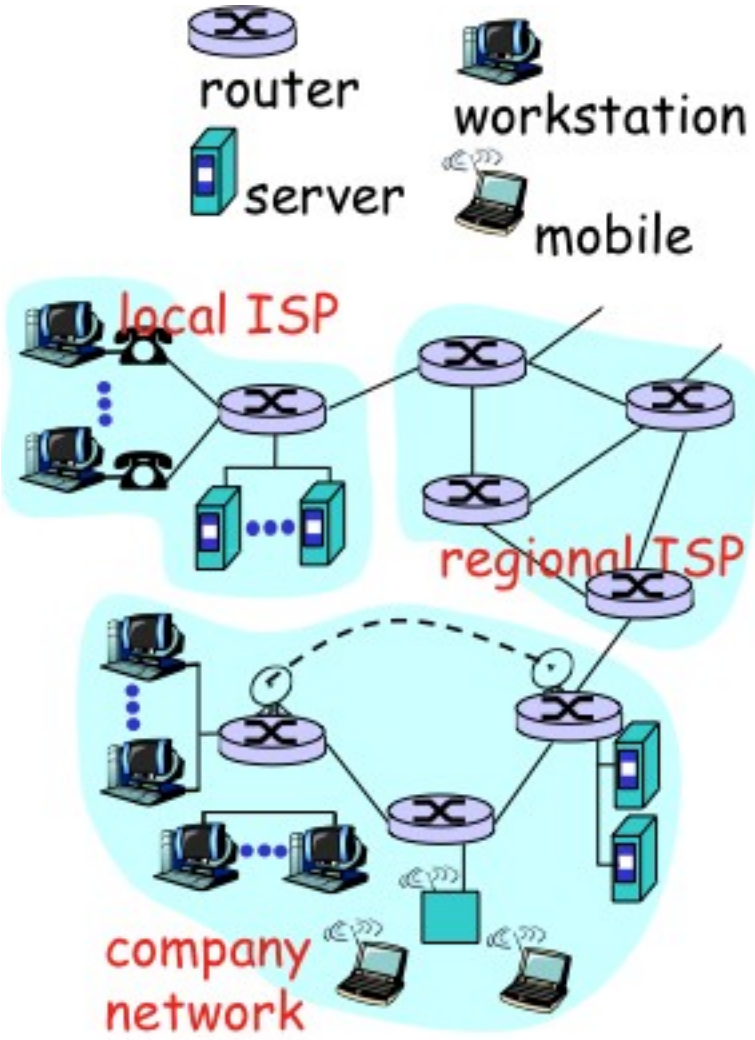
Communication Networks

Overview

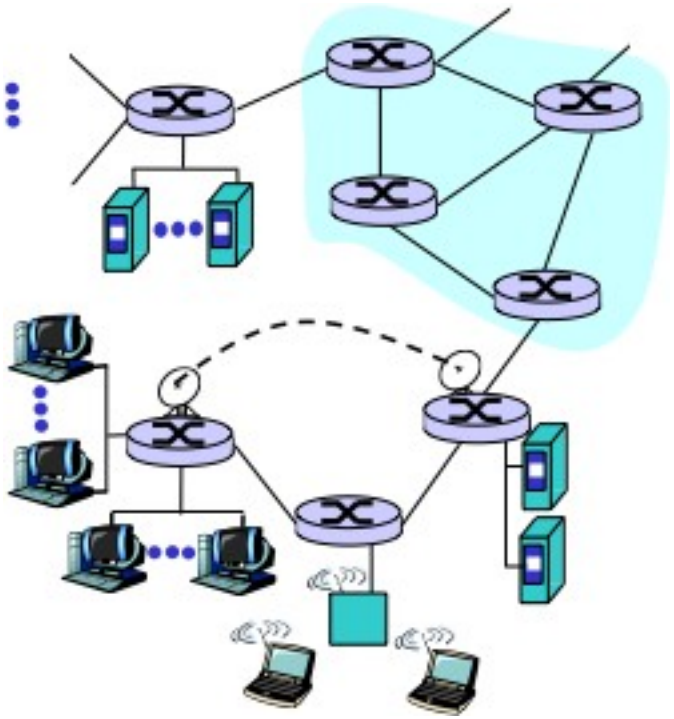
What is it?

- The Internet: a network of networks
  - end systems
    - computers, many other *types* of electronic devices
  - communication links
    - copper, cable, fiber
    - radio, satellite
  - intermediate systems (why needed?)
    - routers, switches, and many other mid-boxes
  - distributed applications



How does it work?

- Network hardware
  - communication infrastructure
    - access links: Ethernet, WiFi, digital subscribe line (DSL), cable
    - backbone links: fiber, satellite
    - network devices: network interface card (NIC), modems, routers, switches
  - switching: circuit vs. packet
  - medium: wired vs. wireless
  - scale: personal/local/metropolitan/wide area network (PAN/LAN/MAN/WAN), the Internet
- Network software



Network architectures

- Network software (network OS)
  - network architecture: a *layered* structure
    - OSI: application, presentation, session, transport, network, link, physical
      - International Standards Organization (ISO)
      - International Telecommunication Union (ITU)
    - the Internet: application, transport, network
      - Internet Engineering Task Force (IETF)
    - PAN/LAN/MAN: IEEE 802
  - network services
  - network protocols

Network services

- Network software (network OS)
  - network architecture: a layered structure
  - network services
    - connection-oriented vs connectionless
      - connection establishment, data transfer
    - reliable vs unreliable
    - stream vs datagram
  - network protocols

Network protocols

- Network software (network OS)
  - network architecture: a layered structure
  - network services
  - network protocols
    - machine-to-machine language
      - define syntax, grammar, semantic
    - protocol mechanisms
    - control policies
      - connection management, flow/error/congestion control

What's a protocol?

human protocols:

- "what's the time?"
- "I have a question"
- introductions

… specific msgs sent

… specific actions taken when msgs received, or other events

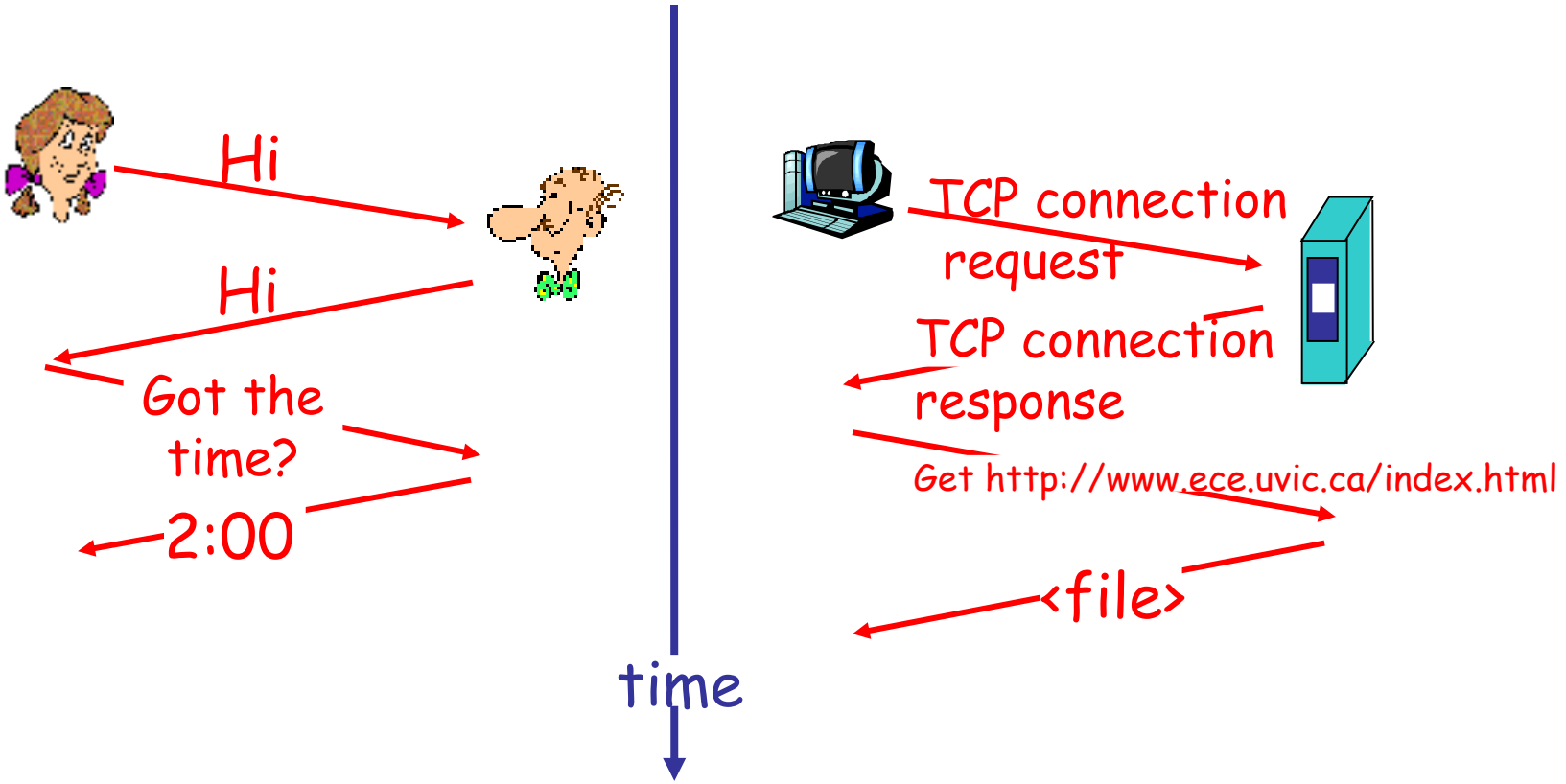
network protocols:

- machines rather than humans
- all communication activity in Internet governed by protocols

protocols define format, order of msgs sent and received among network entities, and actions taken on msg transmission, receipt

What's a protocol?

a human protocol and a computer network protocol:



Q: Other human protocols?

TCP/IP protocol stack

- Application
  - HTTP, SMTP, DNS, SNMP, etc
- Transport
  - TCP, UDP, RTP
- Network
  - IP (Internet Protocol)
  - IP multicast
  - mobile IP
- Link layer
- Physical layer

Network Hardware Overview

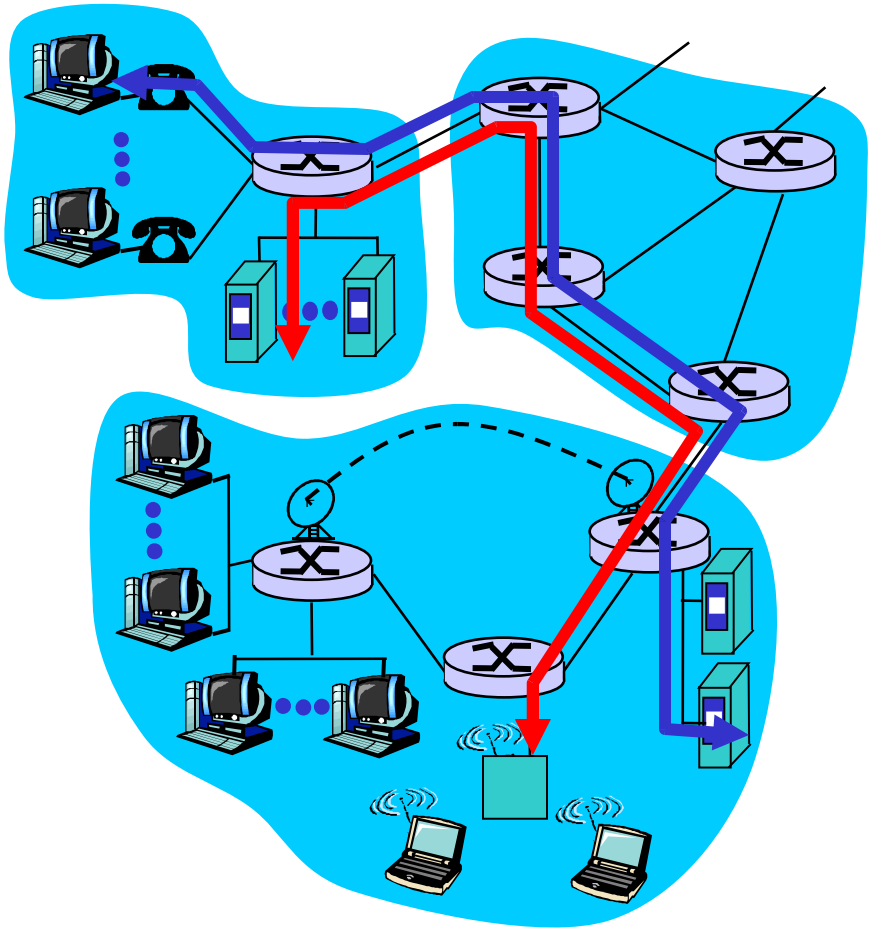
Communication Networks

- Broadcast networks
  - e.g., cable television (CATV)
- Switched networks
  - Why switching?
  - circuit-switching networks
    - e.g., public switched telephone systems (PSTN)
  - packet-switching networks
    - datagram: e.g., the Internet
    - virtual circuit: asynchronous transfer mode (ATM)

Circuit Switching

End-end resources reserved for "call"

- dedicated resources: no sharing
- guaranteed performance
- call setup required



Packet Switching

each end-end data stream divided into *packets*

- user A, B packets *share* network resources
- each packet uses full link bandwidth
- resources used *as needed*

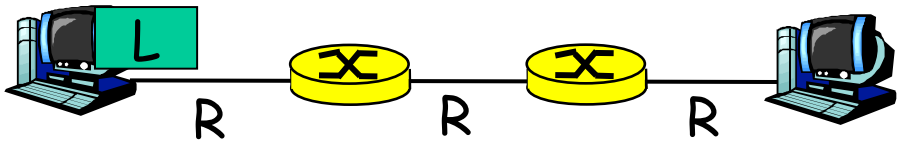
resource contention:

- aggregate resource demand can exceed amount available
- congestion: packets queue, wait for link use

store and forward: packets move one hop at a time

  - Node receives complete packet before forwarding

Packet-switching: store-and-forward



- Takes L/R seconds to transmit (push out) packet of L bits on to link or R bps
- Entire packet must arrive at router before it can be transmitted on next link: *store and forward*
- Total transmission delays of the three-hop path = 3L/R

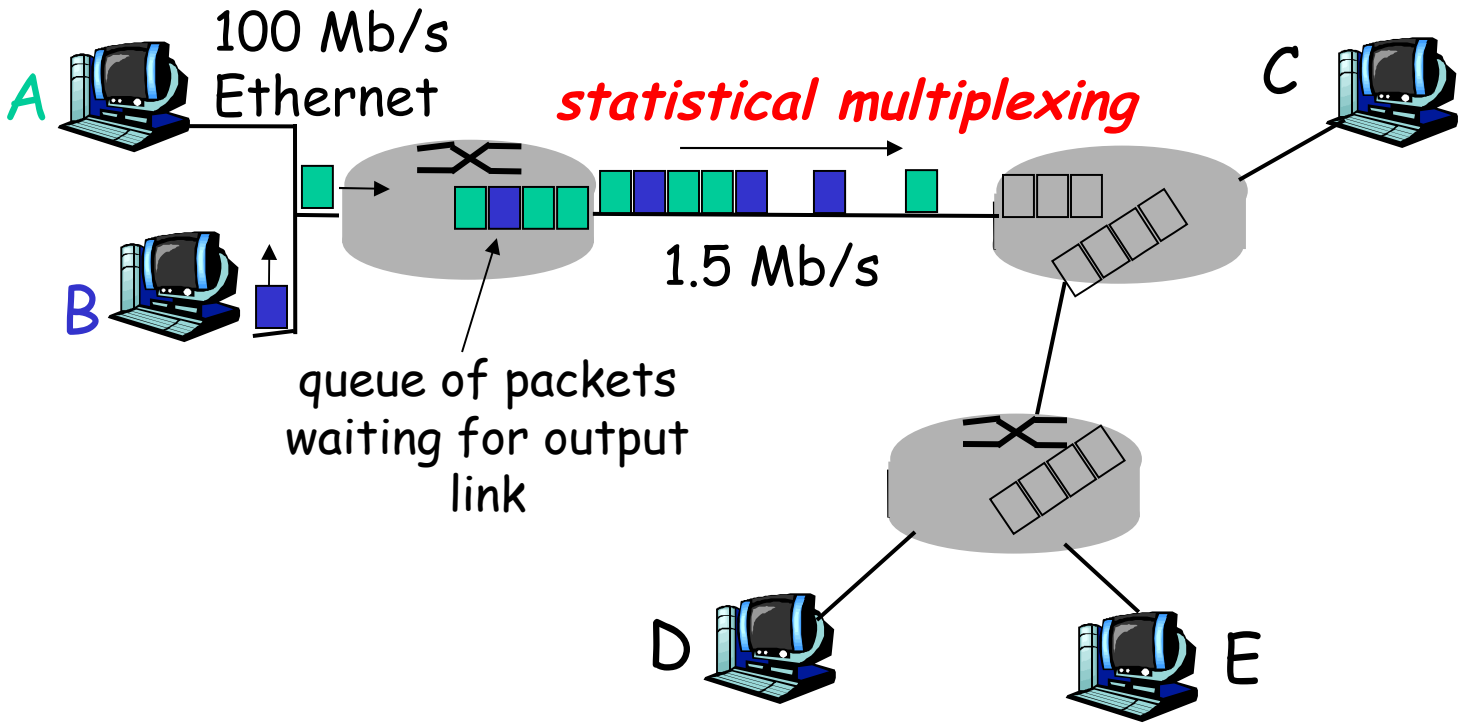
Example:

- L = 7.5 Mbits
- R = 1.5 Mbps
- Total transmission delay = 15 sec

Delay components

- End-to-end delay contains:
  - Transmission delay (L/R)
  - Propagation delay (link-length/propagation-speed)
  - Processing delay
  - Queueing delay (Random!)

Packet Switching: Statistical Multiplexing

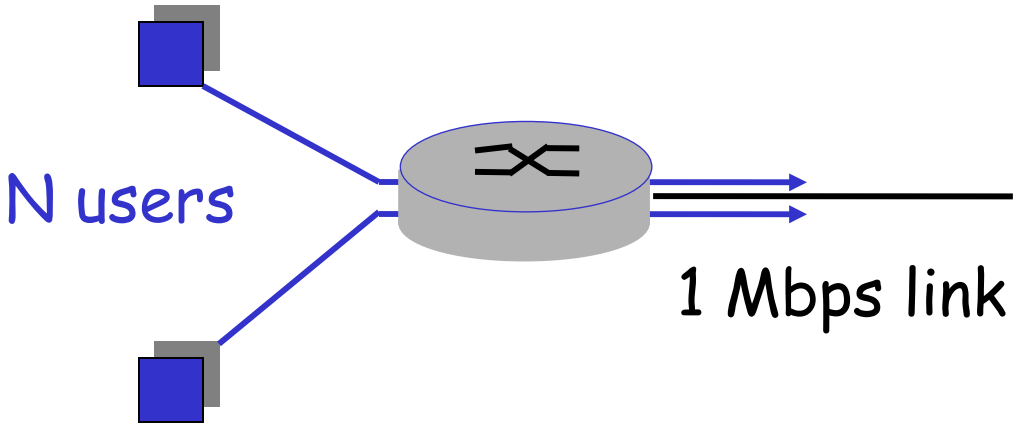


Sequence of A & B packets does not have fixed pattern, shared on demand ***statistical multiplexing***.

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 > 10 active less than .0004



Q: how did we get value 0.0004?

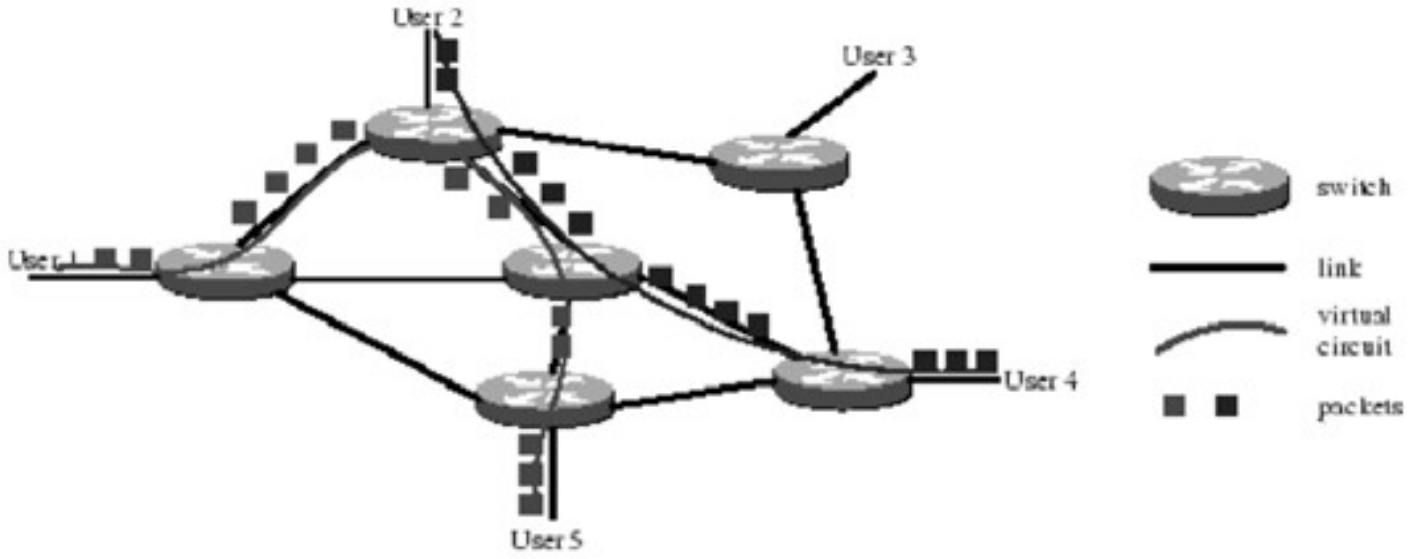
Packet switching versus circuit switching

Is packet switching a "slam dunk winner?"

- Great for bursty data
  - resource sharing
  - simpler, no call setup
- Excessive congestion: packet delay and loss
  - protocols needed for reliable data transfer, congestion control
- Q: How to provide circuit-like behavior?
  - bandwidth guarantees needed for audio/video apps
  - still an unsolved problem

Q: human analogies of reserved resources (circuit switching) versus on-demand allocation (packet-switching)?

Virtual circuit switching



- Connection-oriented
- Packets flow on so-called logical circuits for which no physical resources are dedicated
- Packet uses circuit identifier for routing from its source to its destination.

Internet history

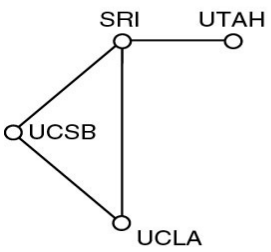
- ARPAnet developed by the Defense Advanced Research Projects Agency (DARPA) of the U.S. Department of Defense (DoD)
- Top level goal [1]: an effective technique for multiplexed utilization of existing interconnected networks => packet switching

[1] David Clark. The design philosophy of the DARPA Internet protocols, *Proc. on Communications architectures and protocols,* Pages: 106 - 114, 1988.

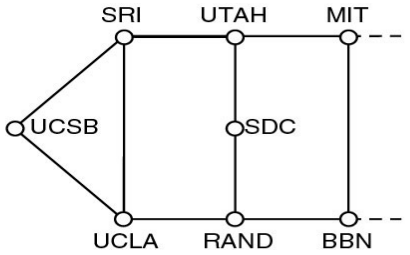
Internet history (2)

- Second level goals:
  - communication must continue despite loss of networks or gateways
  - support multiple types of communications services
  - accommodate a variety of networks
  - ……

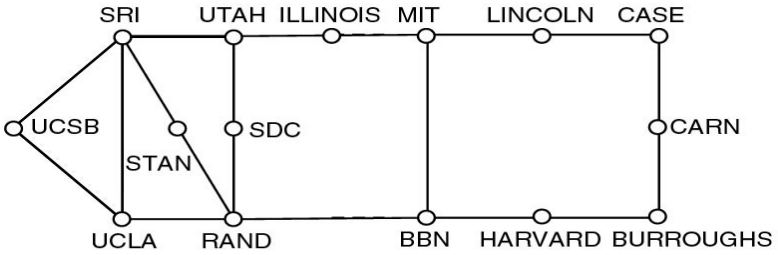
Internet history: ARPAnet (70's)



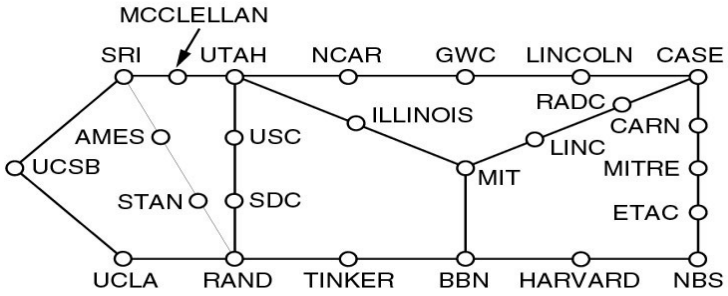
Dec. 1969



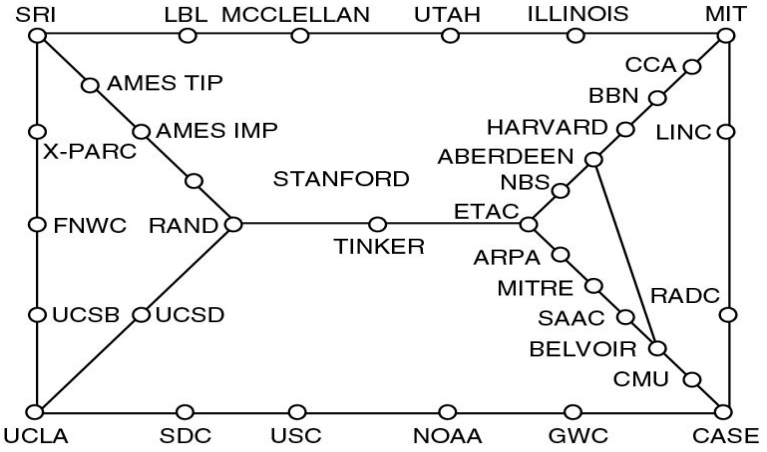
July 1970



March 1971



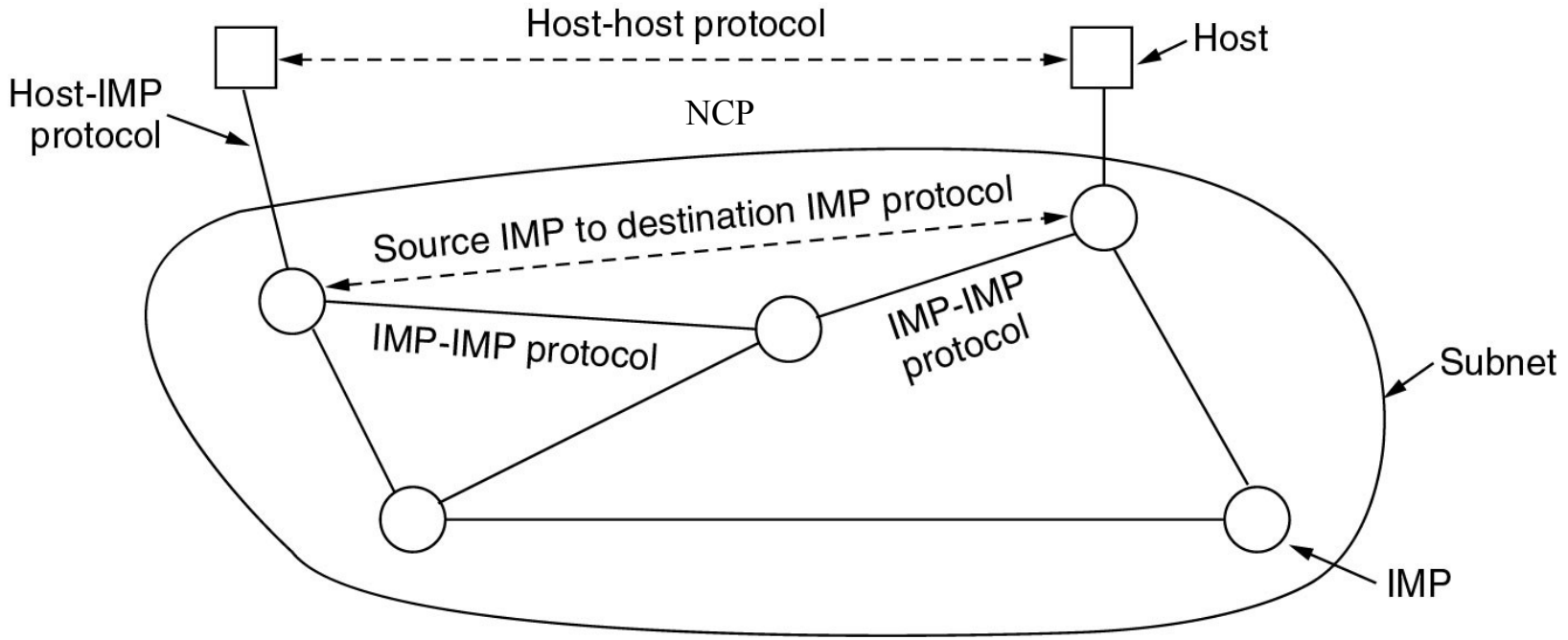
Apr. 1972



Sep. 1972

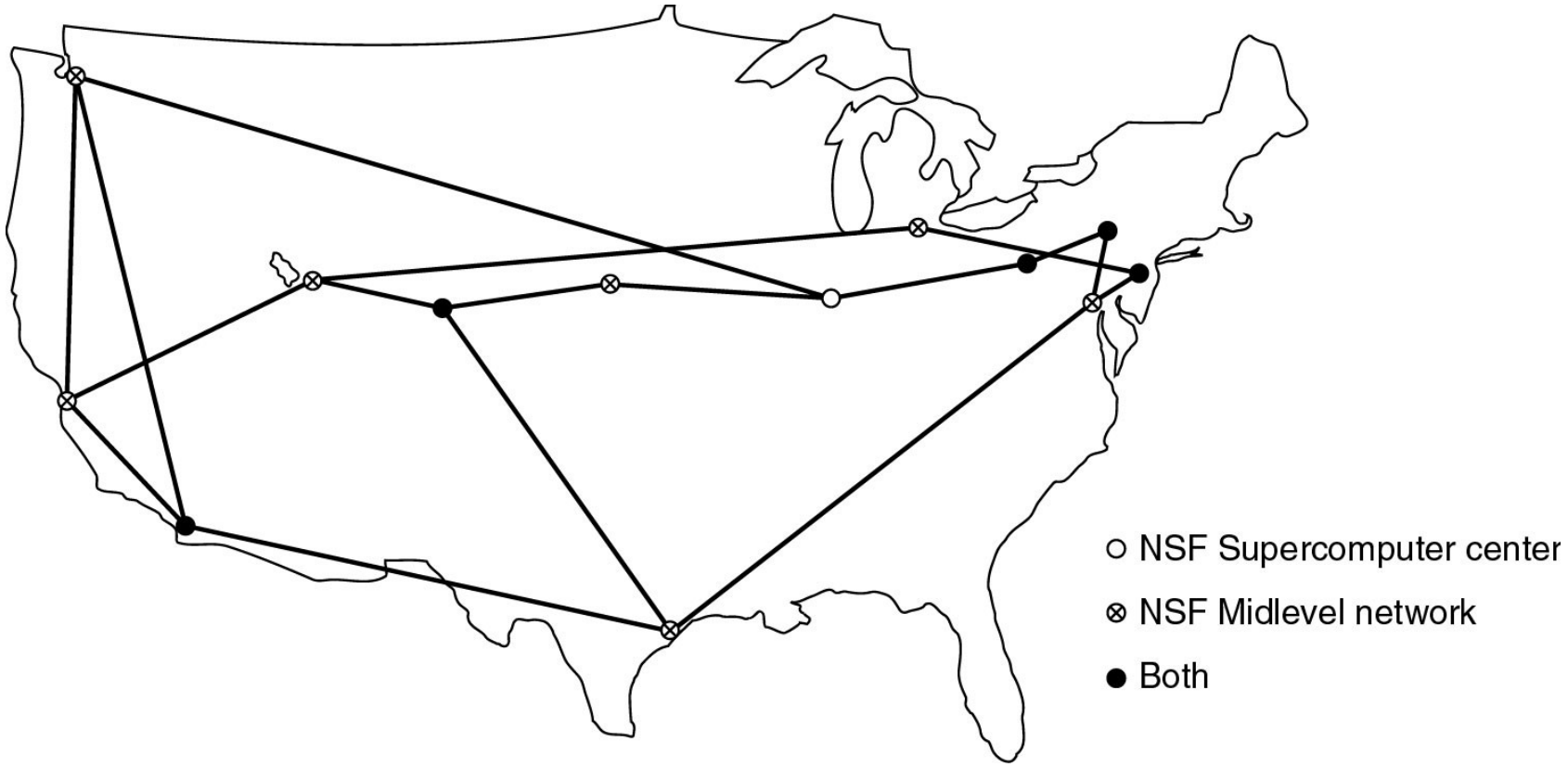
56Kbps

ARPAnet architecture



BBN's Interface Message Processor (IMP)

Internet history: NSFnet (80’s)

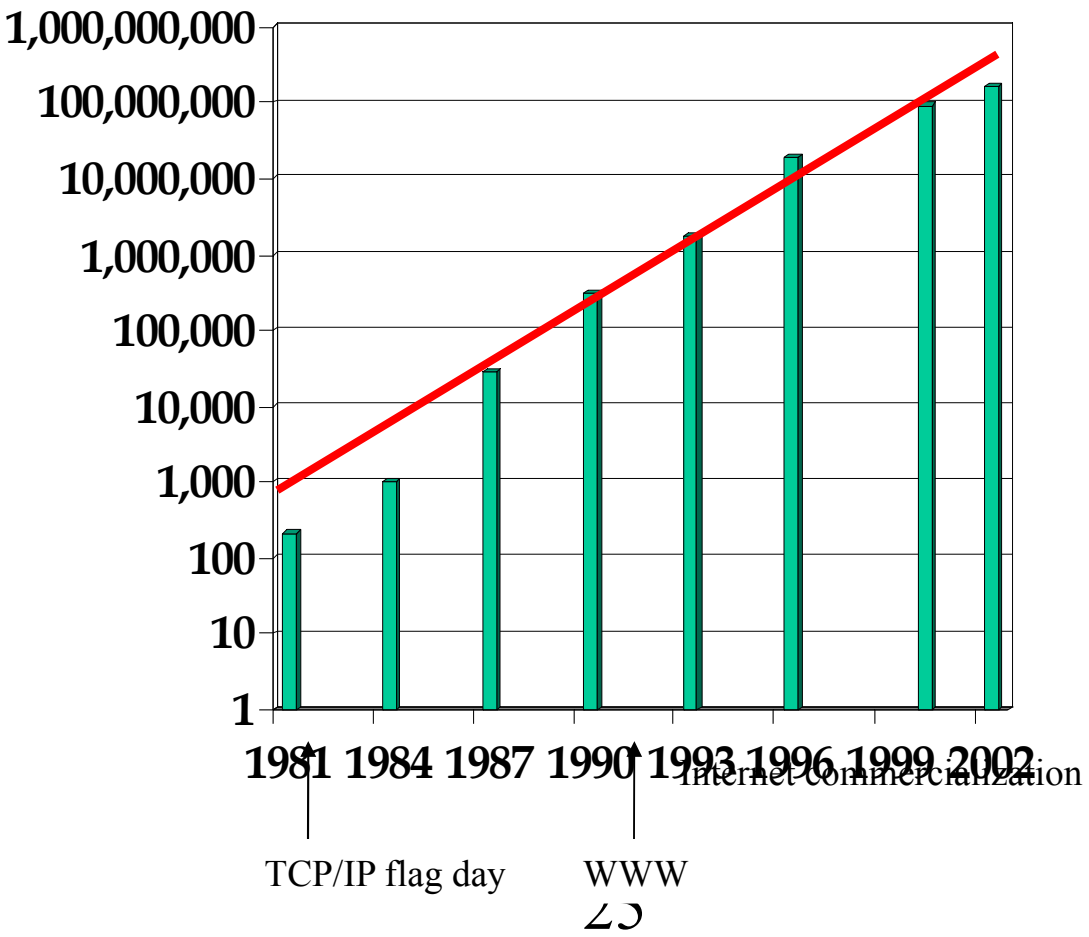


1988 1.5Mbps

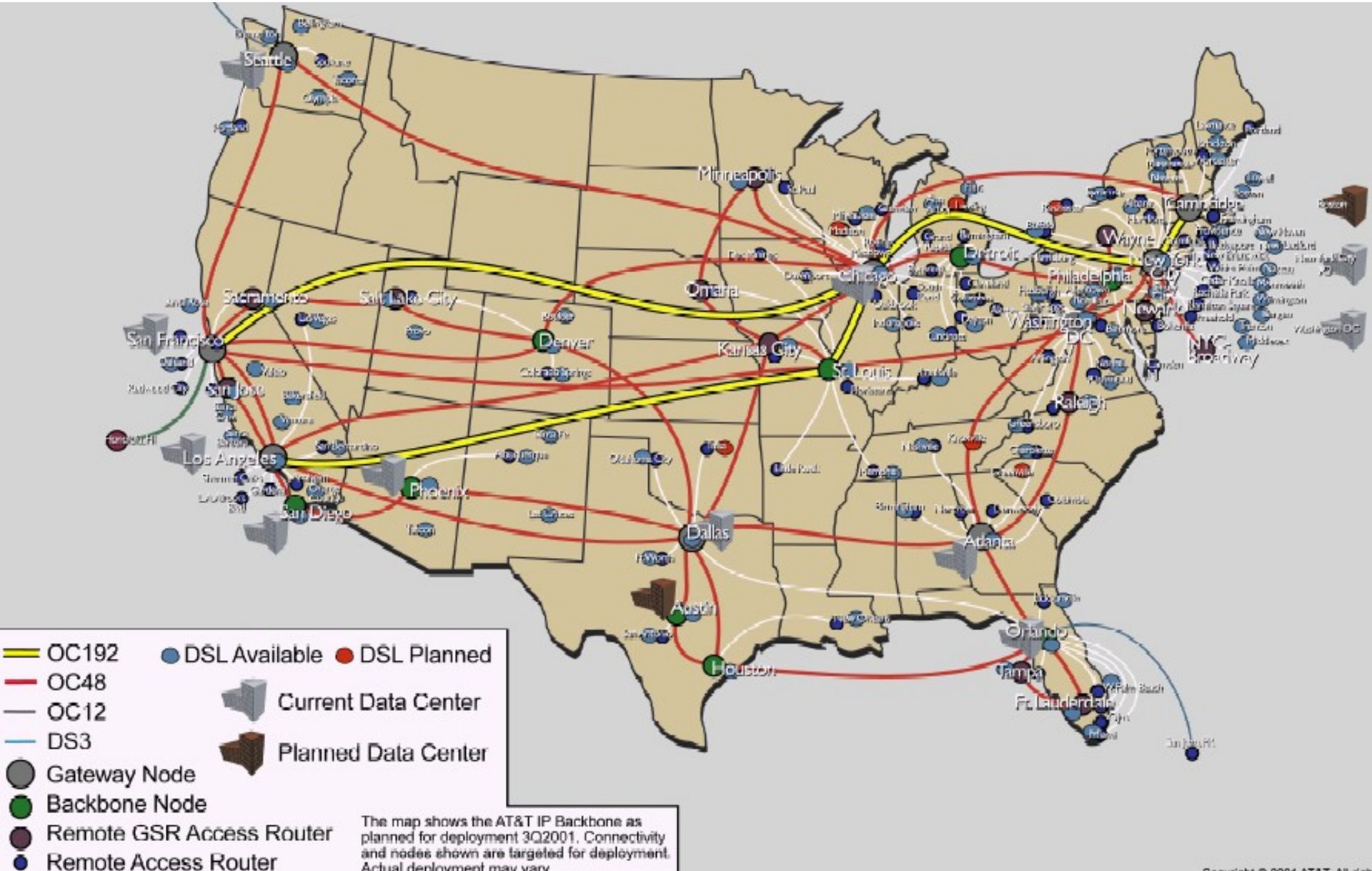
Internet growth

# of Hosts on the Internet:

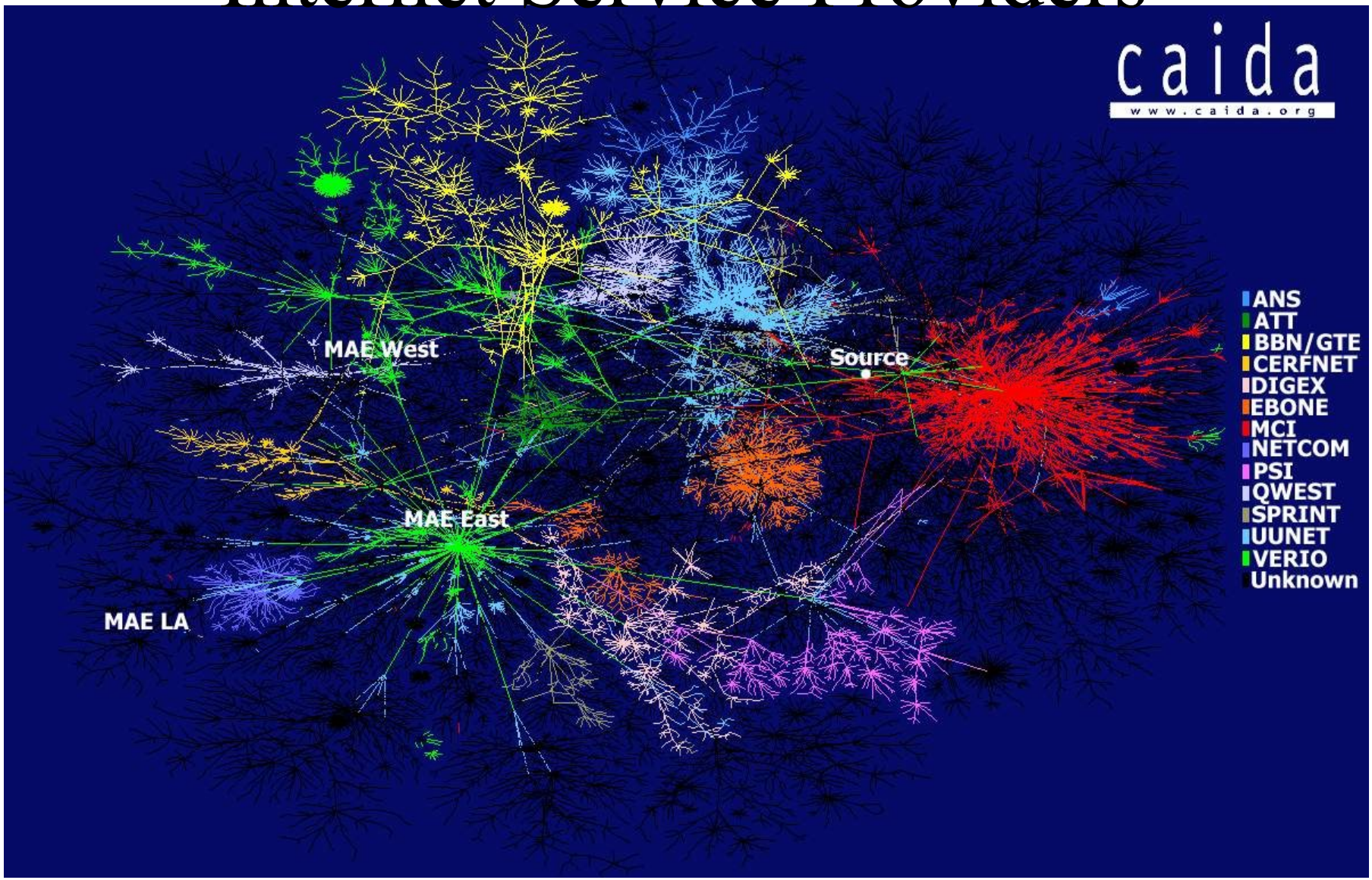
Aug. 1981	213
Oct. 1984	1,024
Dec. 1987	28,174
Oct. 1990	313,000
Jul. 1993	1,776,000
Jul. 1996	19,540,000
Jul. 2000	93,047,000
Jul. 2002	162,128,493



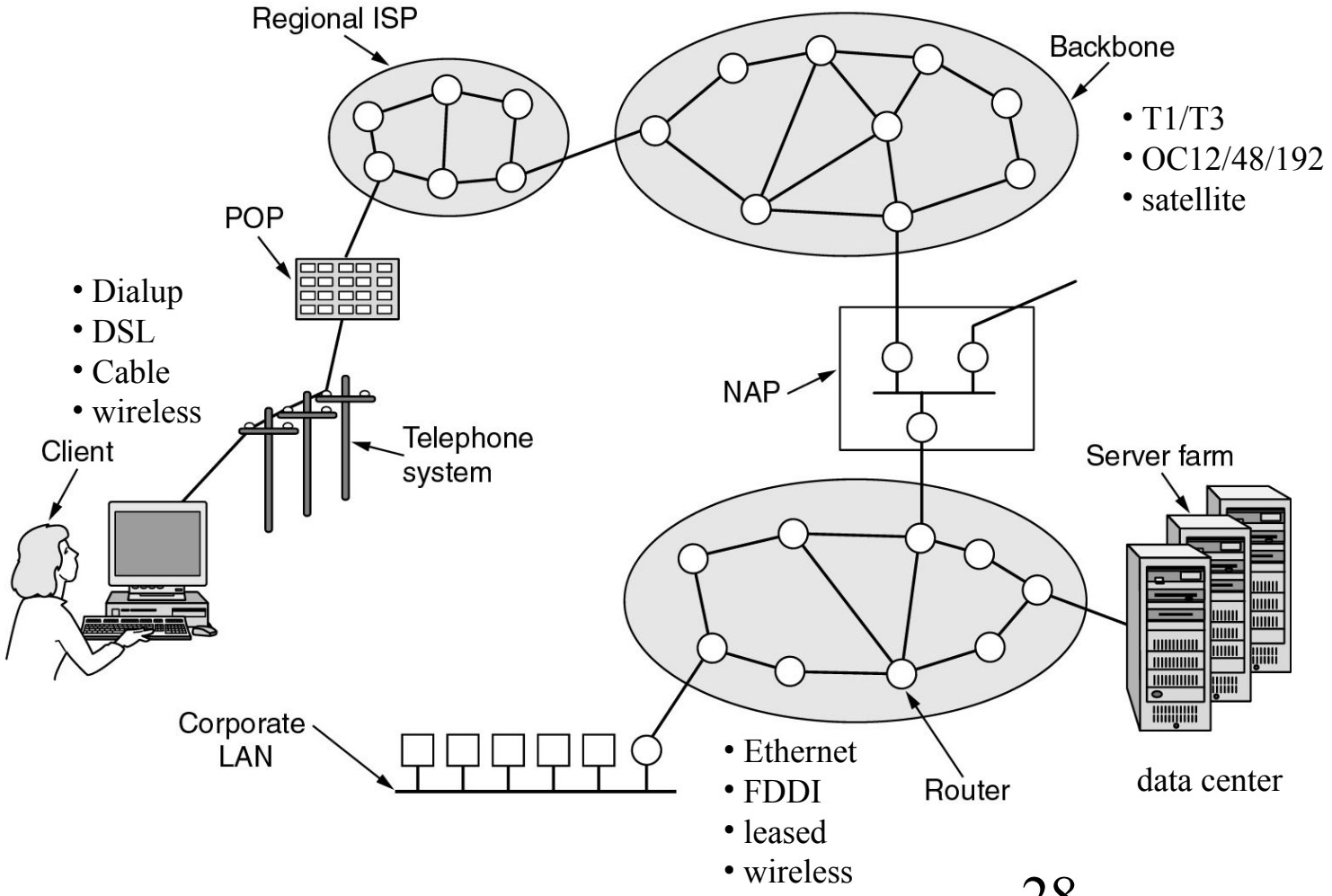
AT&T US backbone



Internet Service Providers



“The Internet”



Internet in Canada

- CA*net: 1990-1997; CANARIE: 1993
  - 56Kbps, T1 (1.5Mbps), T3 (45Mbps)
- CA*net II: 1995-2000
  - national test network: ATM (155Mbps)
- CA*net 3: 1998-2002
  - the world's first national optical R&E network
- CA*net 4: 2002-now
  - high-speed optical network (upto 40Gbps)


CA*net 4
Whitehorse
Yellowknife
Iqaluit
(via CRC)
Edmonton
Vancouver
Victoria
Seattle
Calgary
Saskatoon
Regina
Winnipeg
St. John's
Charlottetown
Fredericton
Halifax
Montréal
Ottawa
Toronto
New York
Chicago
Legend
CA*net 4 Access Point
CA*net 4

Internet @ UVic

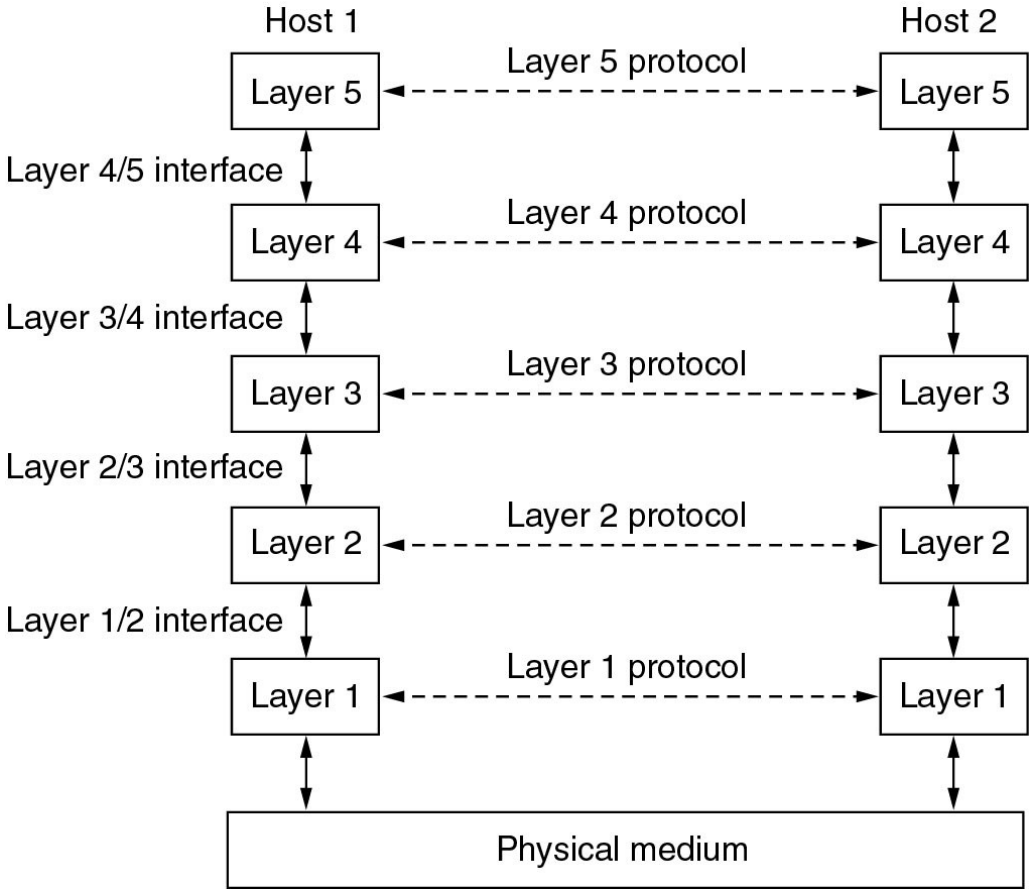
- UVicNet: Gigabit Ethernet backbone
  - switched 10/100Mbps Ethernet access
  - also, UVic research network
- ResNet: switched 10Mbps Ethernet
- UVic AirNet: WLAN: 802.11b 11Mbps; 802.11a/g 54Mbps
- Upstream providers
  - BCnet ORAN: CA*net4
  - VicTX: commercial Internet

UVic => Google

- # traceroute google.com
  traceroute: Warning: google.com has multiple addresses; using 72.14.207.99
  traceroute to google.com (72.14.207.99), 30 hops max, 38 byte packets
  1 gw.net.engr.UVic.CA (142.104.127.254) 8.686 ms 1.471 ms 5.732 ms
  …
  5 csc1cled050.bb.uvic.ca (142.104.252.21) 1.375 ms 1.244 ms 1.156 ms
  …
  8 UVicB-Policy1.VICTX.BC.net (207.23.241.221) 2.041 ms 1.821 ms 2.795
  9 ra1cv-ge3-2-11.gv.bigpipeinc.com (64.251.72.41) 1.832 ms 1.937 ms
  …
  12 rc1wt-pos2-1.wa.shawcable.net (66.163.77.21) 7.415 ms 196.976 ms 199.916 ms
  13 six.sea01.google.com (198.32.180.17) 4.779 ms 4.769 ms 4.657 ms
  14 72.14.233.55 (72.14.233.55) 23.586 ms 24.045 ms 23.684 ms
  …
  18 72.14.207.99 (72.14.207.99) 63.148 ms 63.026 ms 63.126 ms

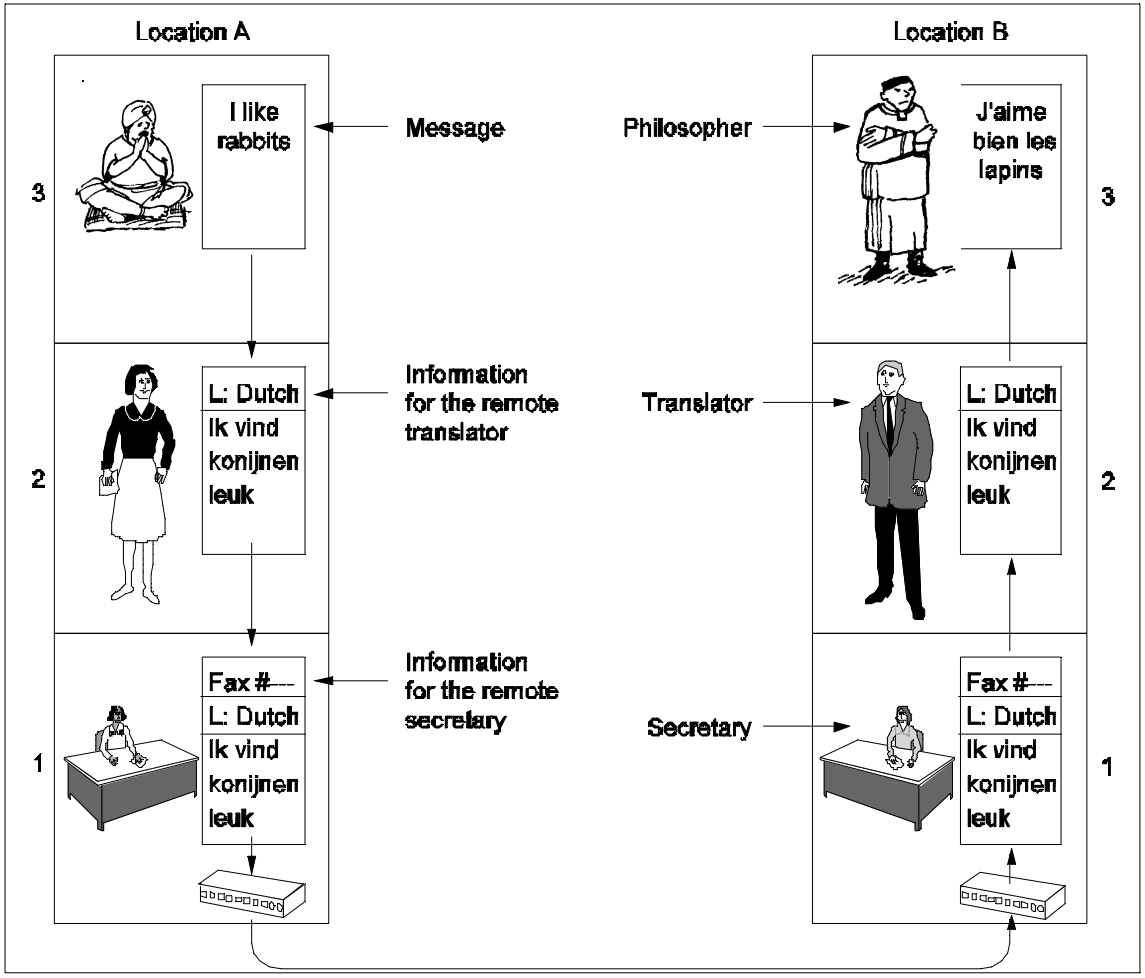
Network Software Overview

Protocol Hierarchies



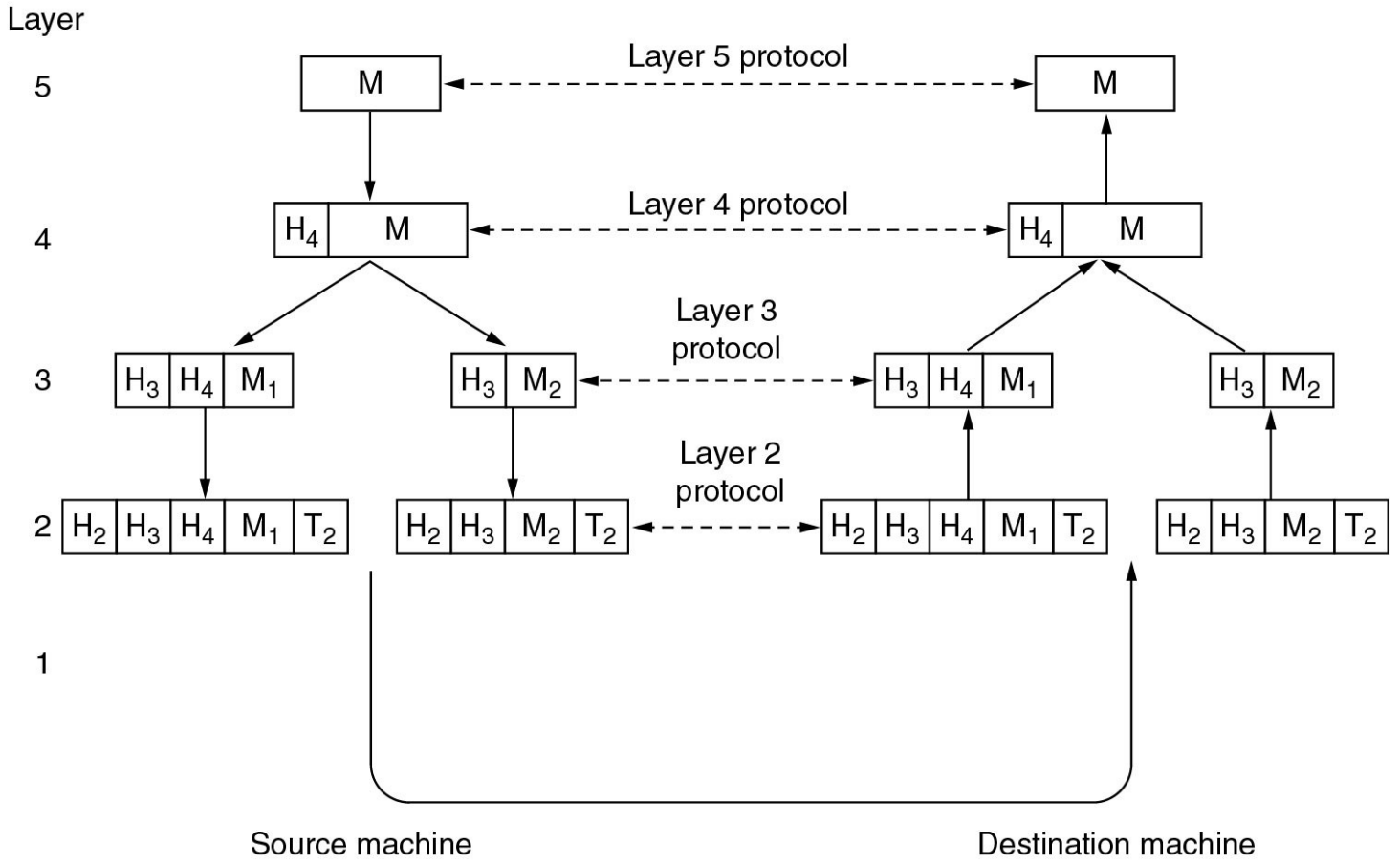
- Layers, protocols, and interfaces.

Protocol Hierarchies (2)



- The philosopher-translator-secretary architecture.

Protocol Hierarchies (3)



- Example information flow supporting virtual communication in layer 5.

Design Issues for the Layers

- Addressing
- Error Control
- Flow Control
- Multiplexing
- Routing

Connection-Oriented and Connectionless Services

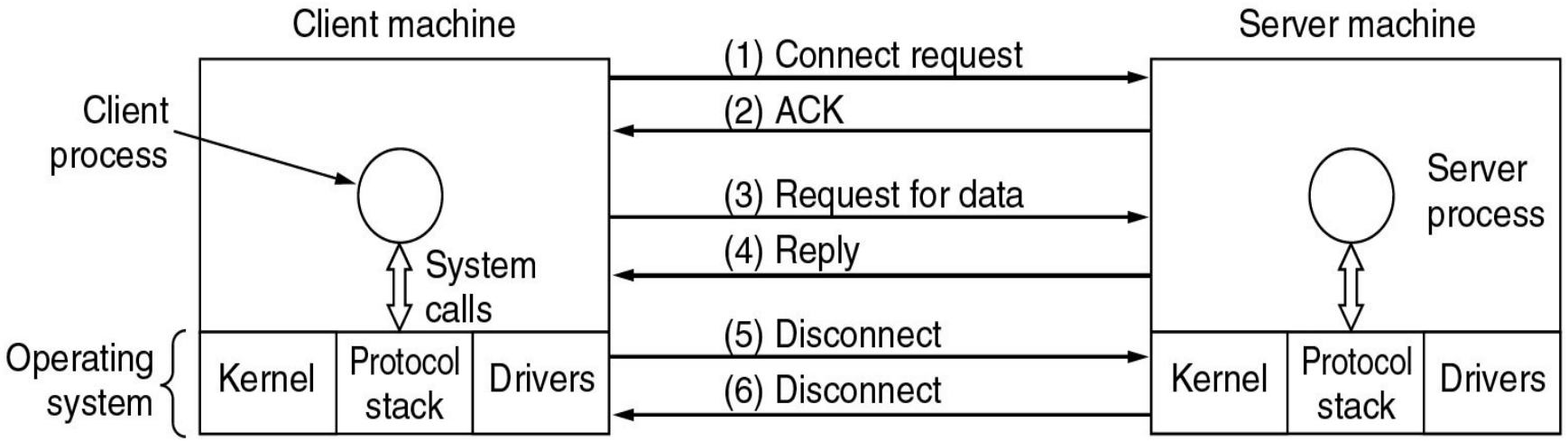
	Service	Example
Connection-oriented	Reliable message stream	Sequence of pages
	Reliable byte stream	Remote login
	Unreliable connection	Digitized voice
Connection-less	Unreliable datagram	Electronic junk mail
	Acknowledged datagram	Registered mail
	Request-reply	Database query

Service Primitives

Primitive	Meaning
LISTEN	Block waiting for an incoming connection
CONNECT	Establish a connection with a waiting peer
RECEIVE	Block waiting for an incoming message
SEND	Send a message to the peer
DISCONNECT	Terminate a connection

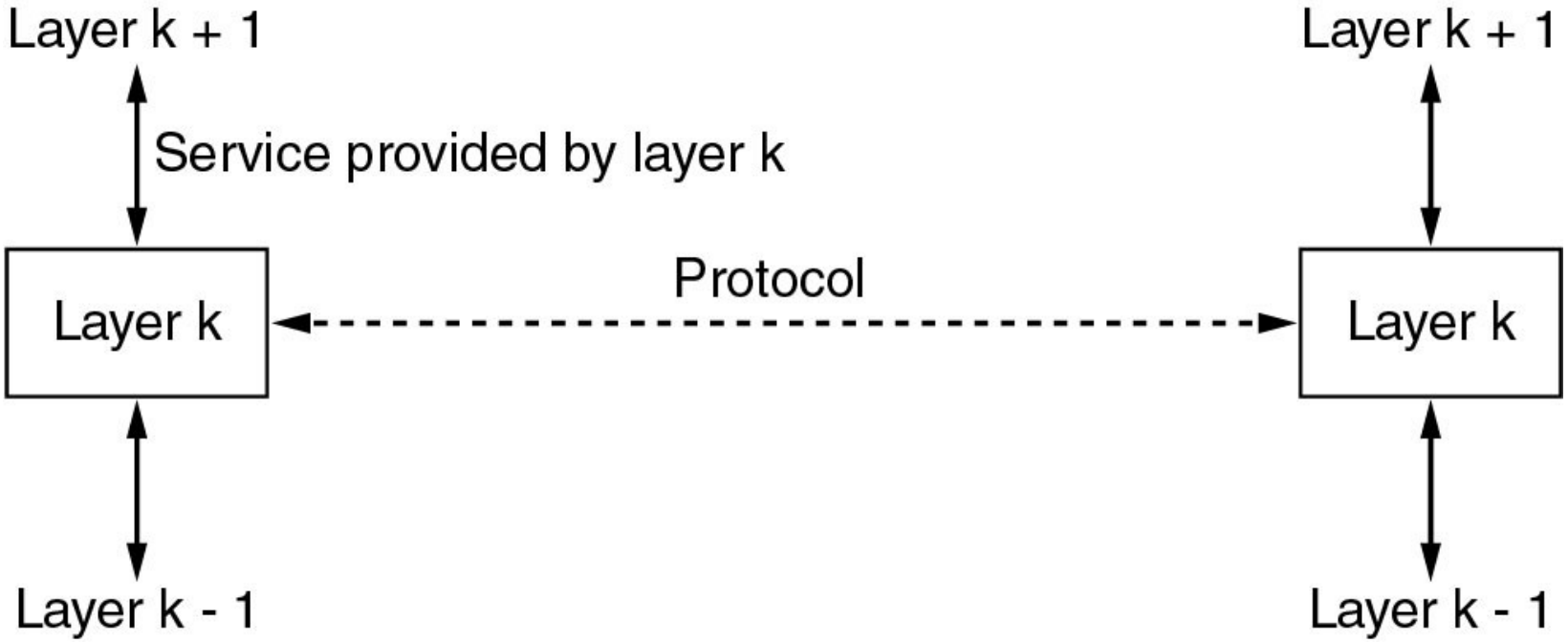
- Five service primitives for implementing a simple connection-oriented service.

Service Primitives (2)



- Packets sent in a simple client-server interaction on a connection-oriented network.

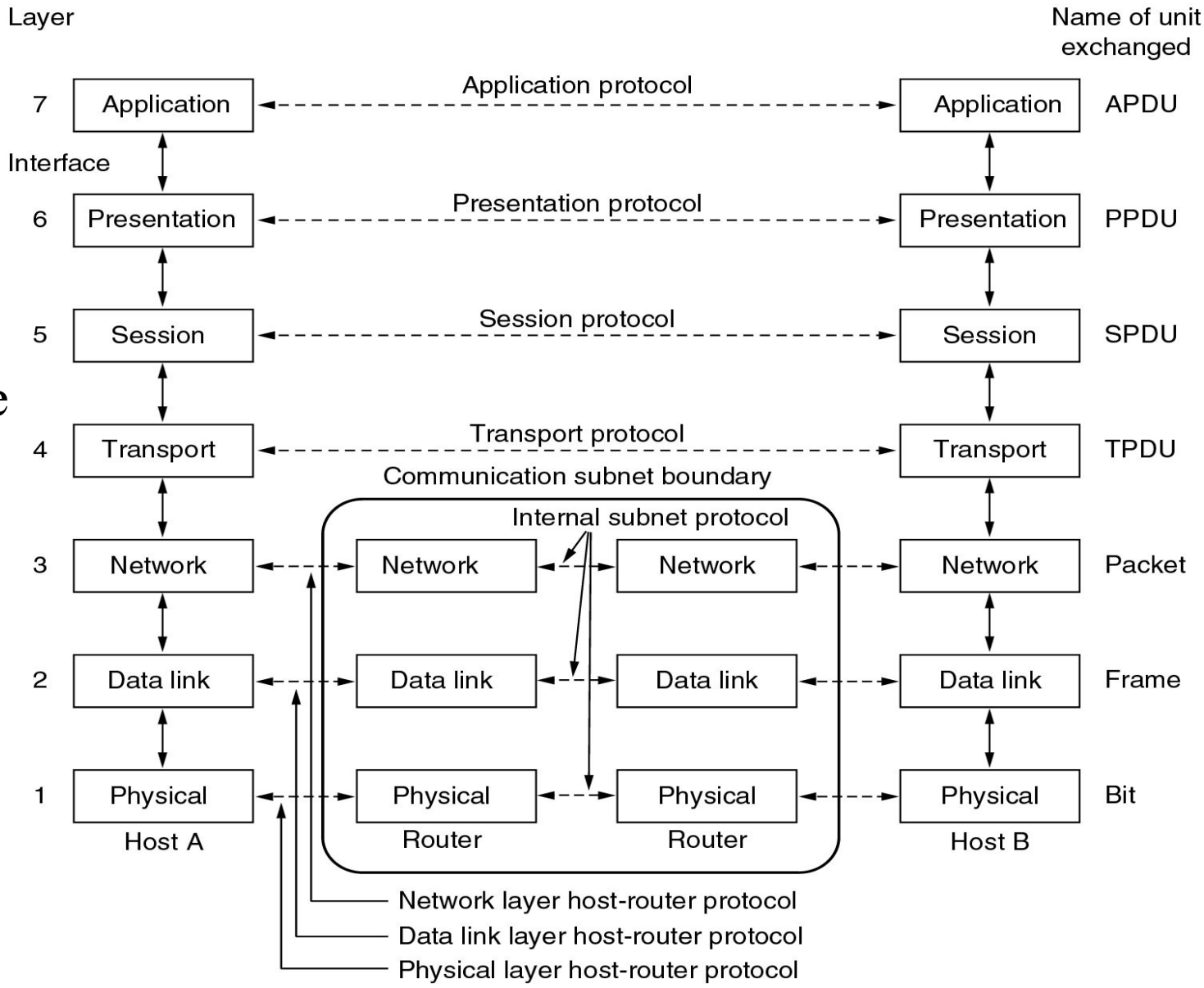
Services to Protocols Relationship



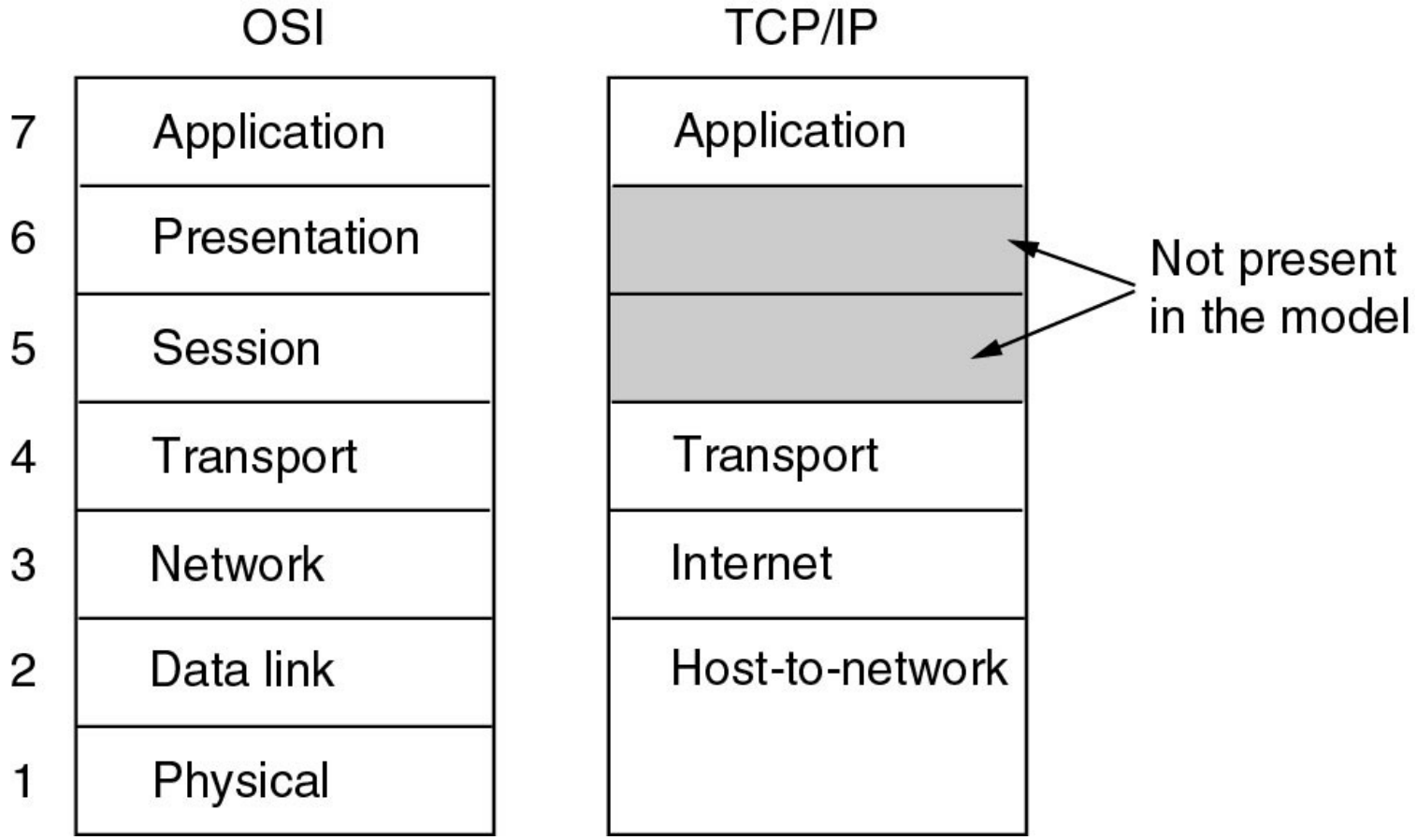
- The relationship between a service and a protocol.

Reference Models

The OSI reference model.

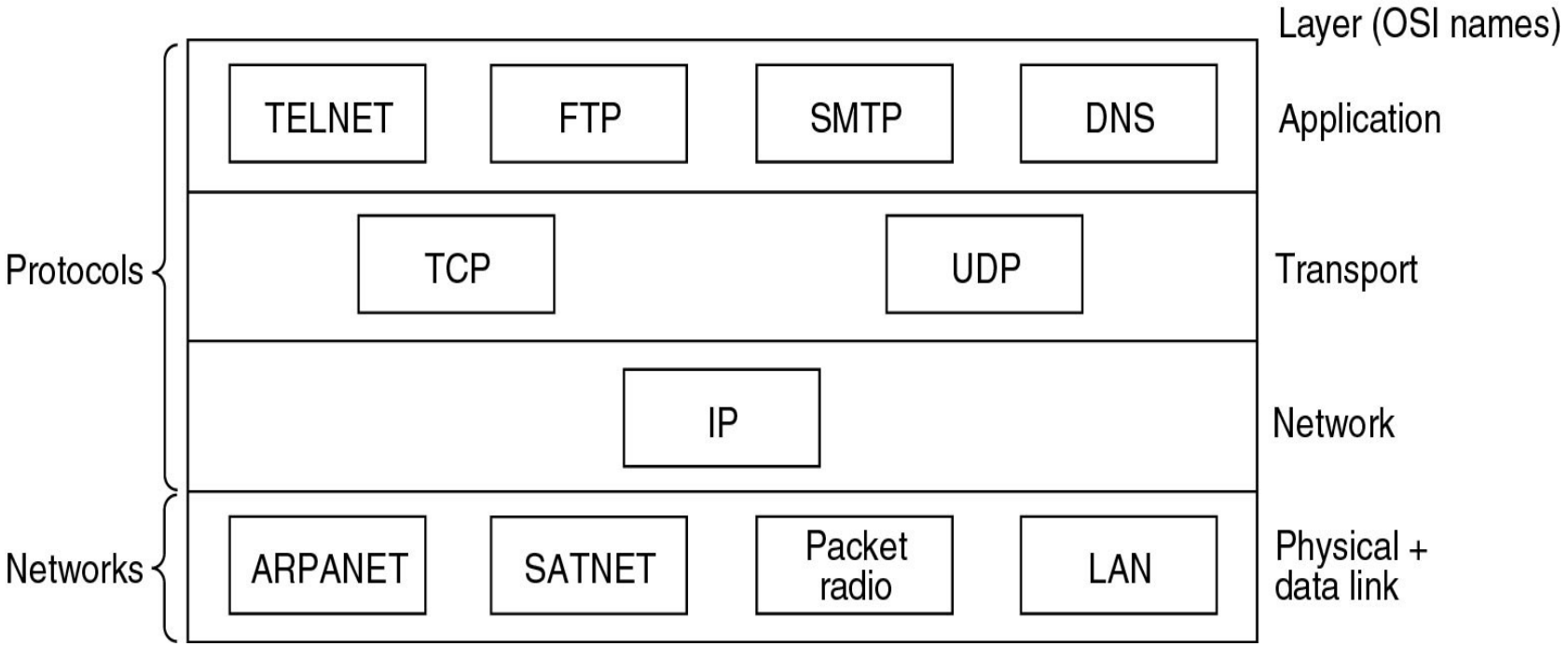


Reference Models (2)



- The TCP/IP reference model.

Reference Models (3)



Google!

- # wget -d www.google.com

  Connecting to www.google.com:80... Caching www.google.com <-> 66.102.7.104
  Created fd 3.
  connected!
  ---request begin---
  GET / HTTP/1.0
  User-Agent: Wget/1.7
  Host: www.google.com
  Accept: */*
  Connection: Keep-Alive
  ---request end---
  HTTP request sent, awaiting response...
  HTTP/1.0 302 Found
  Location: http://www.google.ca/
  Cache-Control: private
  Content-Type: text/html
  Server: GWS/2.1
  Content-Length: 218

Things involved

- You say “www.google.com”, I say “66.102.7.104”
  - Domain Name System (DNS)
  - User Datagram Protocol (UDP)
- “connected”
  - Transmission Control Protocol (TCP)
  - Internet Protocol (IP)
- “request begin”
  - Hyper Text Transfer Protocol (HTTP)

More things involved

- TCP
  - connection management
  - flow, error, and congestion control
- IP
  - Internet addressing and routing
- Link layer
  - Ethernet: IEEE 802.3
  - wireless Ethernet: IEEE 802.11

Suggested approach

- Before lecture
  - read textbook; find questions
- Attend lecture
  - take notes; ask questions and participate discussions!
- After lecture
  - explore further; write assignments
  - get help and help others
- Attend labs
  - Note: Failure to complete all laboratory requirements will result in a grade of N being awarded for the course.

Summary

- An overview on computer networks
  - particularly the Internet
  - brief Internet history and structure
  - applications, protocols, services, architectures
- Explore further
  - find out your Internet access at home
    - your ISP's ISP, your "traceroute" to google.com
  - try traceroute "server"

Next

- Physical layer
  - Physical layer technologies, access, backbone
  - Read CN Chapter 2