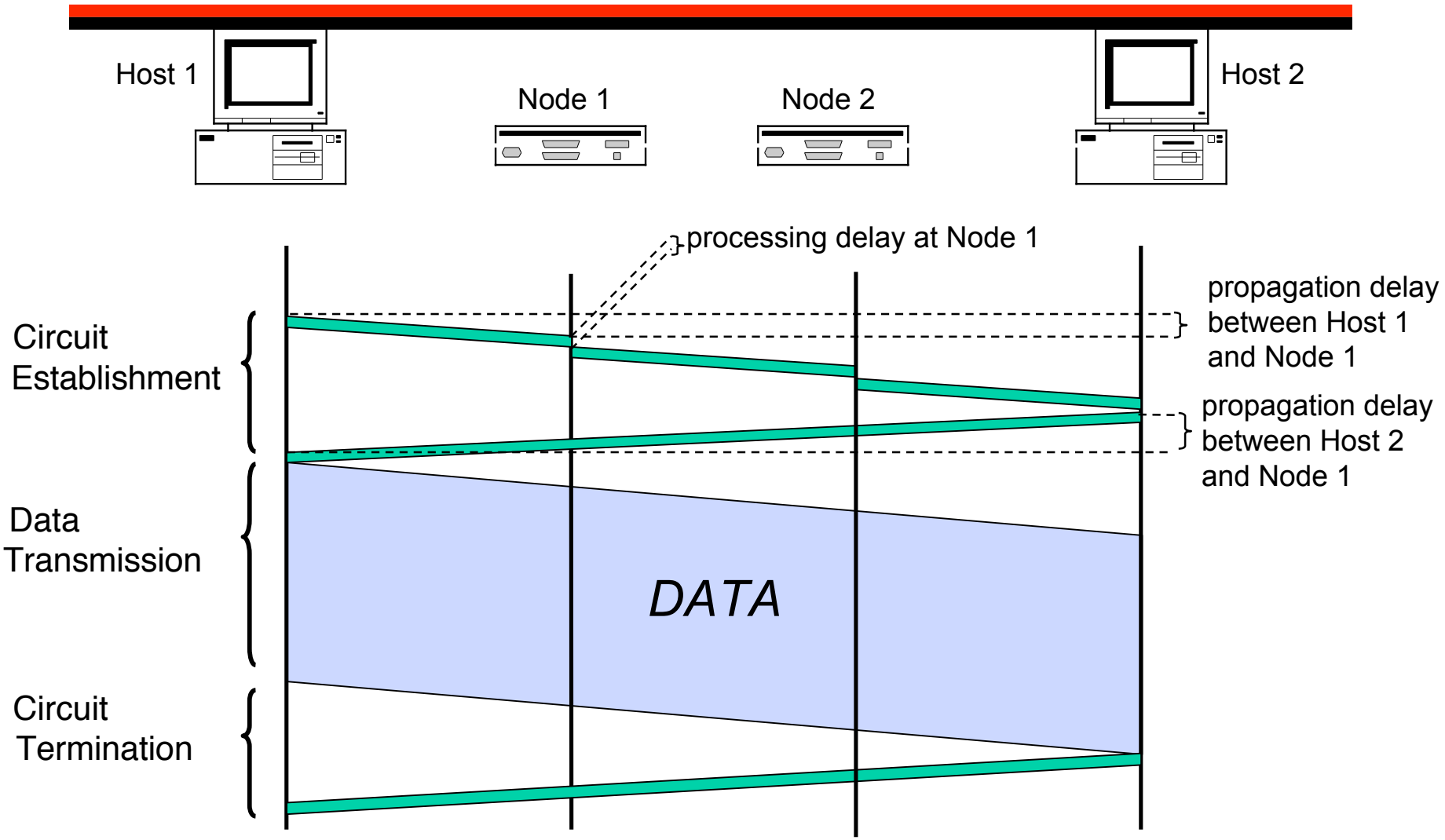
# A Taxonomy of Communication Networks



# Circuit Switching

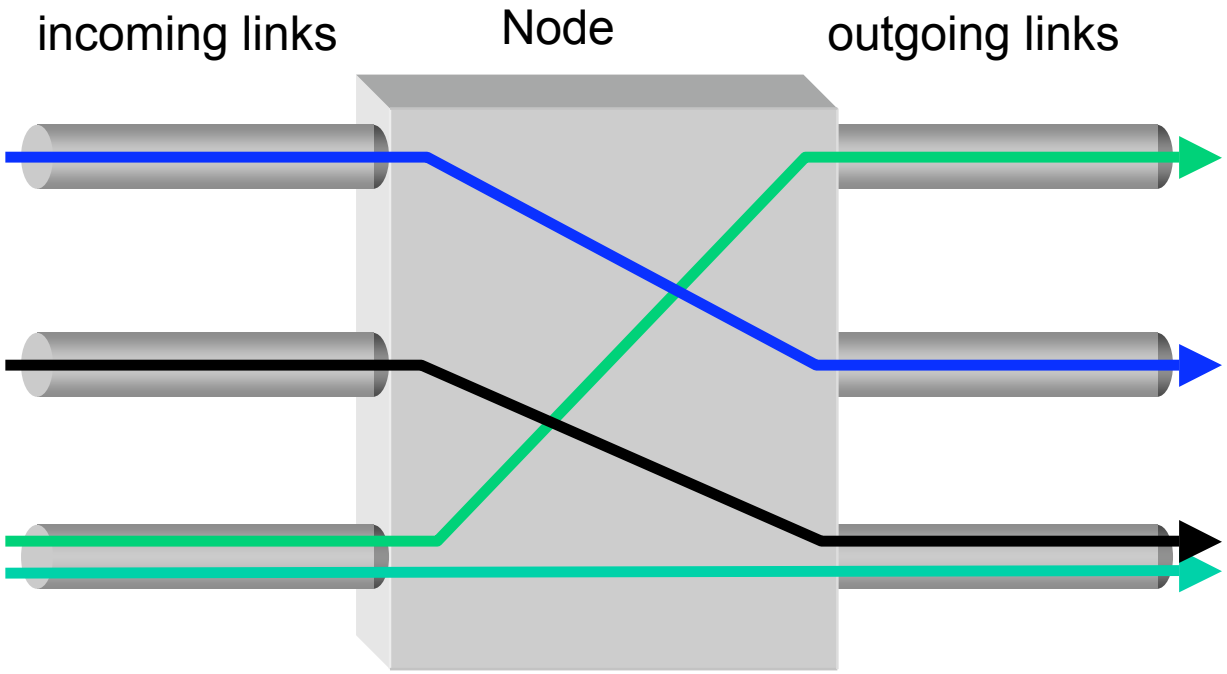
- Three phases
  1. circuit establishment
  2. data transfer
  3. circuit termination
- If circuit not available: “Busy signal”
- Examples
  - Telephone networks
  - ISDN (Integrated Services Digital Networks)

# Timing in Circuit Switching

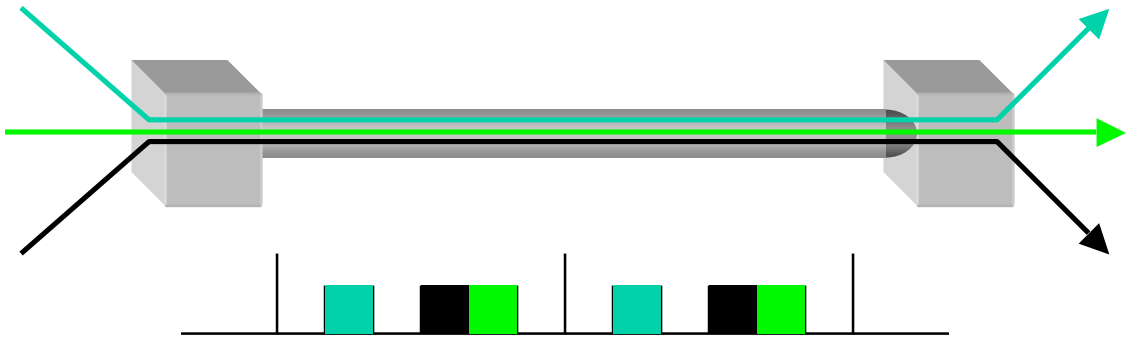


# Circuit Switching

- A node (switch) in a circuit switching network

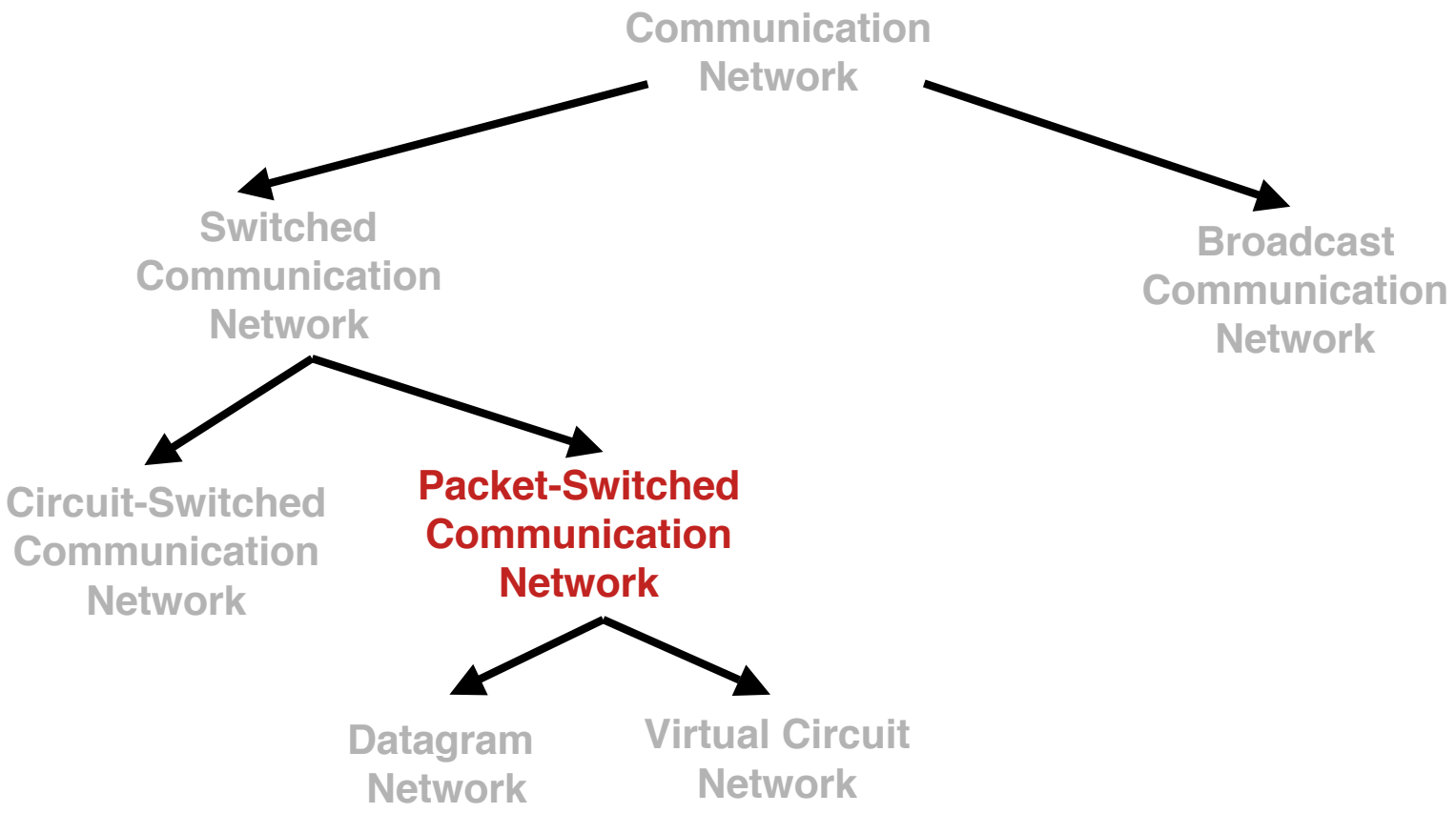


# Circuit Switching: Multiplexing/Demultiplexing



- Time divided in frames and frames divided in slots
- Relative slot position inside a frame determines which conversation the data belongs to
- 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?

# A Taxonomy of Communication Networks



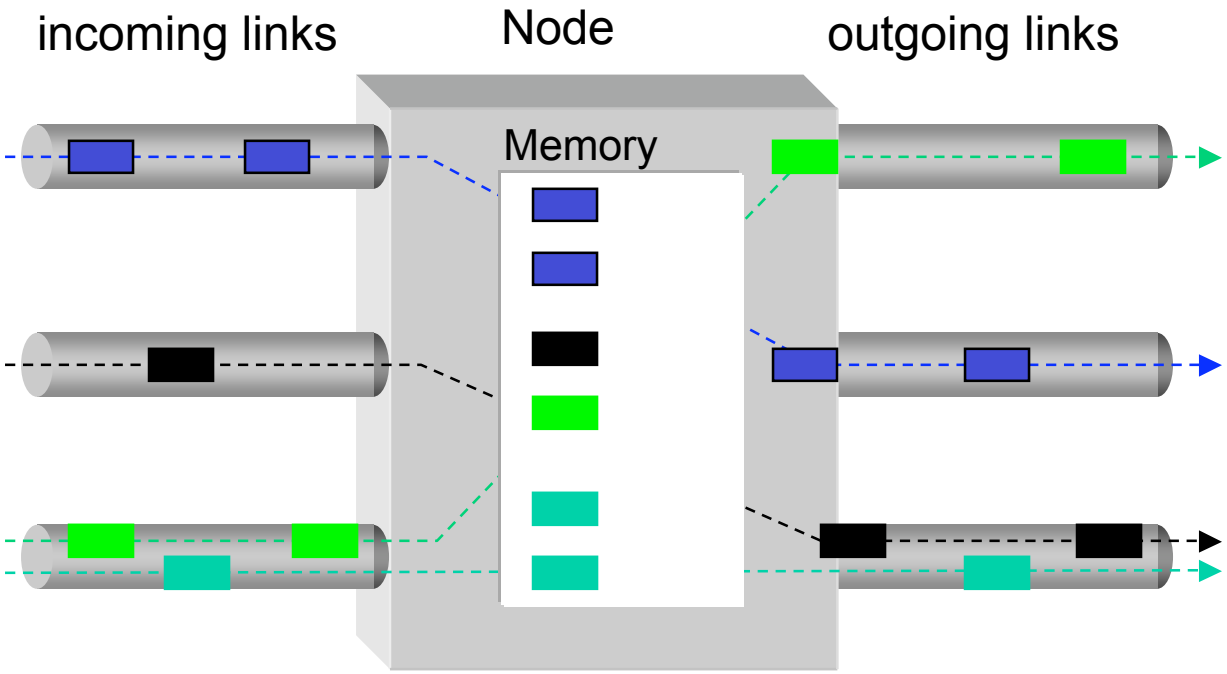
# Packet Switching

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

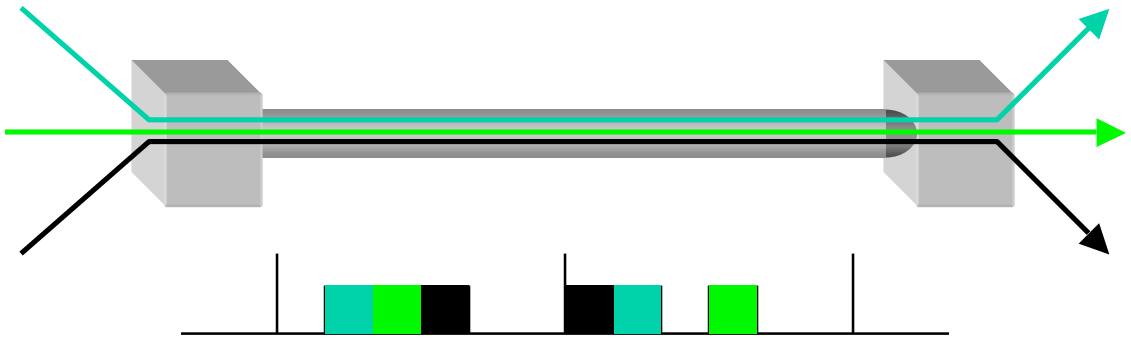

  - Header and Trailer carry control information (e.g., destination address, check sum)
- Each packet is passed through the network from node to node along some path (**Routing**)
- At each node the entire packet is received, stored briefly, and then forwarded to the next node (**Store-and-Forward Networks**)
- Typically no capacity is allocated for packets

# Packet Switching

- A node in a packet switching network

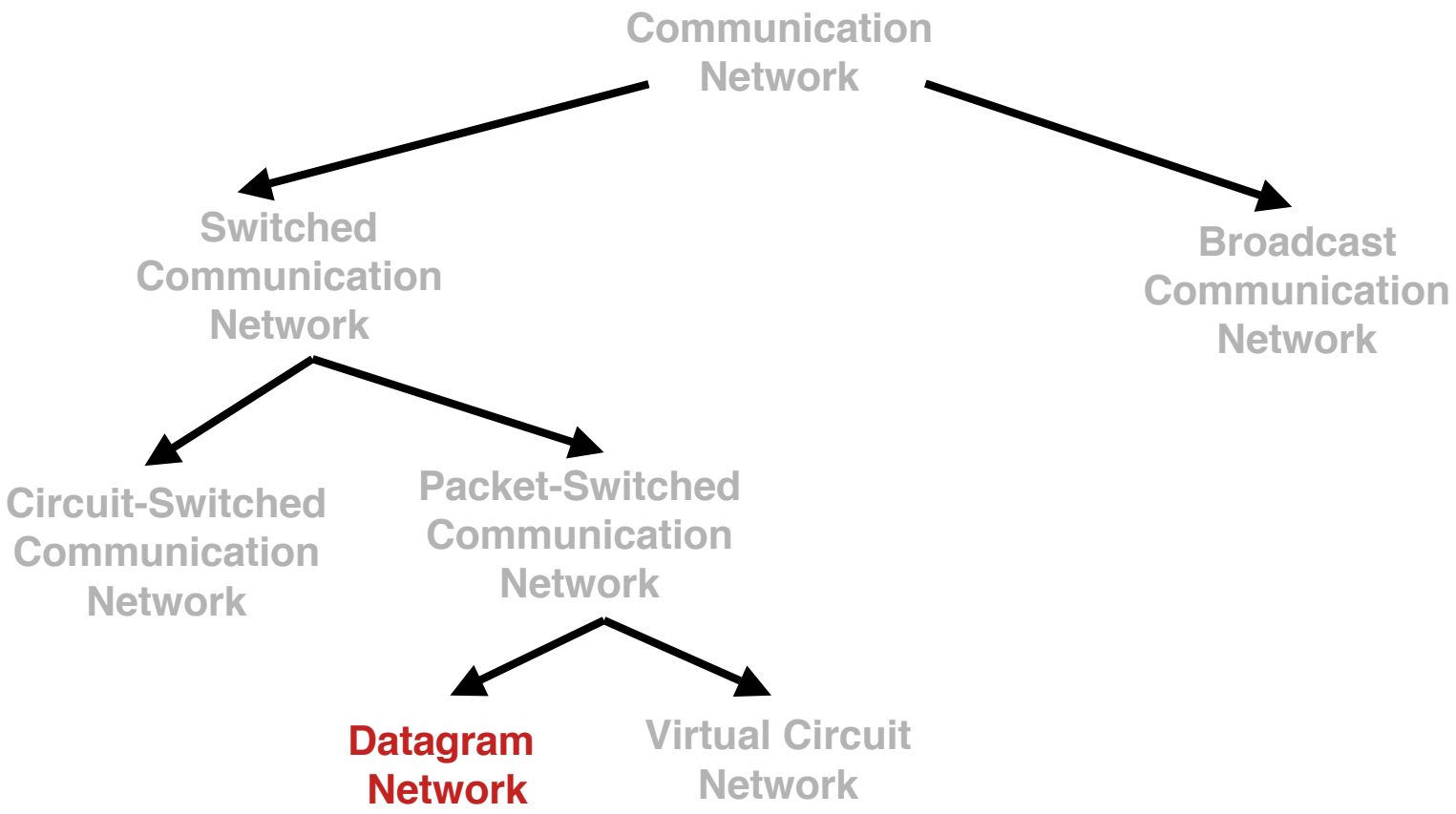


# Packet Switching: Multiplexing/Demultiplexing



- Data from any conversation can be transmitted at any given time
- How to tell them apart?
  - Use meta-data (header) to describe data

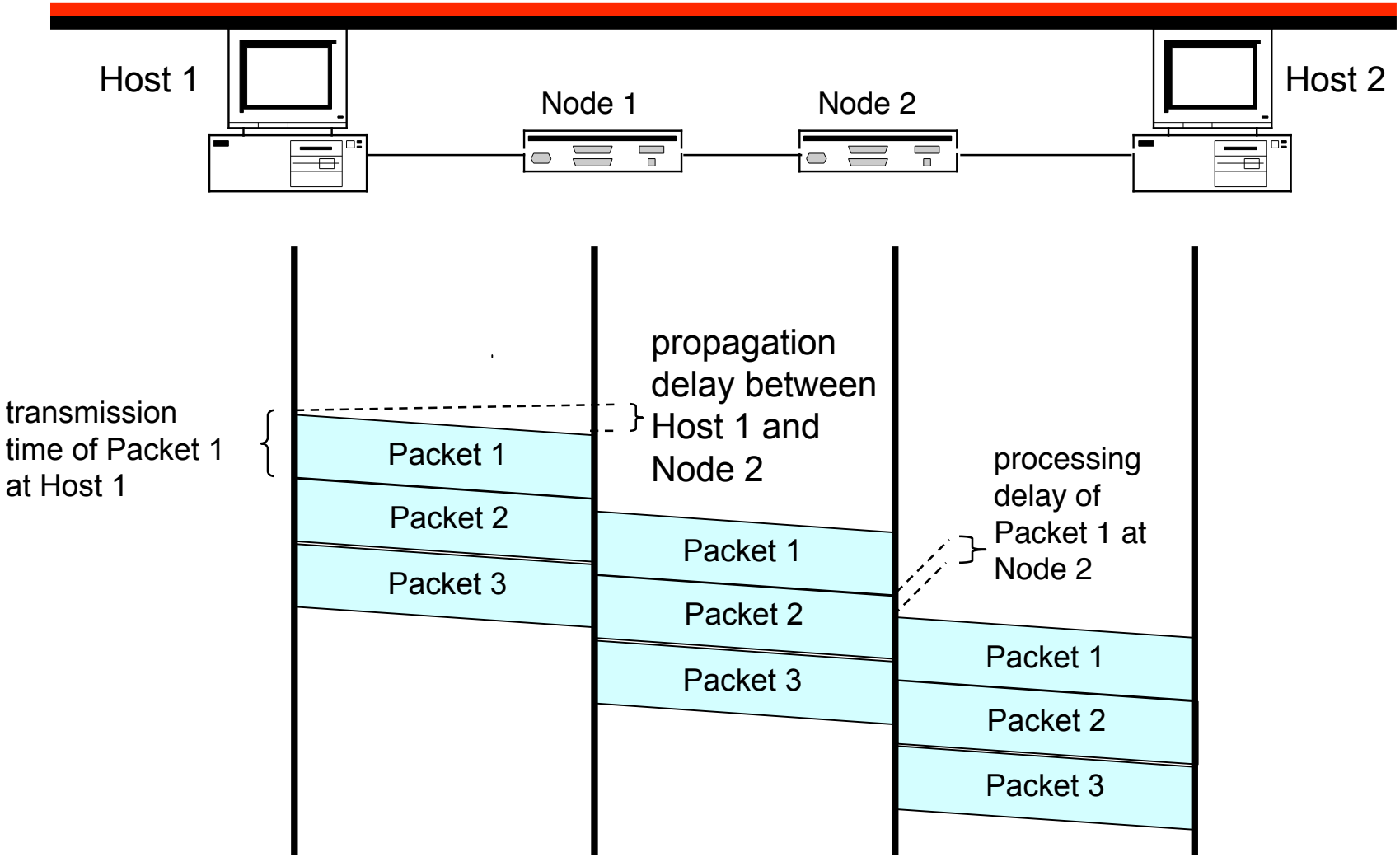
# A Taxonomy of Communication Networks



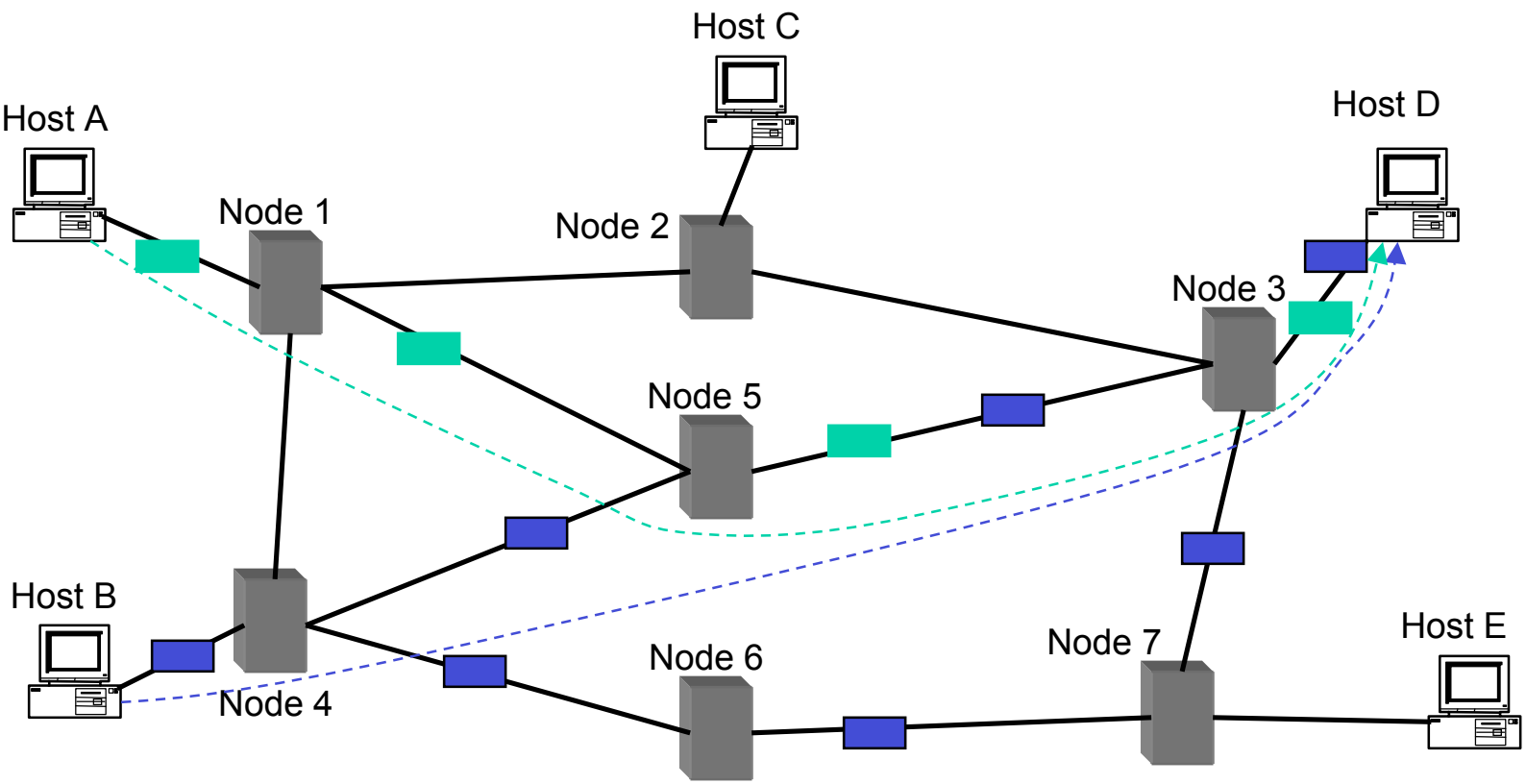
# Datagram Packet Switching

- Each packet is independently switched
  - Each packet header contains destination address
- No resources are pre-allocated (reserved) in advance
- Example: IP networks

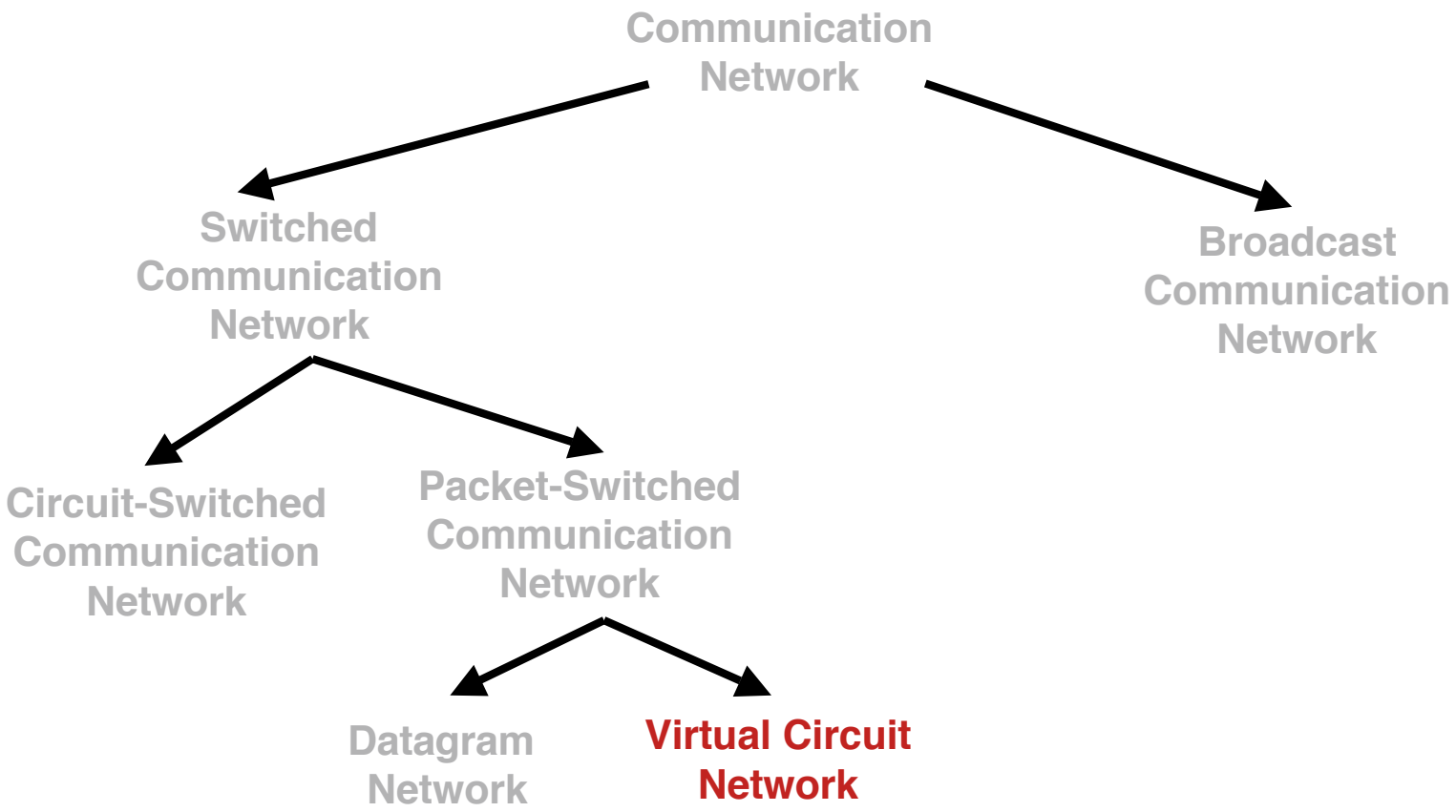
# Timing of Datagram Packet Switching



# Datagram Packet Switching



# A Taxonomy of Communication Networks



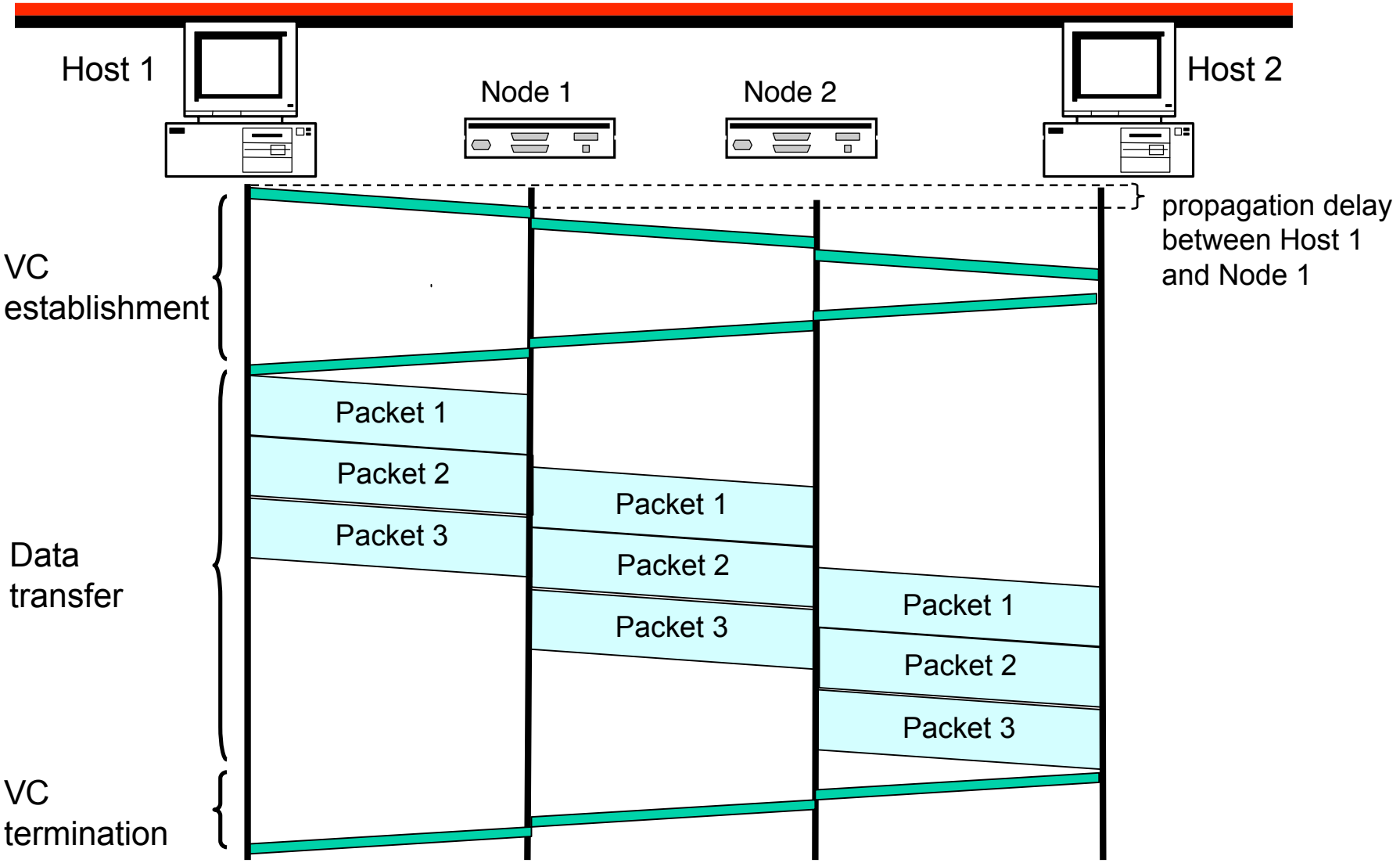
# Virtual-Circuit Packet Switching

- 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)
- Guarantees in-sequence delivery of packets
- **However**: Packets from different virtual circuits may be interleaved
- 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 Datagram Packet Switching



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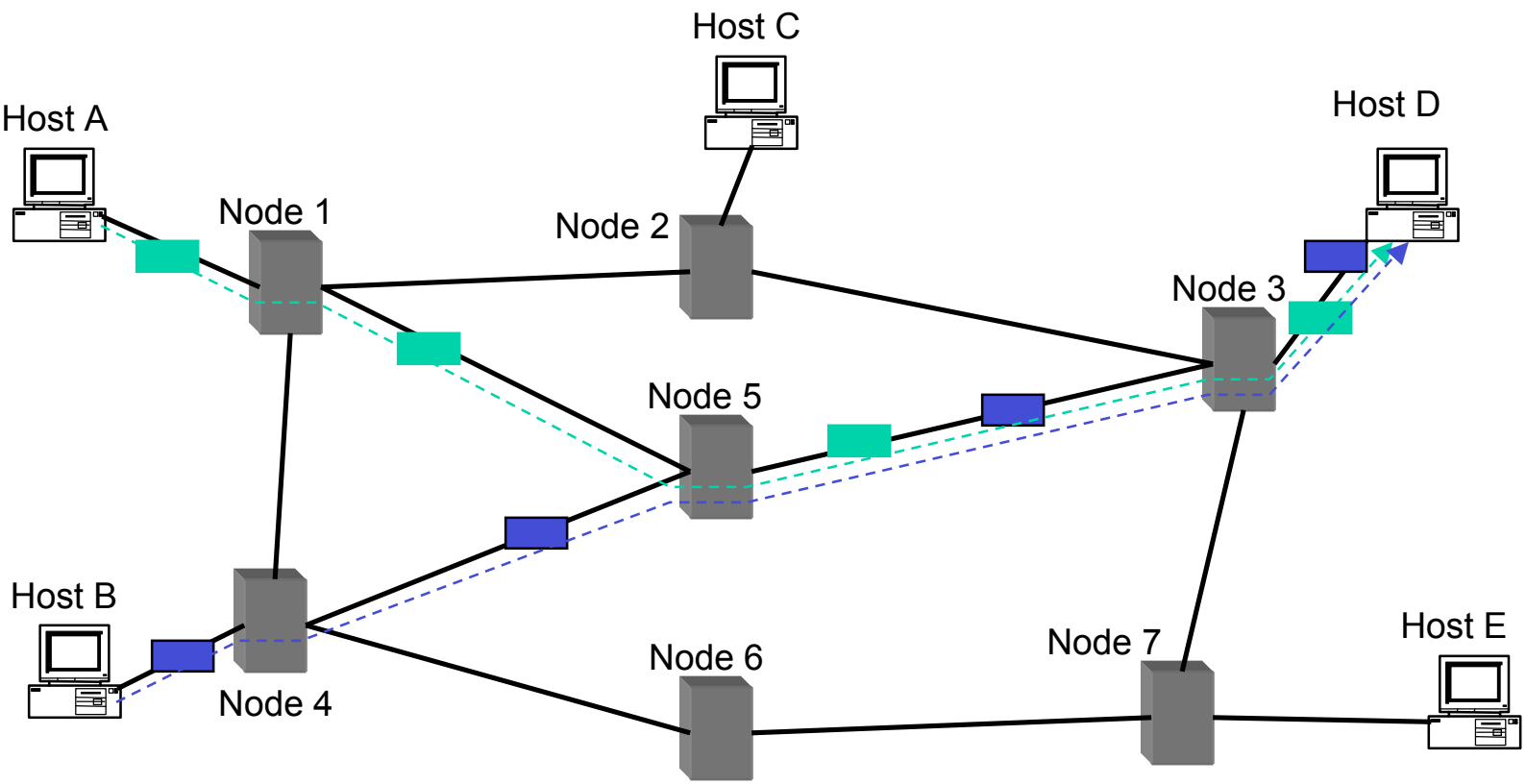


# Packet-Switching vs. Circuit-Switching

- Most important advantage of packet-switching over circuit switching: ability to exploit statistical multiplexing:
  - Efficient bandwidth usage; ratio between peek and average rate is 3:1 for audio, and 15:1 for data traffic
- However, packet-switching needs to deal with congestion:
  - More complex routers
  - Harder to provide good network services (e.g., delay and bandwidth guarantees)
- In practice they are combined:
  - IP over SONET, IP over Frame Relay

# Network Components (Examples)

## Links

Fibers

Coaxial Cable

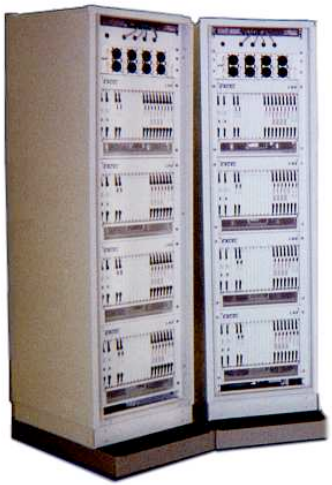
## Interfaces

Ethernet card

Wireless card


## Switches/routers

Large router



Telephone switch

# Next week

- 1st assignment will be posted
- 4 readings on routing paradigms
  - Node-centric
    - Packet switching (Internet)
    - Circuit switching (SS7)
  - Geometric (position-centric) (TBF)
  - Data-centric (Diffusion)