Chapter 1 Introduction

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Key Points

基本概念	概念，组成，功能	熟练掌握
	分类与拓扑结构	熟练掌握
	发展	了解
	Internet 标准化	掌握
网络体系结构	分层结构 / 相关概念	熟练掌握
	ISO/OSI 参考模型	熟练掌握
	TCP/IP 参考模型	熟练掌握
	LAN 参考模型	熟练掌握

Fundamental Problems

- What is a Computer Network?
- How to connect computers together?
- How to make computers to communicate?
- How to evaluate communication performance?
- How to design and organize a computer network system?
- What does network architecture mean?
- In a computer network architecture, what is the role and function of each layer?

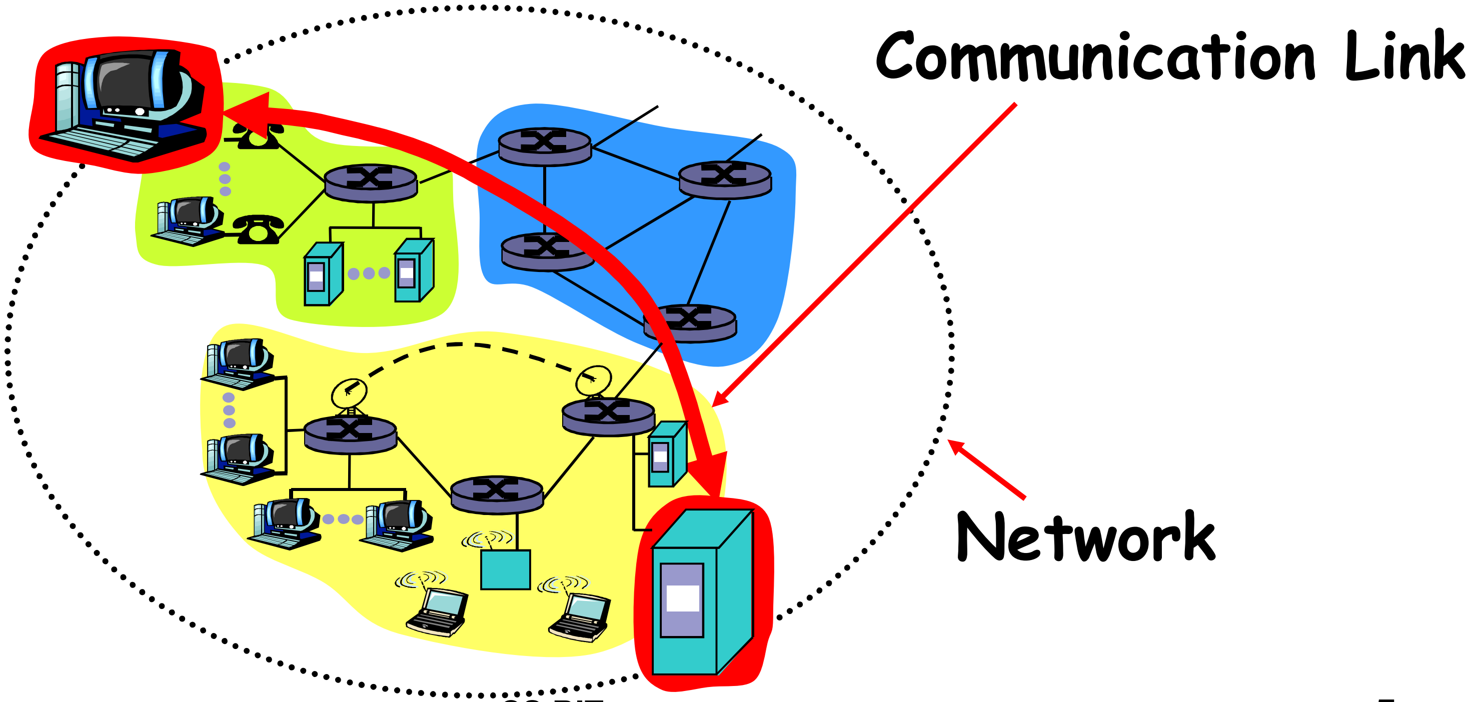
Chapter 1: Roadmap

1.1 Computer network and the Internet
1.2 Network edge and core
1.3 Network access and physical media
1.4 Transmission Technology
1.5 Type and Topology
1.6 Network Performance
1.7 Protocol layers, service models
1.8 Architecture, OSI and TCP/IP Models
1.9 Internet History

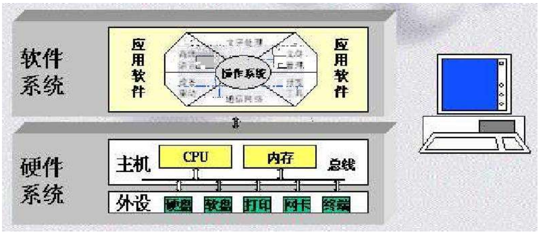
What is a computer network?

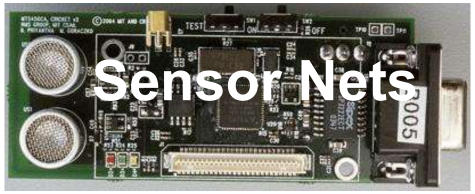
- **Tanenbaum's definition**

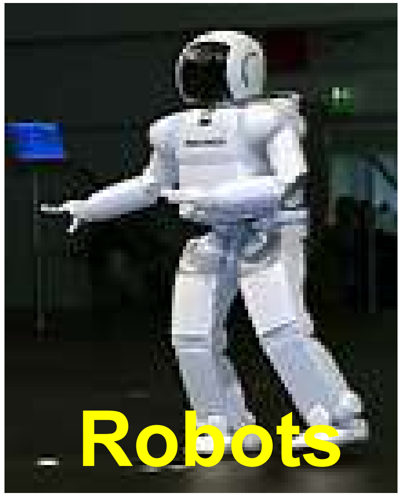
  Interconnected collection of autonomous computers connected by a communication technology

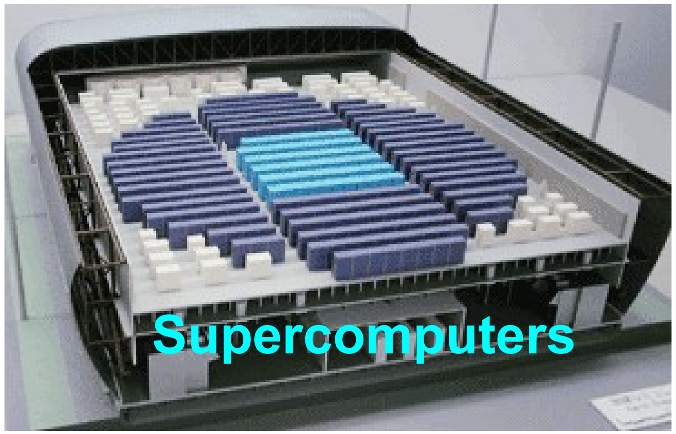


Autonomous computers

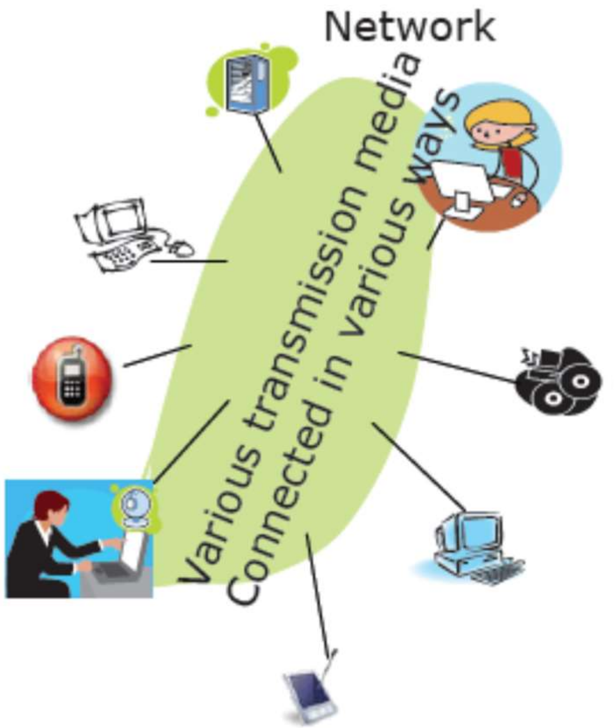


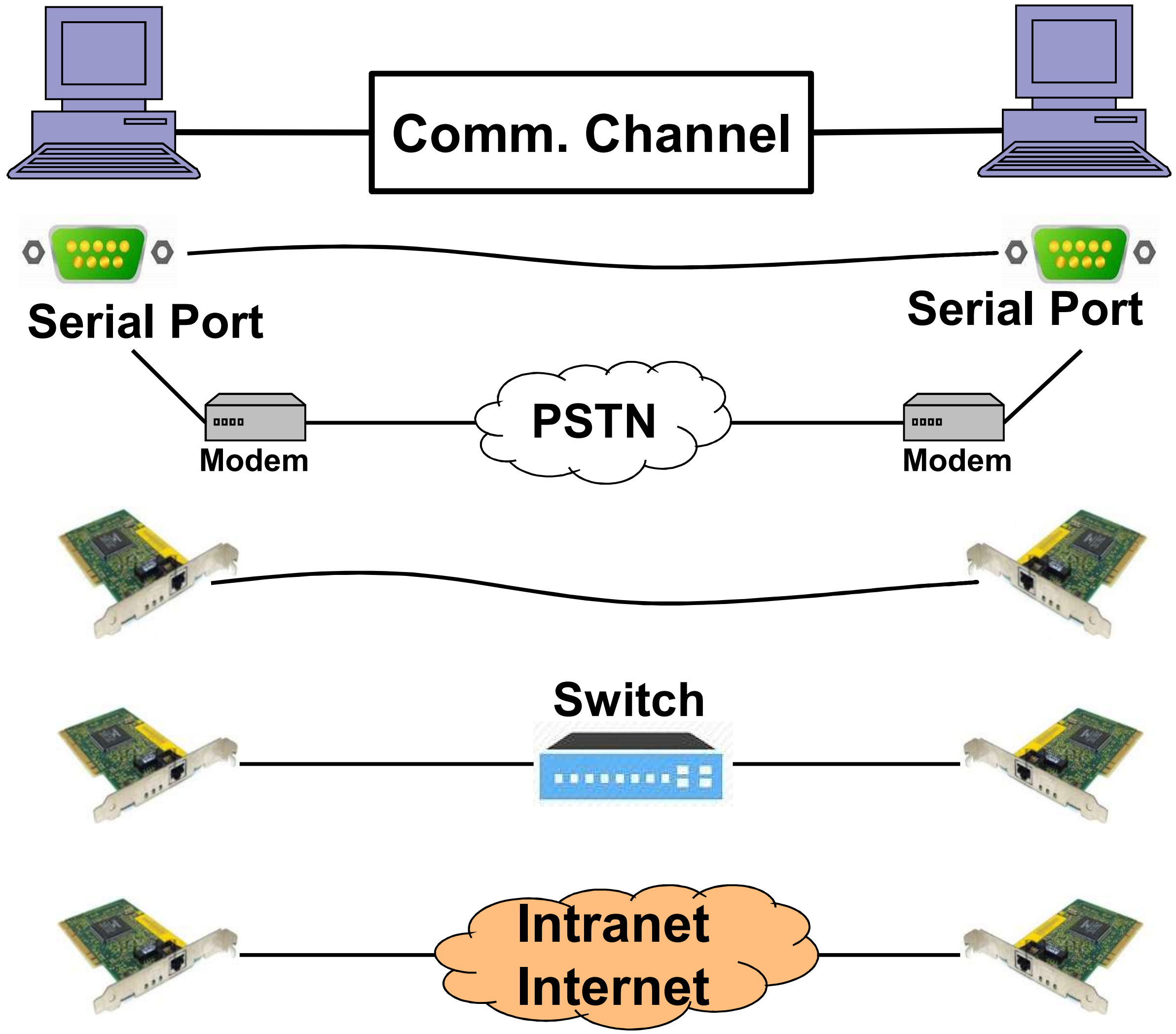




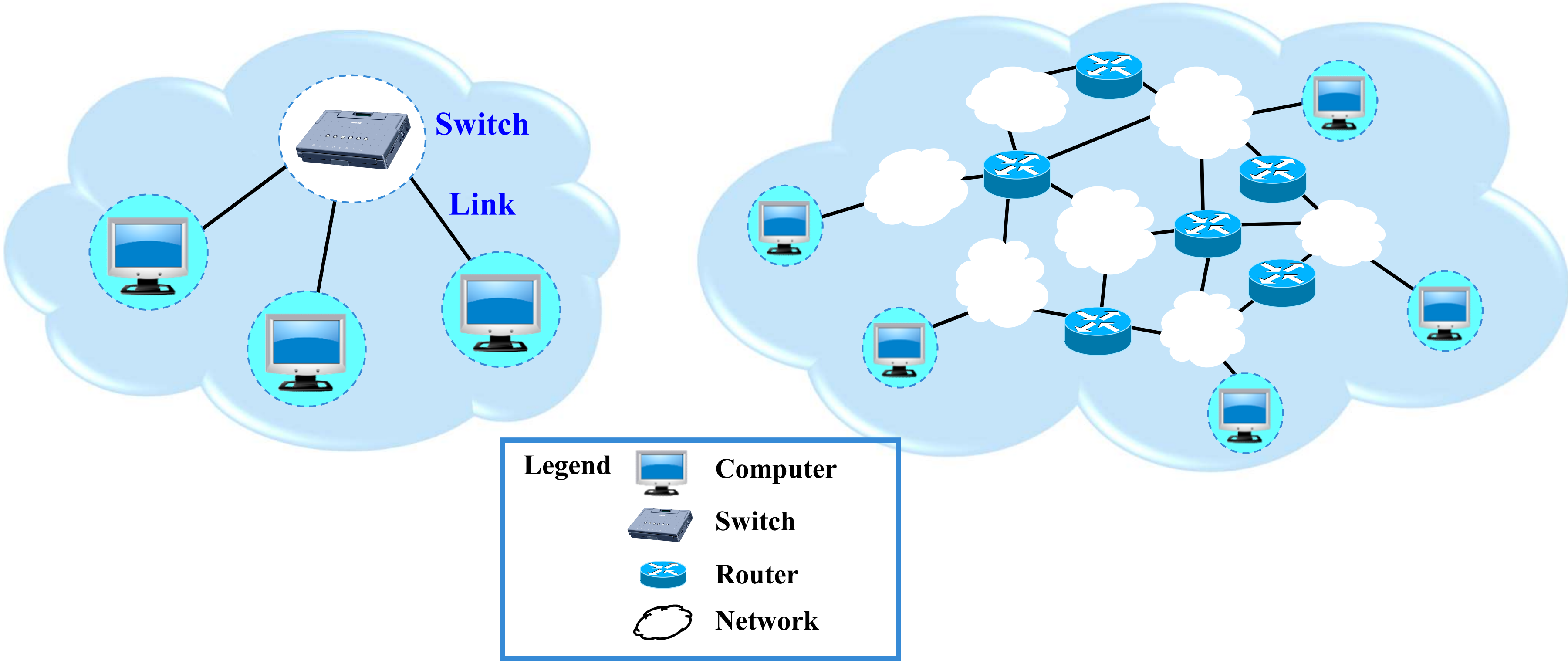


Connected by comm. technology





Interconnected collection



A simple computer network An interconnected network

Services/Functions Provided by a computer network

Communication (通信)

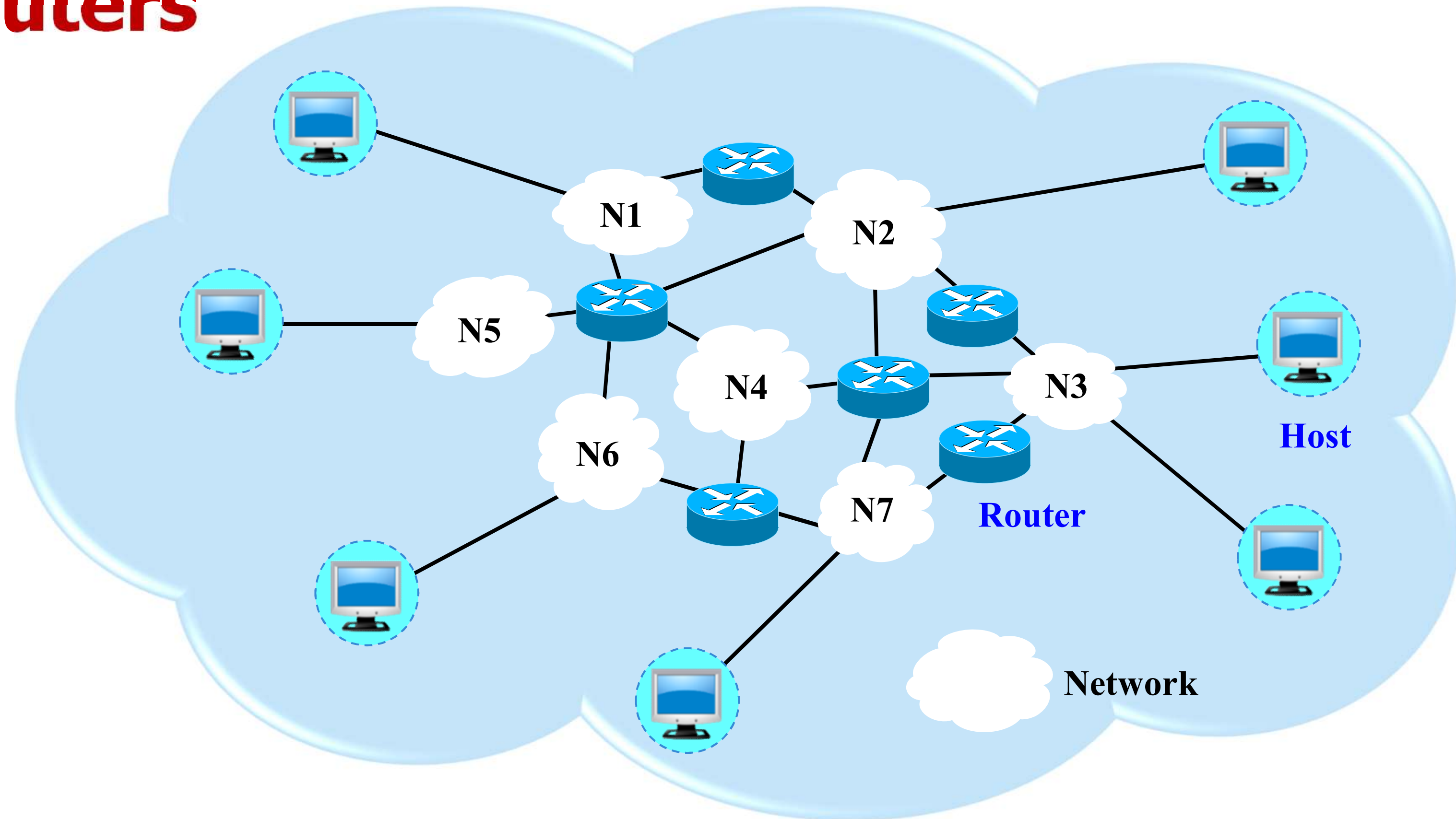
- Allow users to exchange various information easily, quickly and economically.
- as if these user terminals are all directly connected to each other.

Sharing (资源共享)

- Sharing of information, software, and hardware, etc.
- Because of the existence of the network, these resources are as convenient to use as if they are right next to the user.

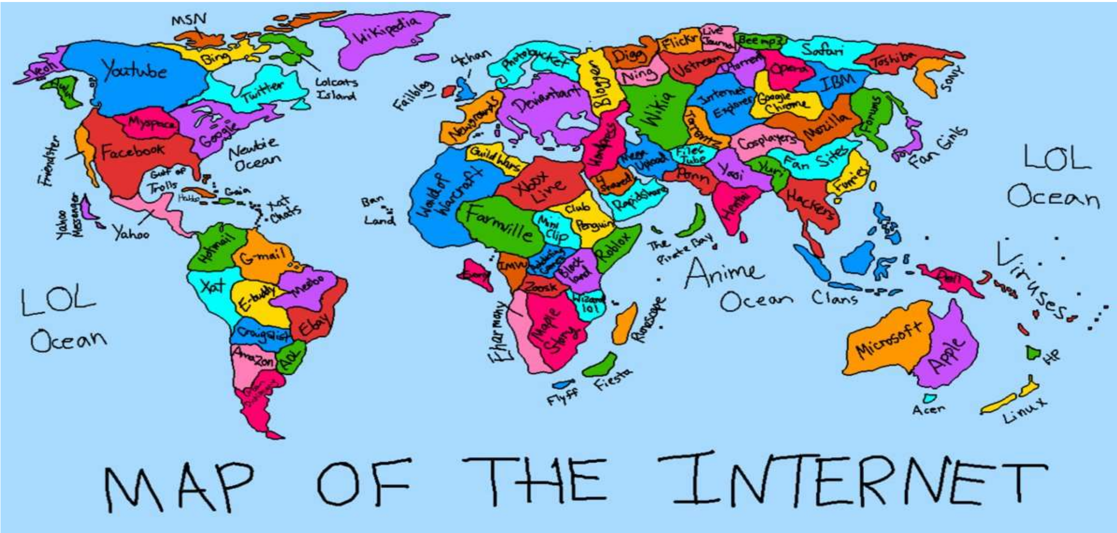
What is the Internet?

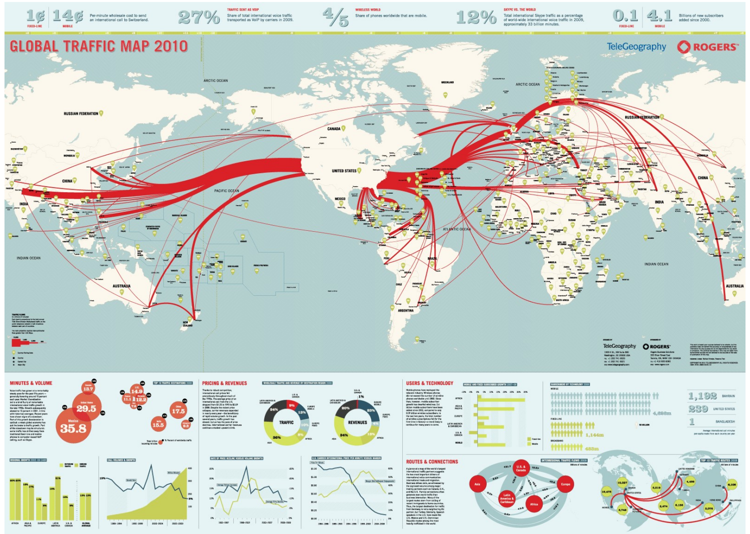
- "a network of networks"
- "collection of networks interconnected by routers"



What is the Internet?

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





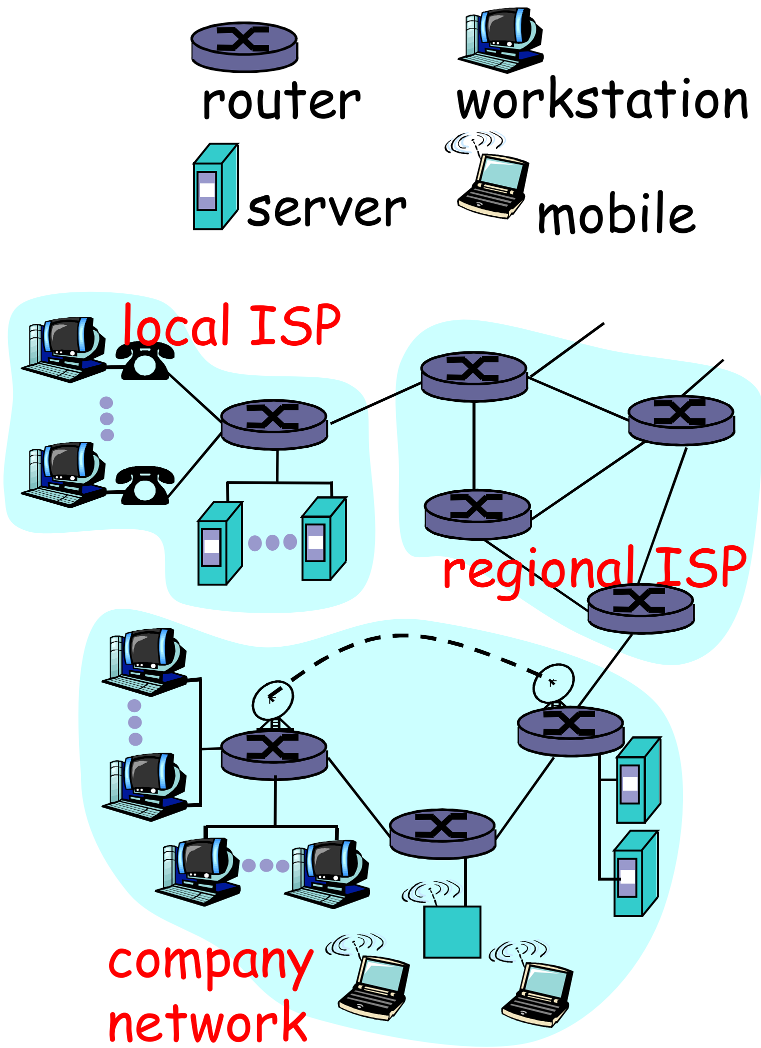
Services Provided by the Internet

- **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, instant messaging (1990's)
  - Audio, video (1990's)
    - Replacing telephone network?
- **A medium for information dissemination**
  - USENET (1980's)
  - **WWW** (1990's)
    - Replacing newspaper, magazine?
  - Audio, video (2000's)
    - Replacing radio, CD, TV?

What's the Internet: "nuts and bolts" view

- **Millions of connected computing devices:** ***hosts, end-systems***
  - PCs, Servers
  - Tablets
  - Phones, Smart Phones
  - Sensors
  - Toasters

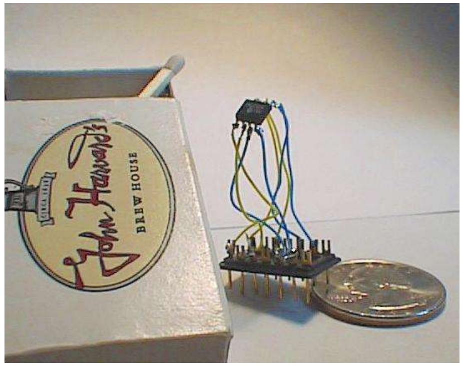
  running *network apps.*



“Cool” internet appliances

IP picture frame
http://www.ceiva.com/

Web-enabled toaster +
weather forecaster

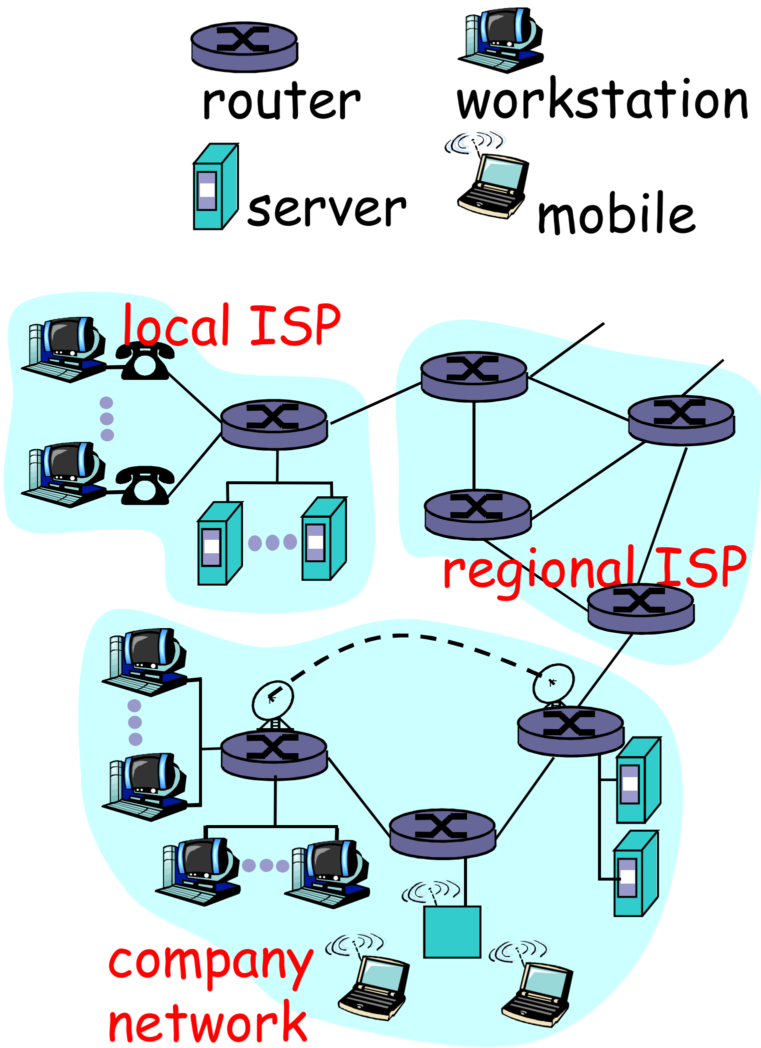


World’s smallest web server
http://www-ccs.cs.umass.edu/~shri/iPic.html

Internet phones

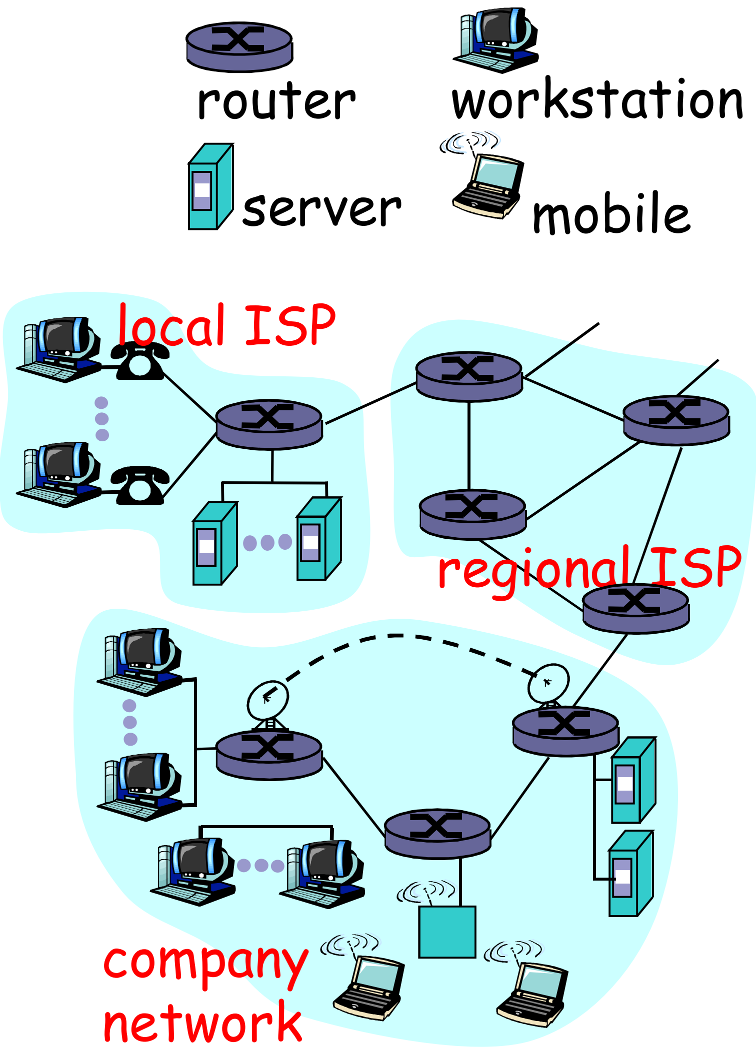
What's the Internet: "nuts and bolts" view

- ***Communication links***
  - fiber, copper,
  - radio, satellite
- ***Routers:***
  - **forward packets (chunks) of data thru network**



What's the Internet: "nuts and bolts" view

- **Protocols: control sending, receiving of messages**
  - e.g., TCP, IP, HTTP, FTP, PPP
- ***Internet:* "network of networks"**
  - loosely **hierarchical**
  - **public Internet** versus **private intranet**



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

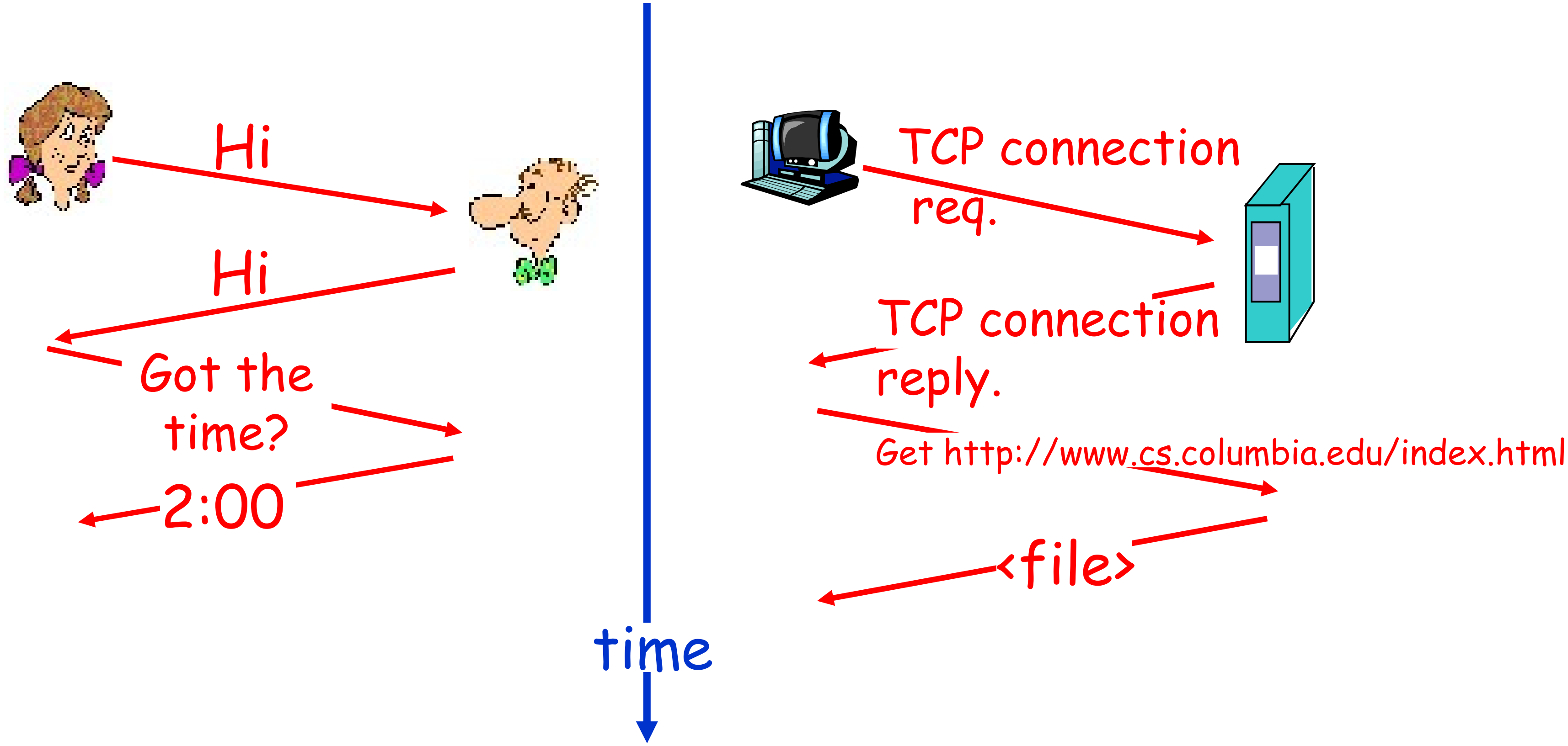
network protocols:

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

Protocols define format & order of messages sent and received among network entities, and actions taken on message transmission and receipt.

What's a protocol?

a human protocol and a computer network protocol:



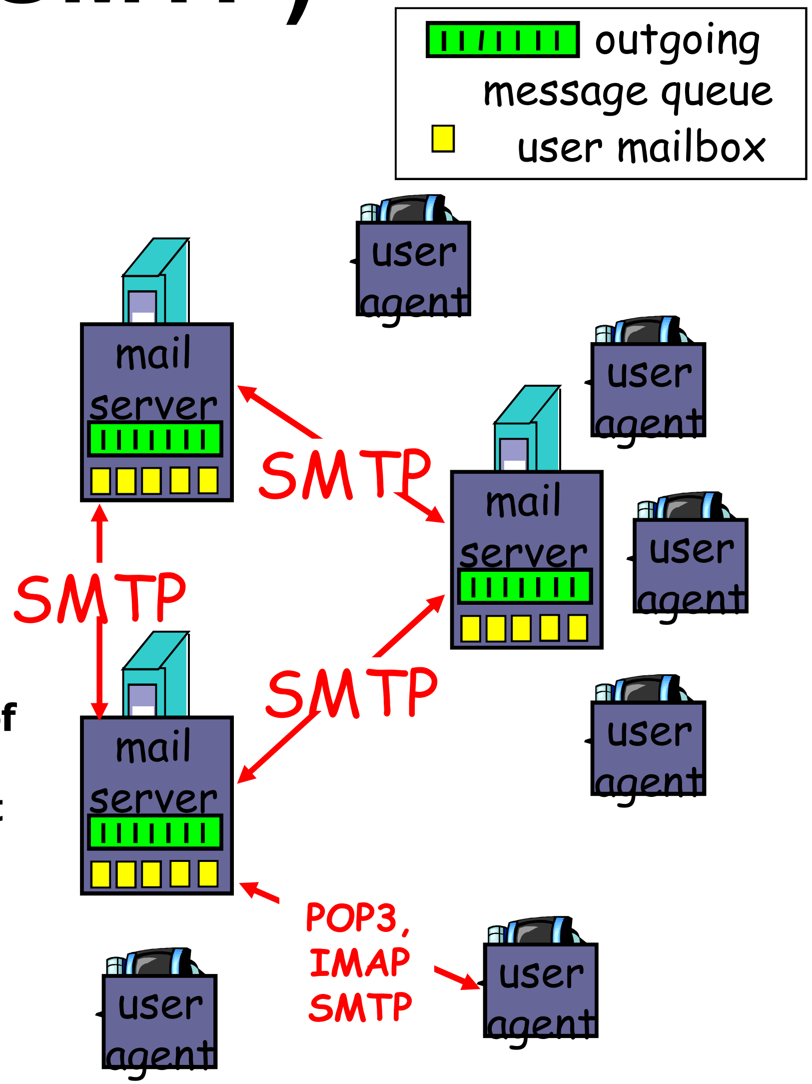
Q: Other human protocol?

Examples of Protocols in Life

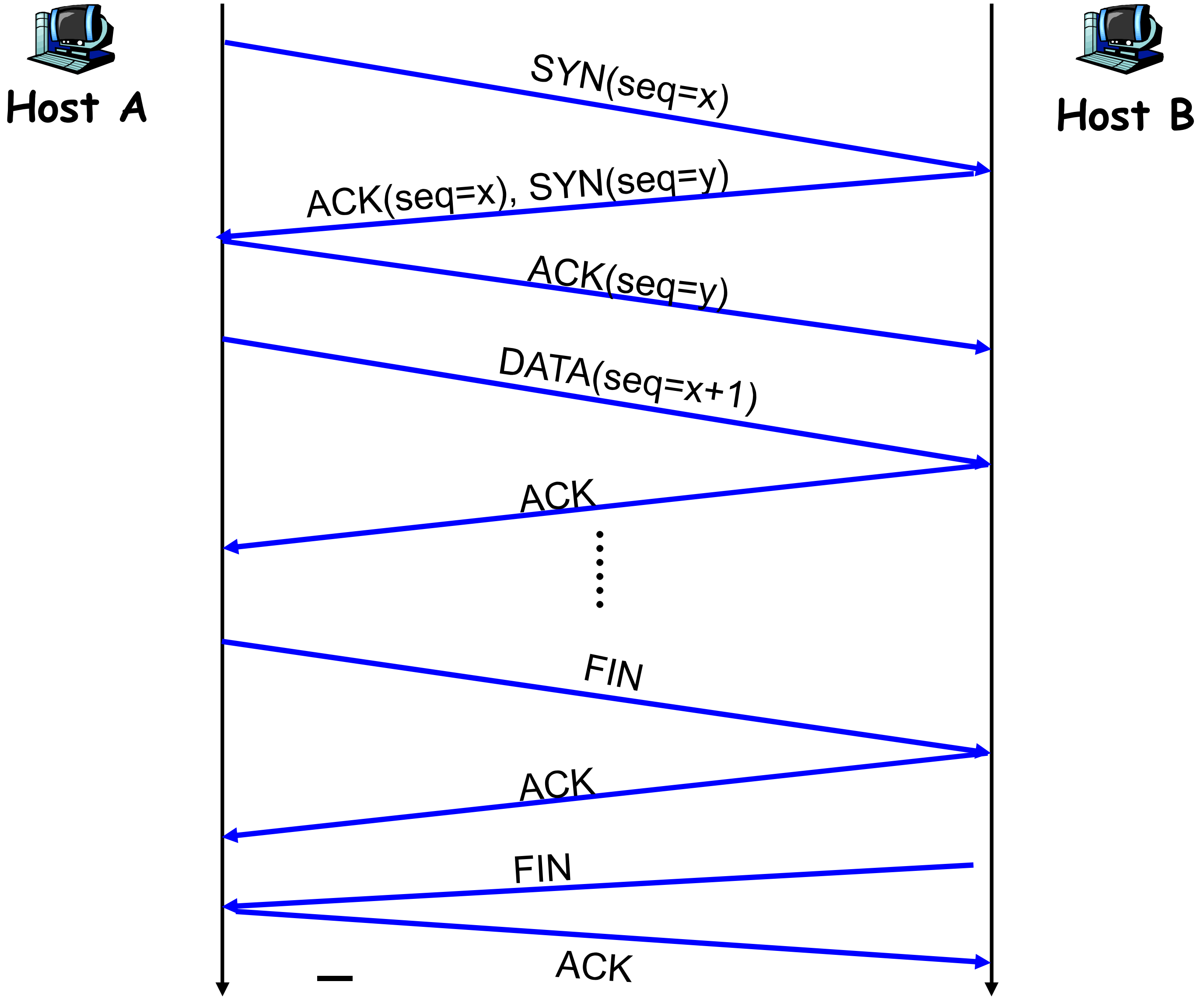
- Asking a question in class
- Turn-taking in conversations
  - Pause is a signal for the next person's response
  - When do these rules break?
- Boarding and exiting an airplane
  - Not all countries have the same protocol!
- Answering the phone
  - Starting with hello as signal for other party to talk
  - Other party identifies themselves, then conversation
- Teenagers (an example of unreliable transport!)
  - Information and money only flow in one direction

Example Protocol: Simple Mail Transfer Protocol (SMTP)

- **Messages from a client to a mail server**
  - HELO
  - MAIL FROM: <address>
  - RCPT TO: <address>
  - DATA
    <This is the text end with a line with a single .>
  - QUIT
- **Messages from a mail server to a client**
  - status code
    - 1xx - Informative message
    - 2xx - Command ok
    - 3xx - Command ok so far, send the rest of it.
    - 4xx - Command was correct, but couldn't be performed for some reason.
    - 5xx - Command unimplemented, or incorrect, or a serious program error occurred.
  - content



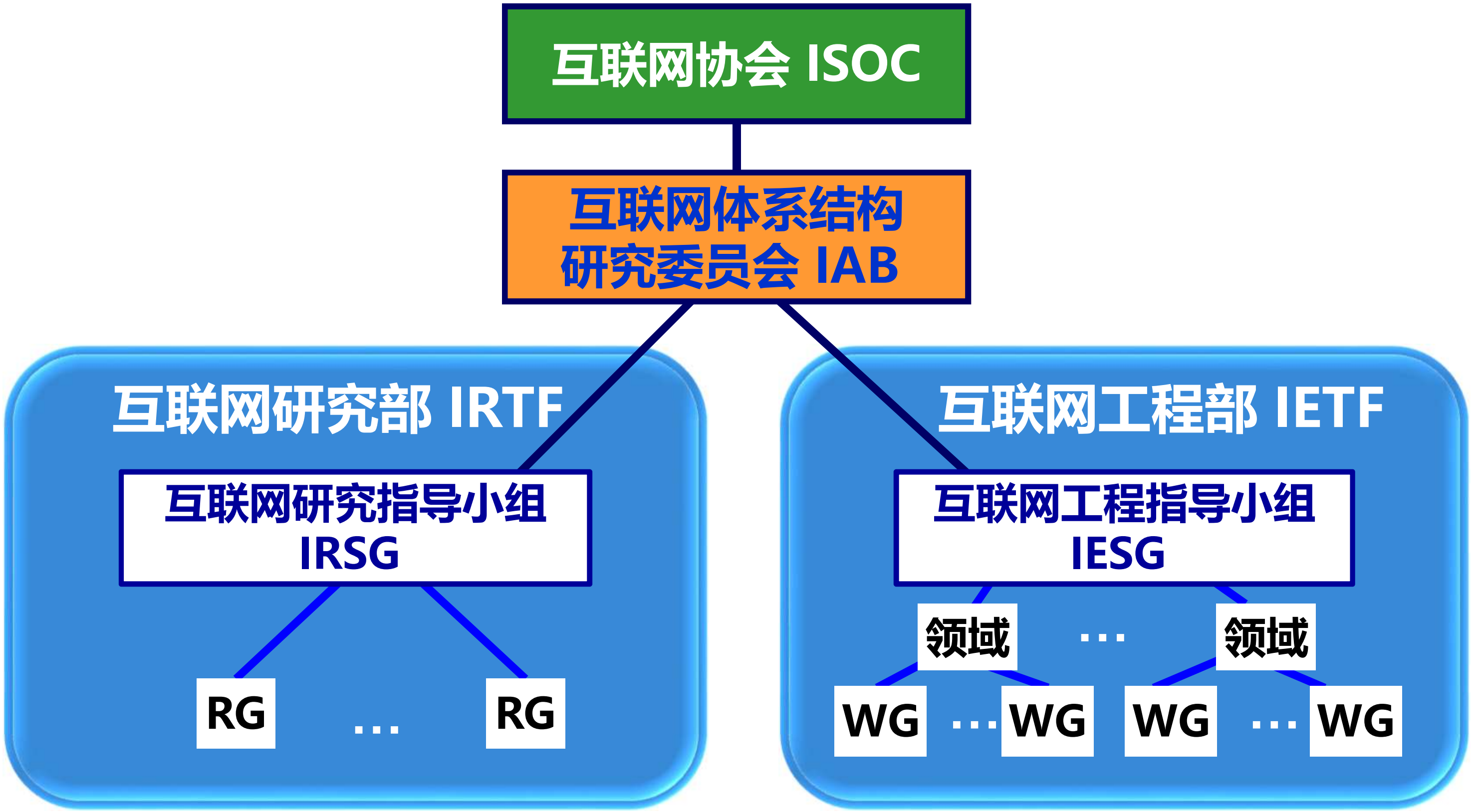
Example: TCP Reliability



Who is Who in the Internet ?

- Internet Society (ISOC)
- Internet Engineering Task Force (IETF)
- Internet Research Task Force (IRTF)
- Internet Architecture Board (IAB)

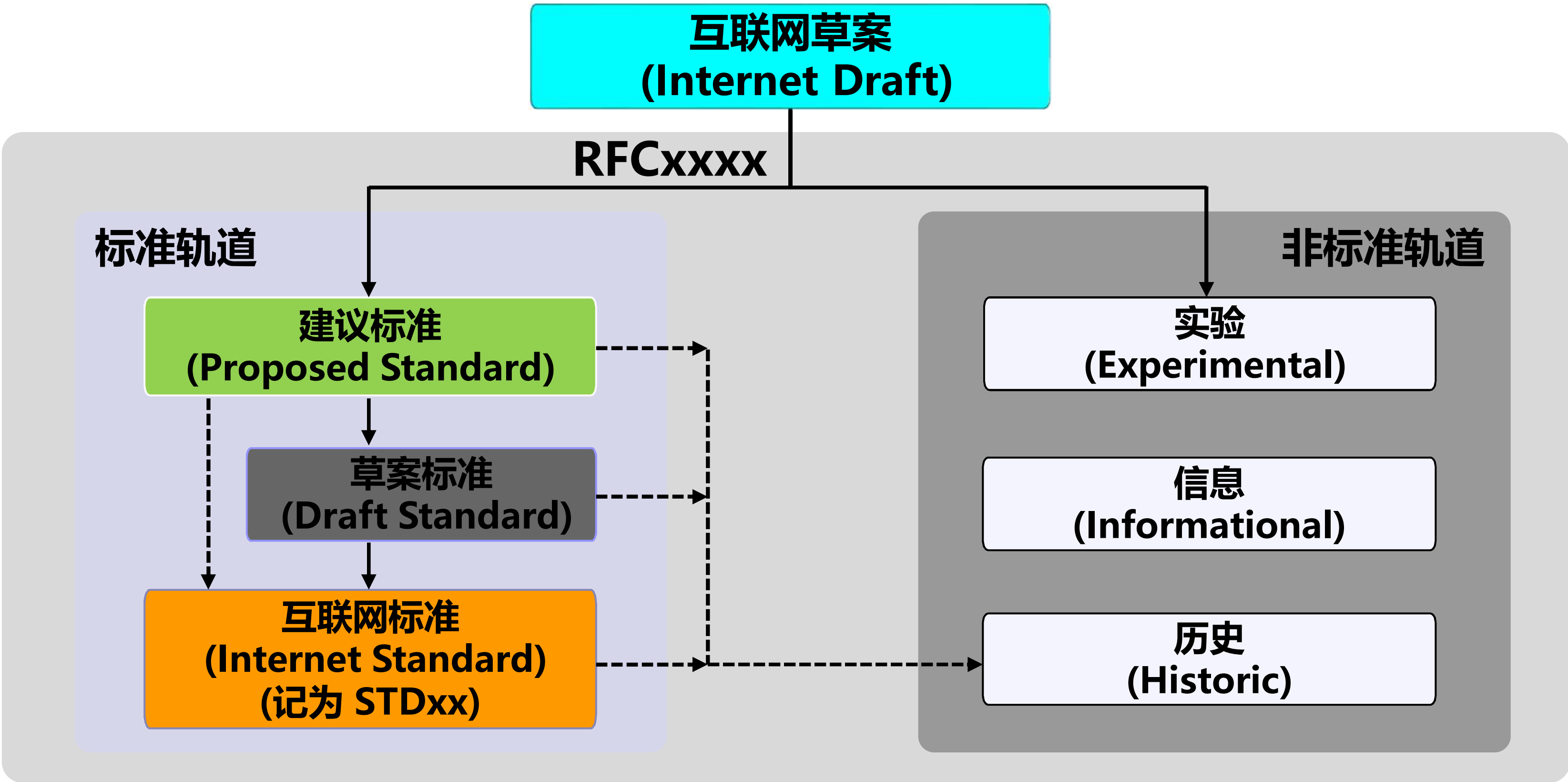
Who is Who in the Internet？



组织架构

Internet Standardization Process

- **All standards of the Internet are published as RFC (Request for Comments). But not all RFCs are Internet Standards !**



Internet Standardization Process

David Clark, MIT, 1992:

"We reject: kings, presidents, and voting.

We believe in: rough consensus and

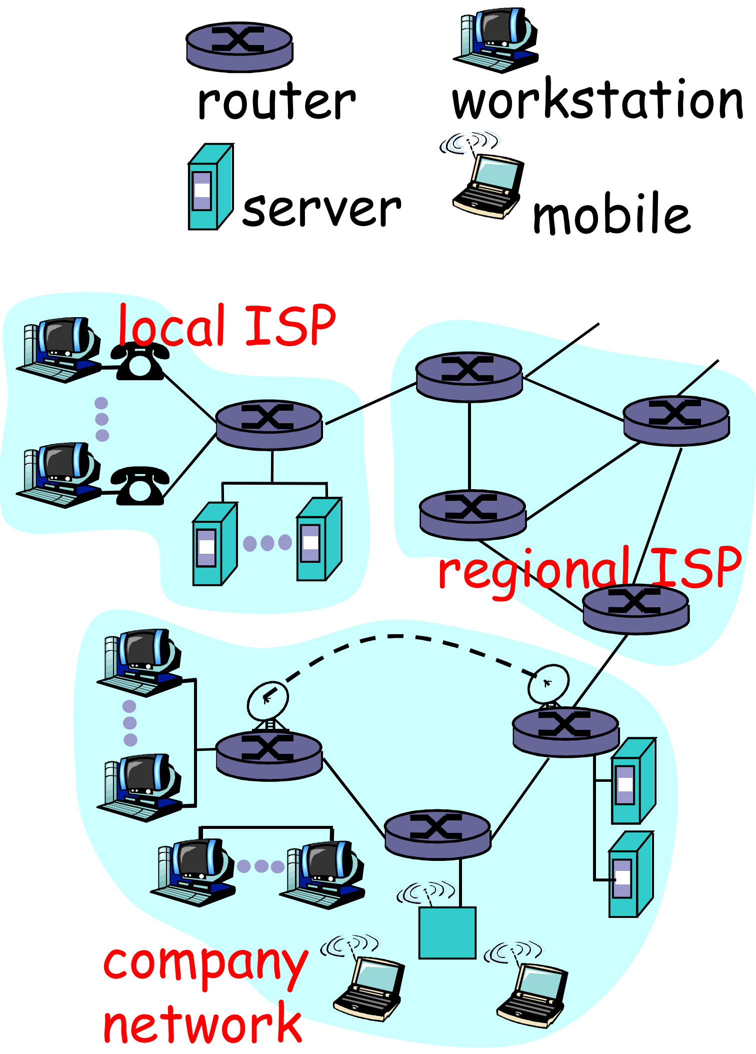
running code."

What's the Internet: a service view

- **communication *infrastructure*** enables distributed applications:
  - WWW, email, games, e-commerce, databases, voting, telephony, multimedia, IM, …
  - more?
- **communication services provided:**
  - **Datagram (Connectionless)**

vs.

  - **Virtual Circuit (connection-oriented)**



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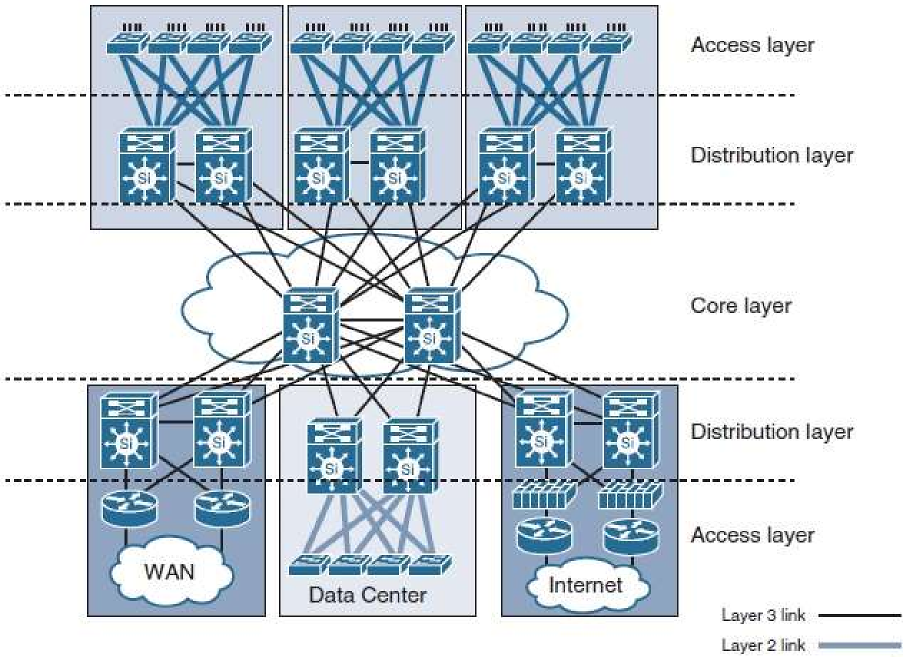
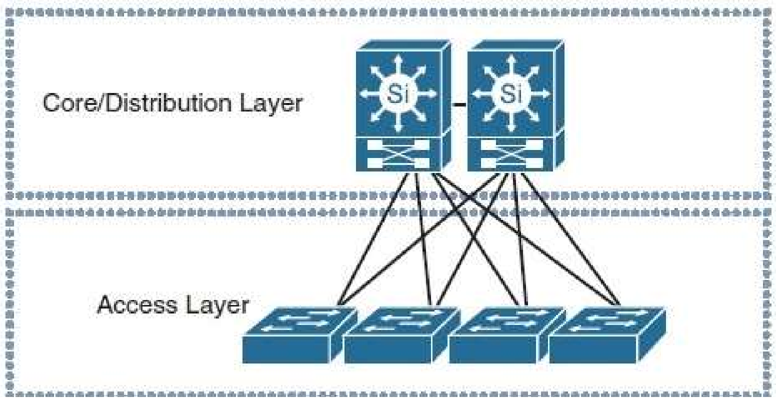
A closer look at network structure

- **Hierarchical Network Model**
  - Core layer
  - Distribution layer
  - Access layer

"build today with tomorrow in mind."



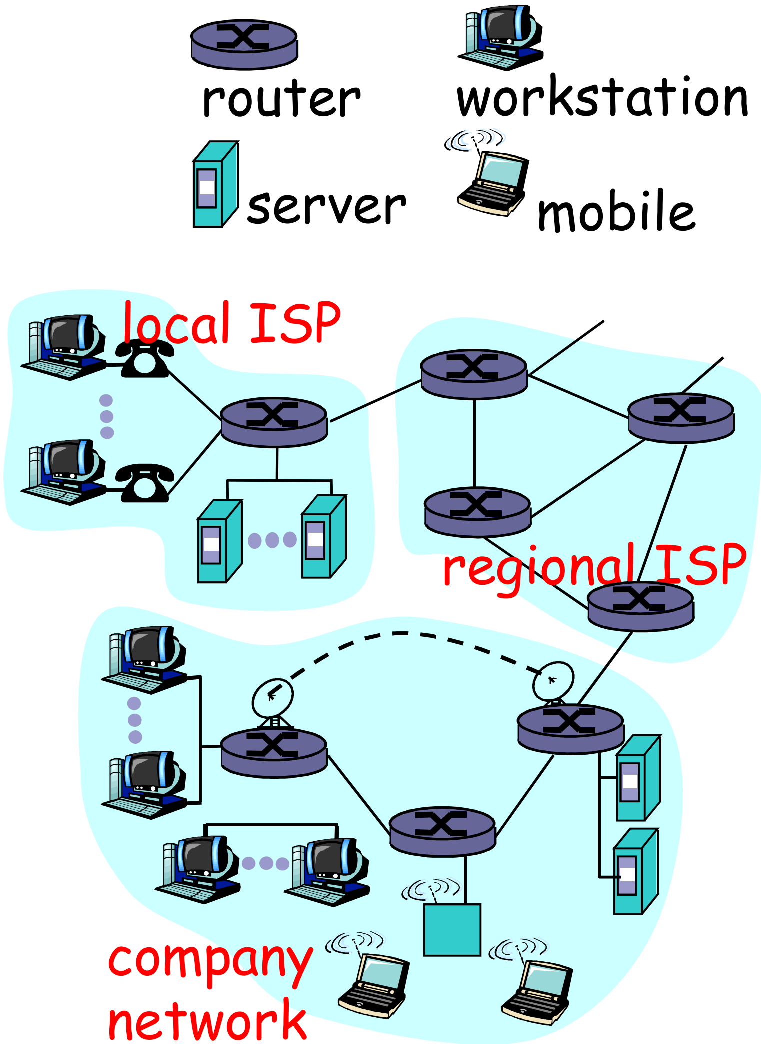
Three-tier model



Two-tier model

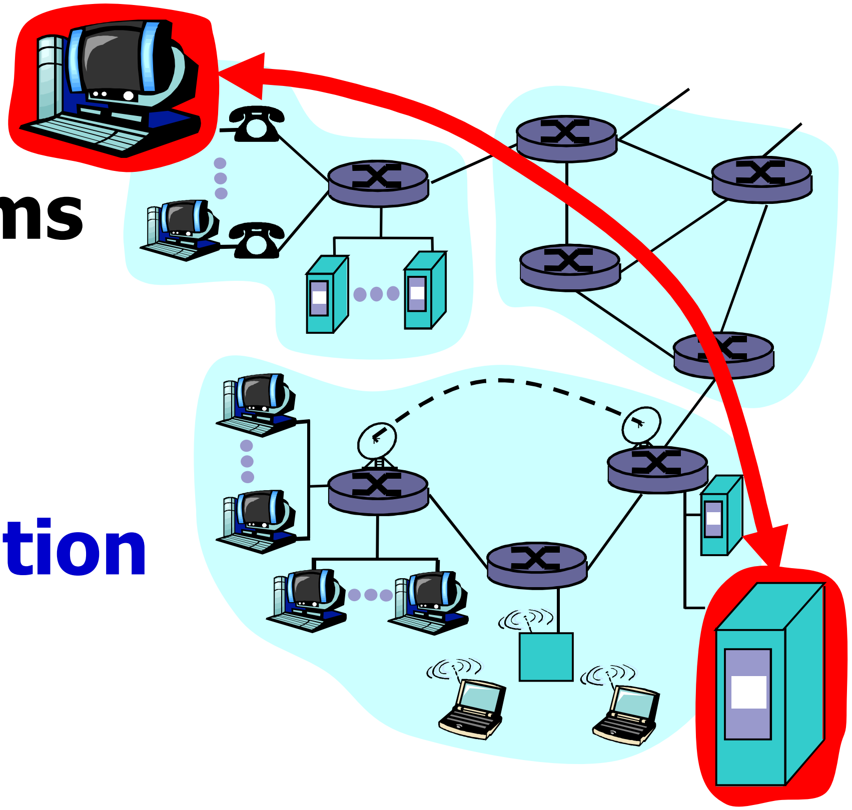
A closer look at network structure

- **Network edge:**
  - applications and hosts
  - resources
- **Network core:**
  - routers
  - network of networks
  - communications
- **physical media, Access networks:**
  - communication links
  - access



The network edge

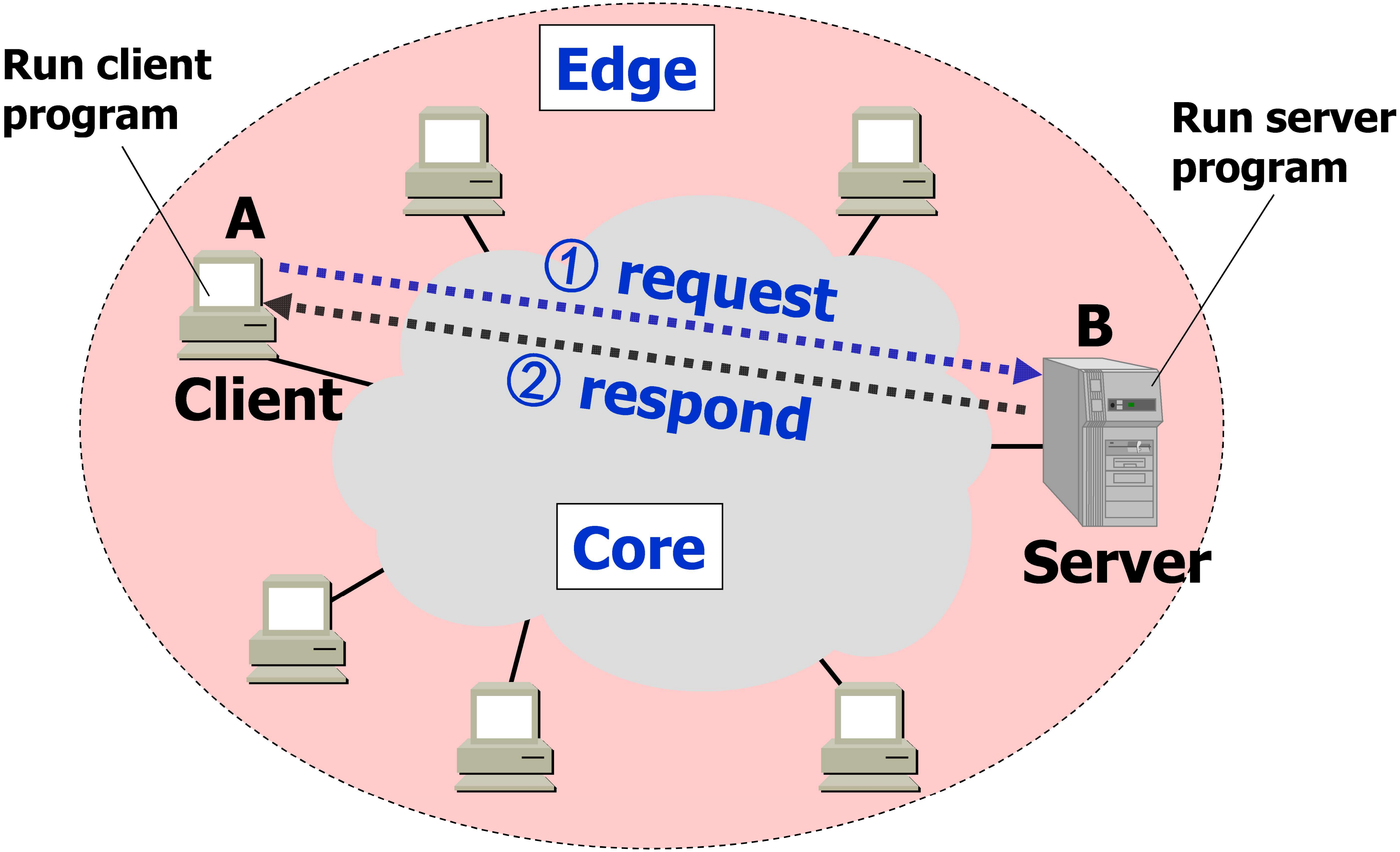
- **End Systems (hosts)**
  - run application programs
  - e.g., WWW, email
  - at "edge of network"
- **End-to-End Communication**
  - client/server model
  - peer-to-peer model



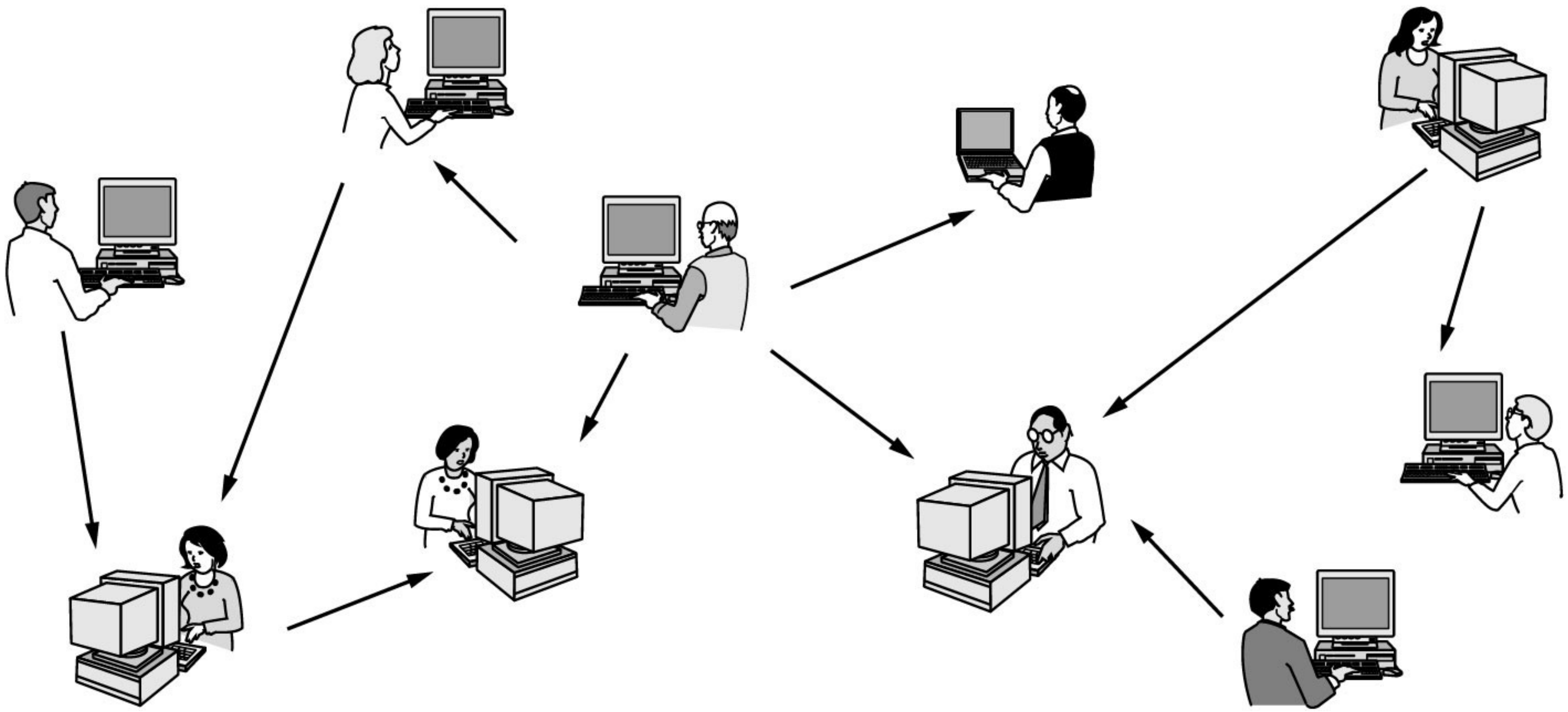
Host A communicate with host B actually means: "a program running on host A communicates with another program running on host B"

End-to-End Communication = process-to-process Communication

Client / Server Model

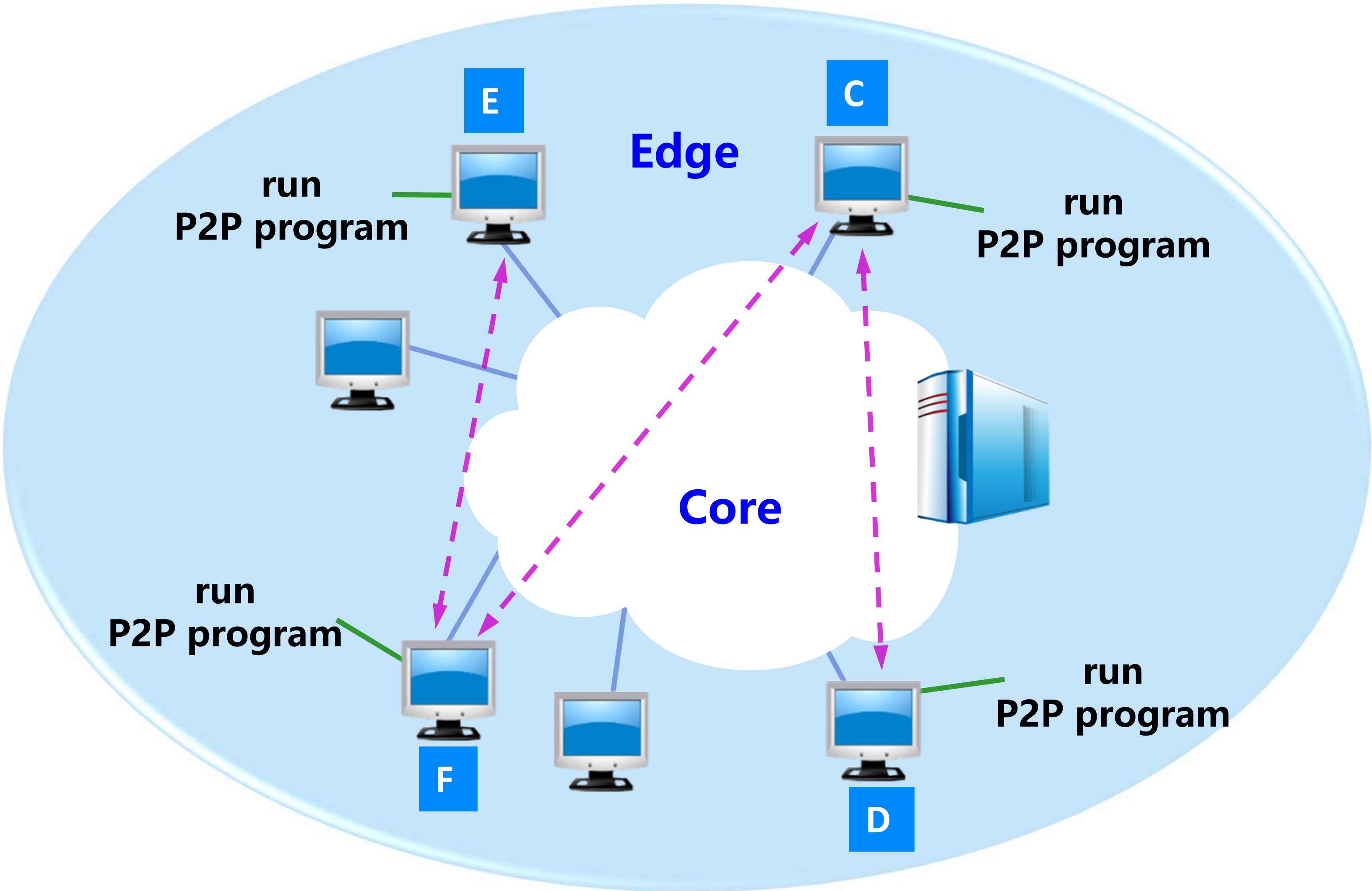


Peer-to-Peer model



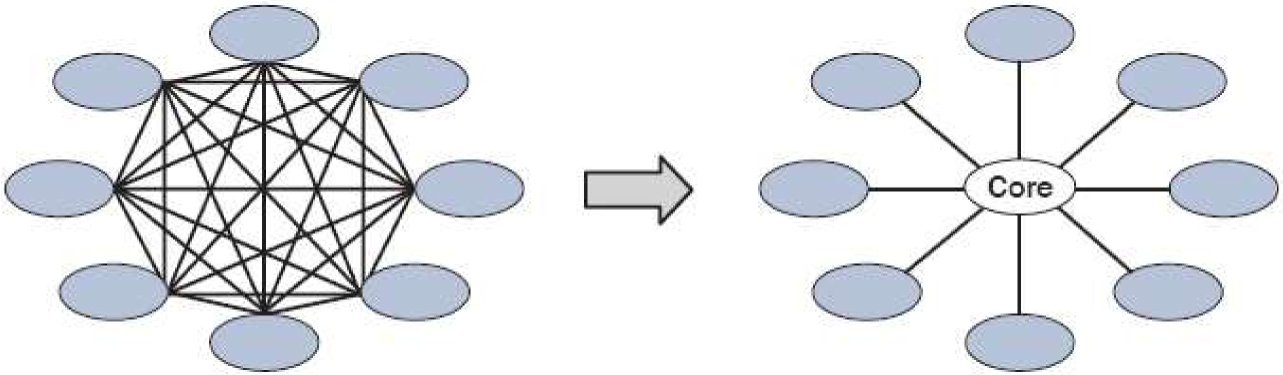
In a peer-to-peer system there are no fixed clients and servers.

Peer-to-Peer model



The Network Core

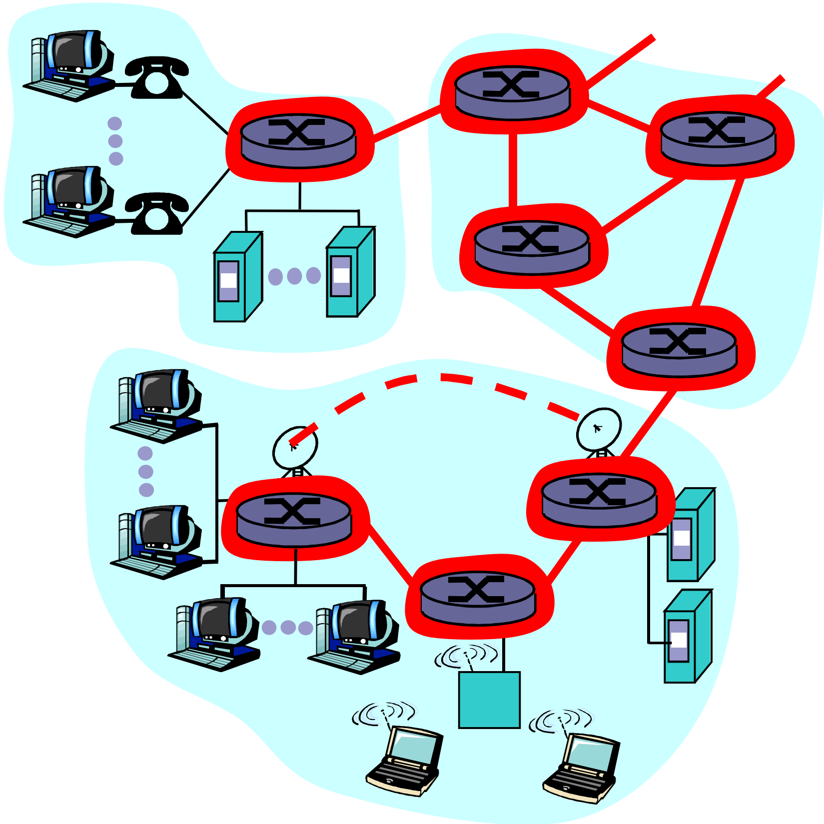
- **Network core provides the capability to scale the size of the network in a structured fashion that minimizes overall complexity when the size of the network grows.**



Connectivity without core vs. with core

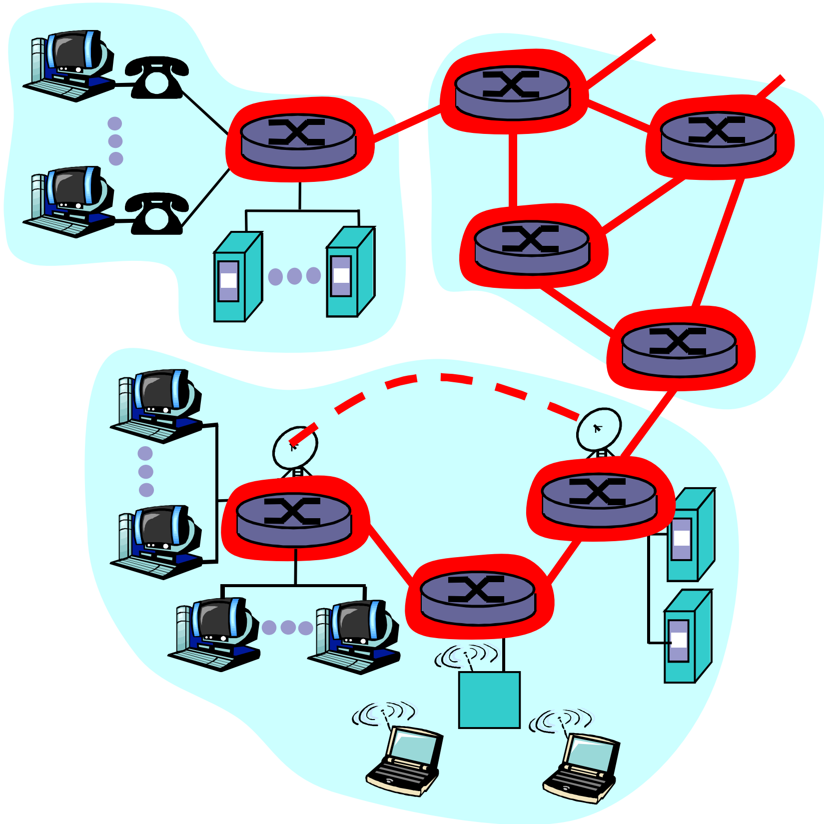
The Network Core

- **Generally: mesh of interconnected routers**
- **Support end system communication.**
- **Q: How is data transferred through core?**



The Network Core

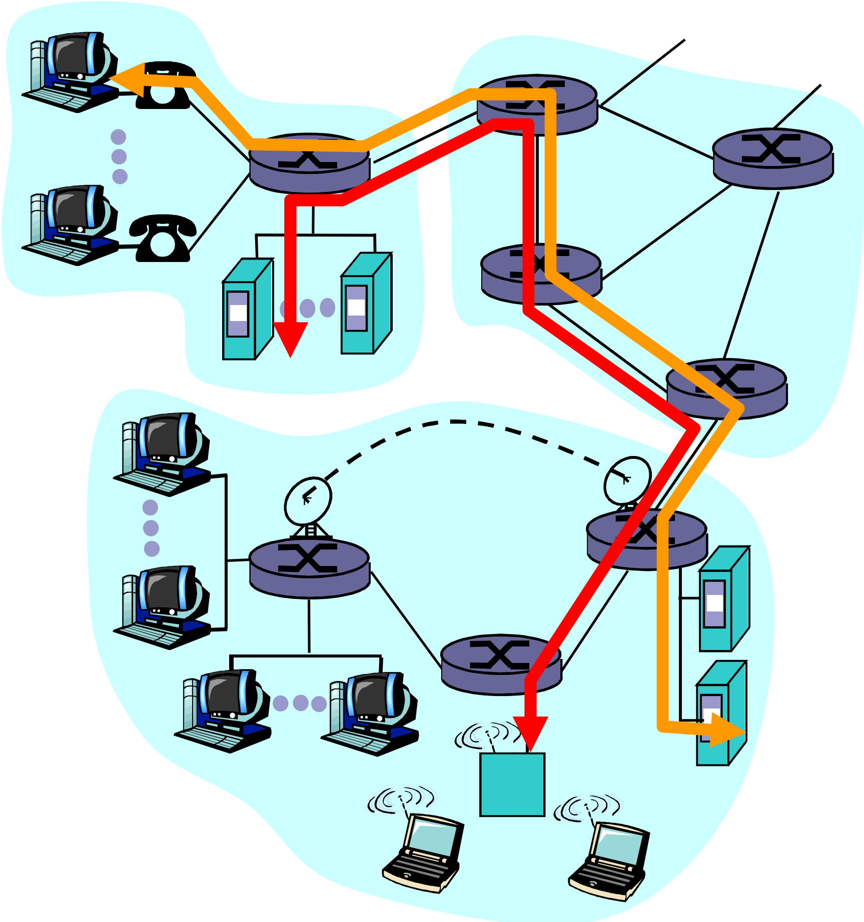
- **Solution**
  - **Circuit switching:** dedicated circuit per call: telephone net
  - **Message switching:** application units
  - **Packet-switching:** data sent thru net in discrete "chunks"



Network Core: Circuit Switching

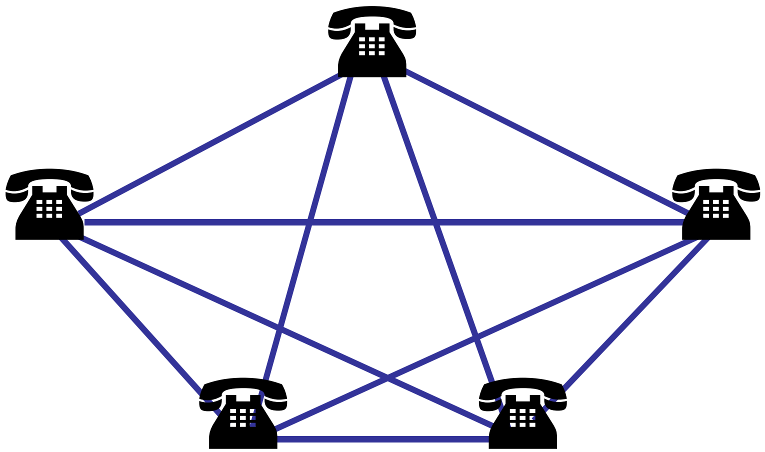
End-end resources reserved for "call"

- Resources: link bandwidth, switch capacity, etc.
- dedicated resources: no sharing
- circuit-like (guaranteed) performance
- call setup required

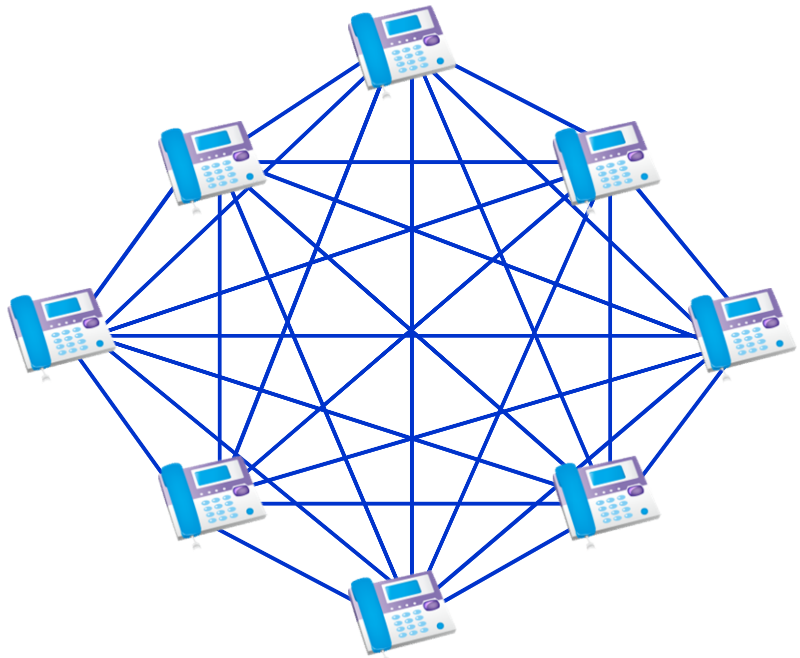


Telephone network uses circuit switching

Communication between 2 telephones: just one pair of wires



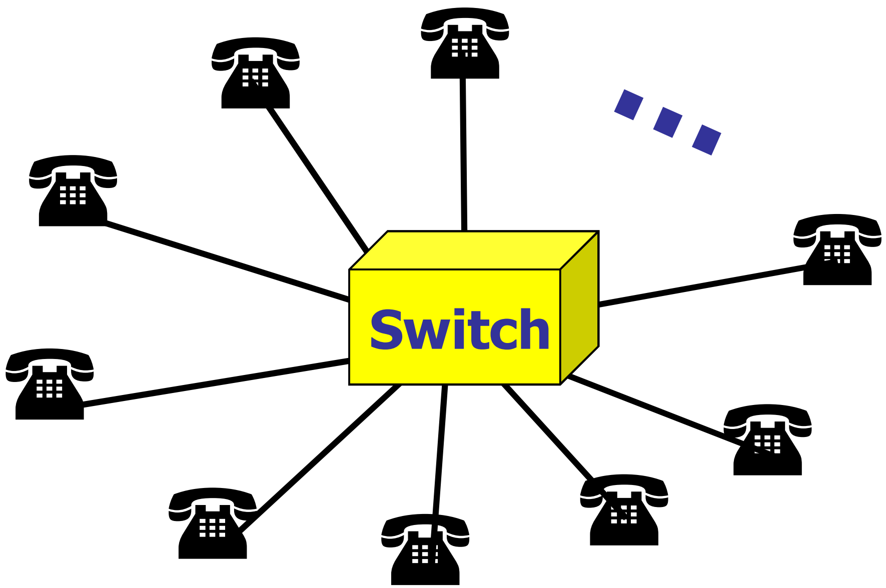
Communication between any 2 of 5 telephones: 10 pairs of wires required



Direct connection between any 2 of N telephones requires N(N – 1)/2 pairs of wires!!!

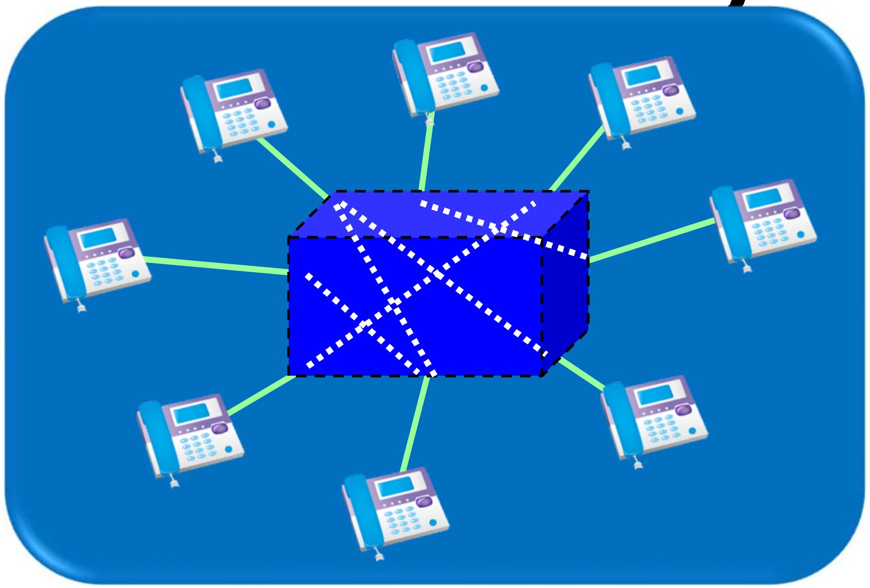
Telephone network uses circuit switching

- When the number of telephones increases, it is a more economical and efficient method to implement communication between telephones by means of switches.

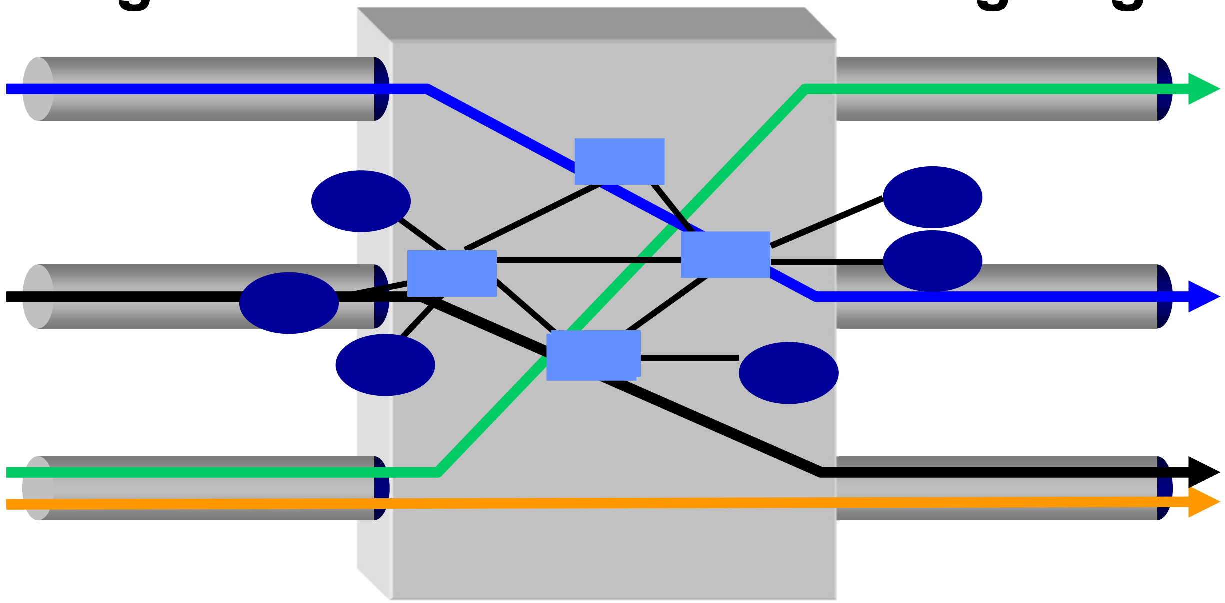


What does “switching" mean?

- **The transfer of one telephone line to another so that they are connected.**
- **From the perspective of the allocation of communication resources, "switching" is to dynamically allocate the resources of the transmission line in some way.**

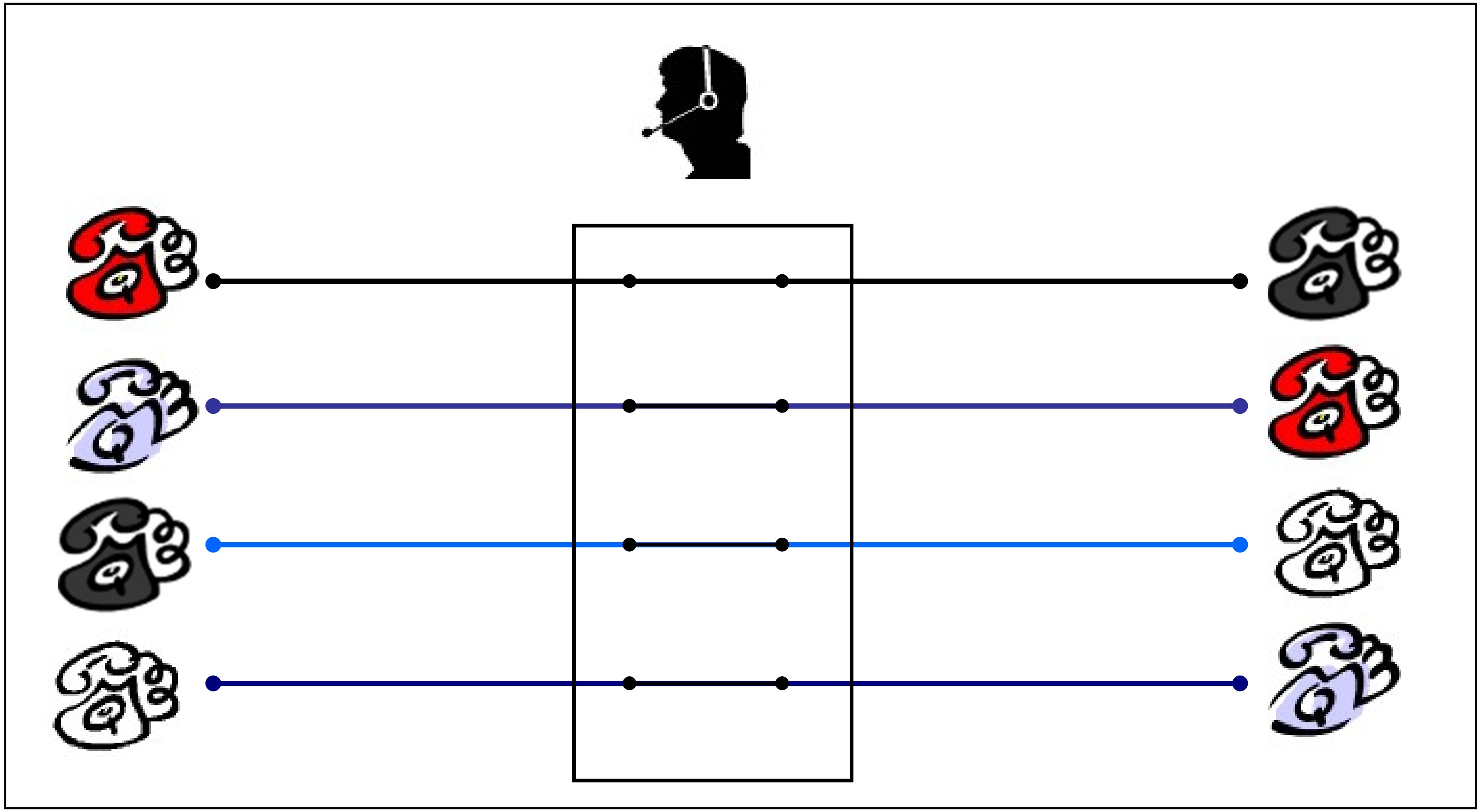


The switch in "circuit switching"



How does the node connect the incoming link to the outgoing link?

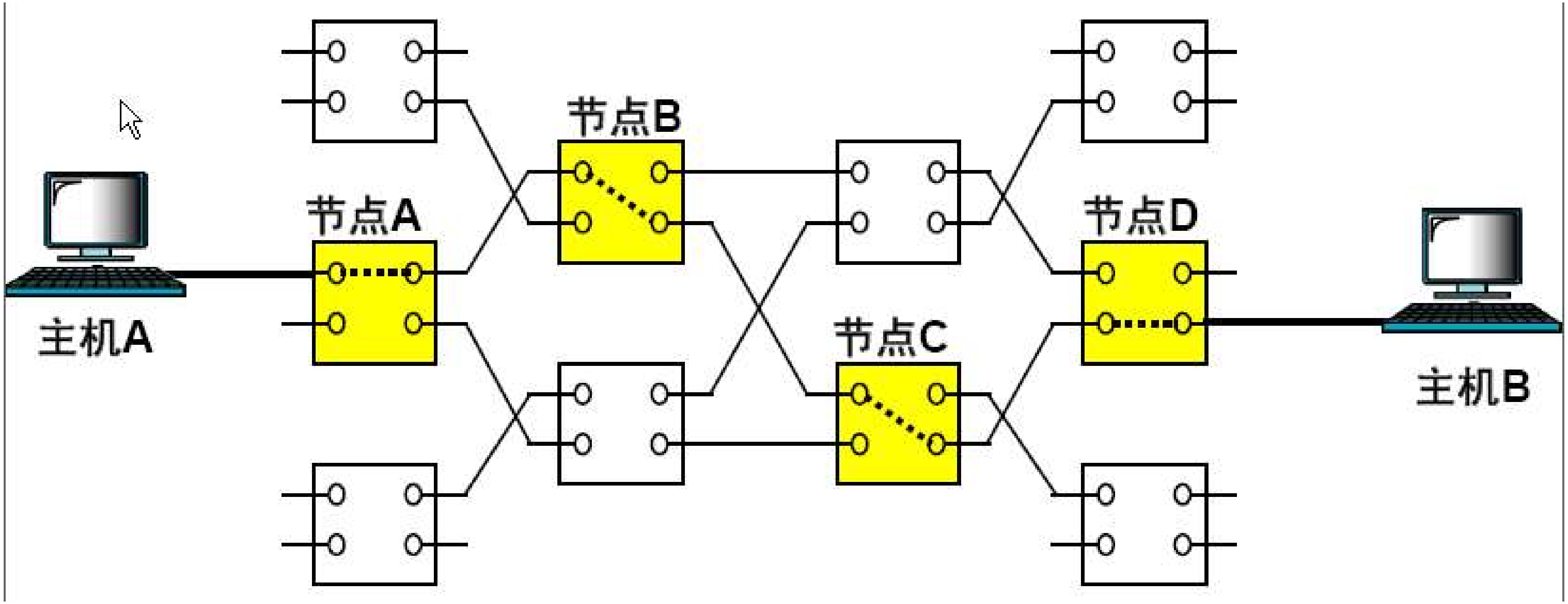
Circuit Switching With Human Operator



Computer network uses circuit switching

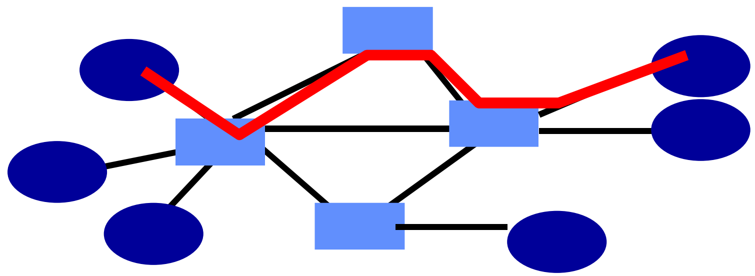
3 phases:

Circuit Establishment, Data Transfer, Circuit Release

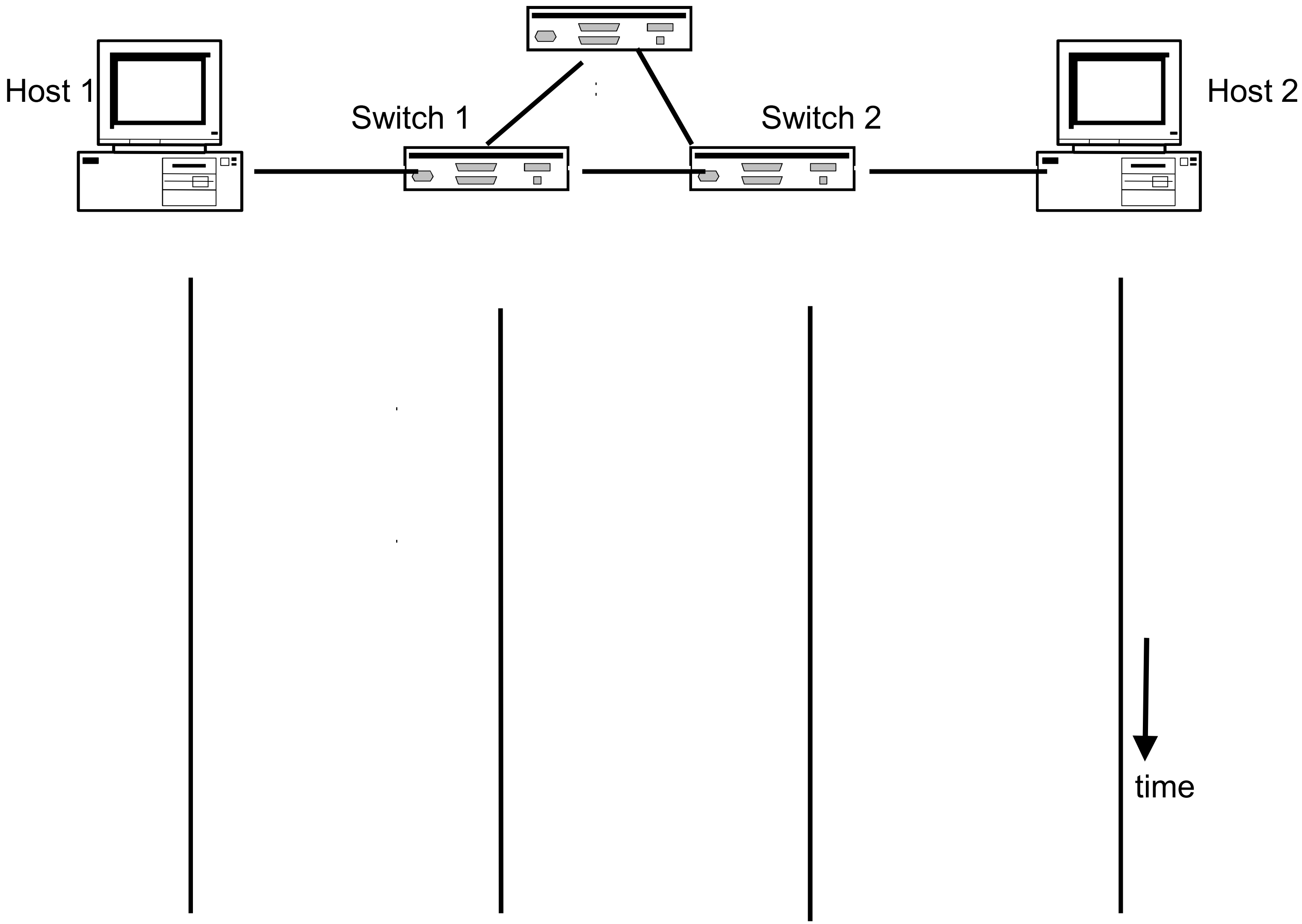


Computer network uses circuit switching

- **Establish: source creates circuit to destination**
  - Nodes along the path store connection info
  - And reserve resources for the connection
  - If circuit not available: “Busy signal”
- **Transfer: source sends data over the circuit**
  - No destination address, since nodes know path
  - Continual stream of data
- **Release: source tears down circuit when done**



Timing in Circuit Switching



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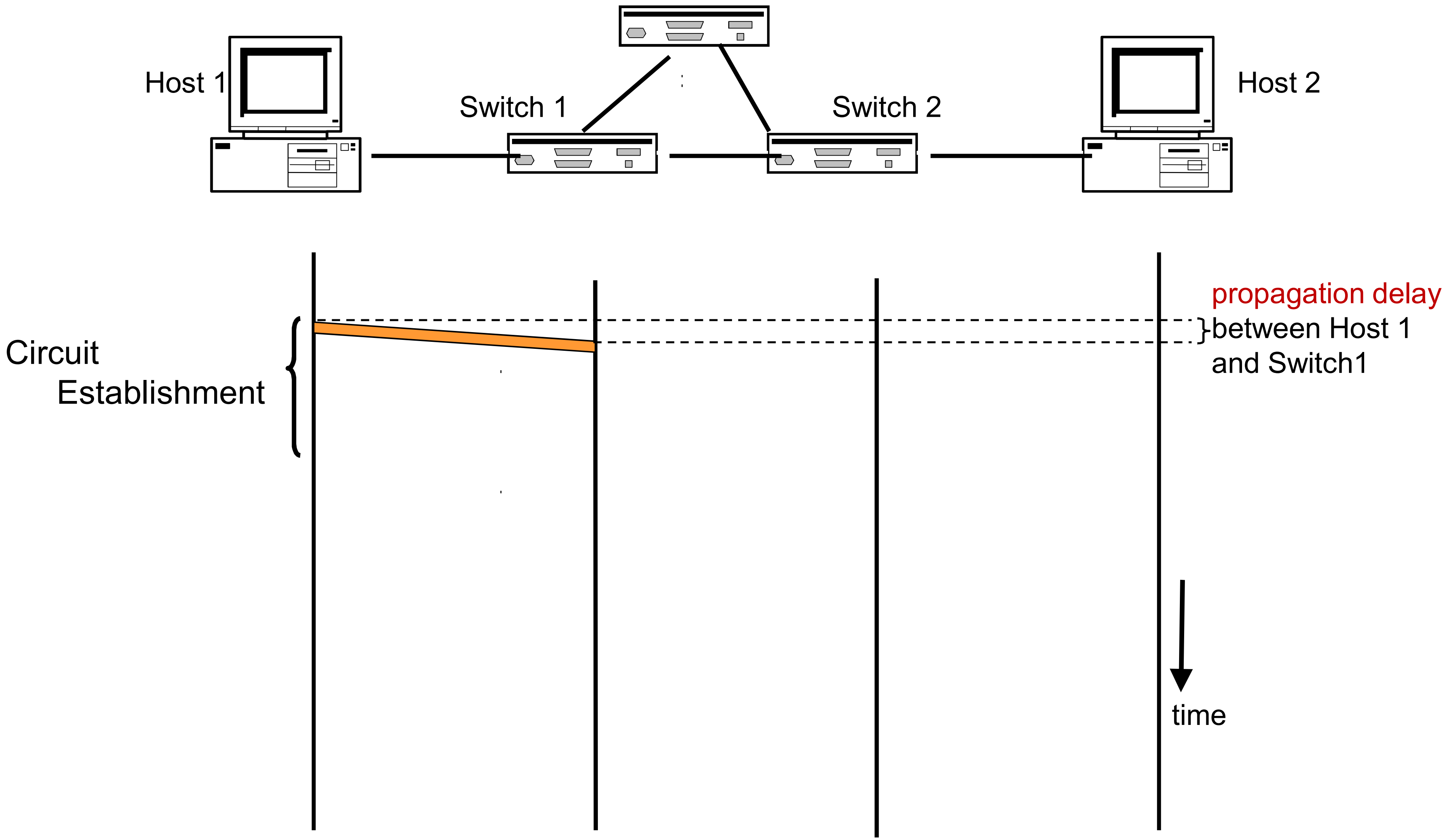

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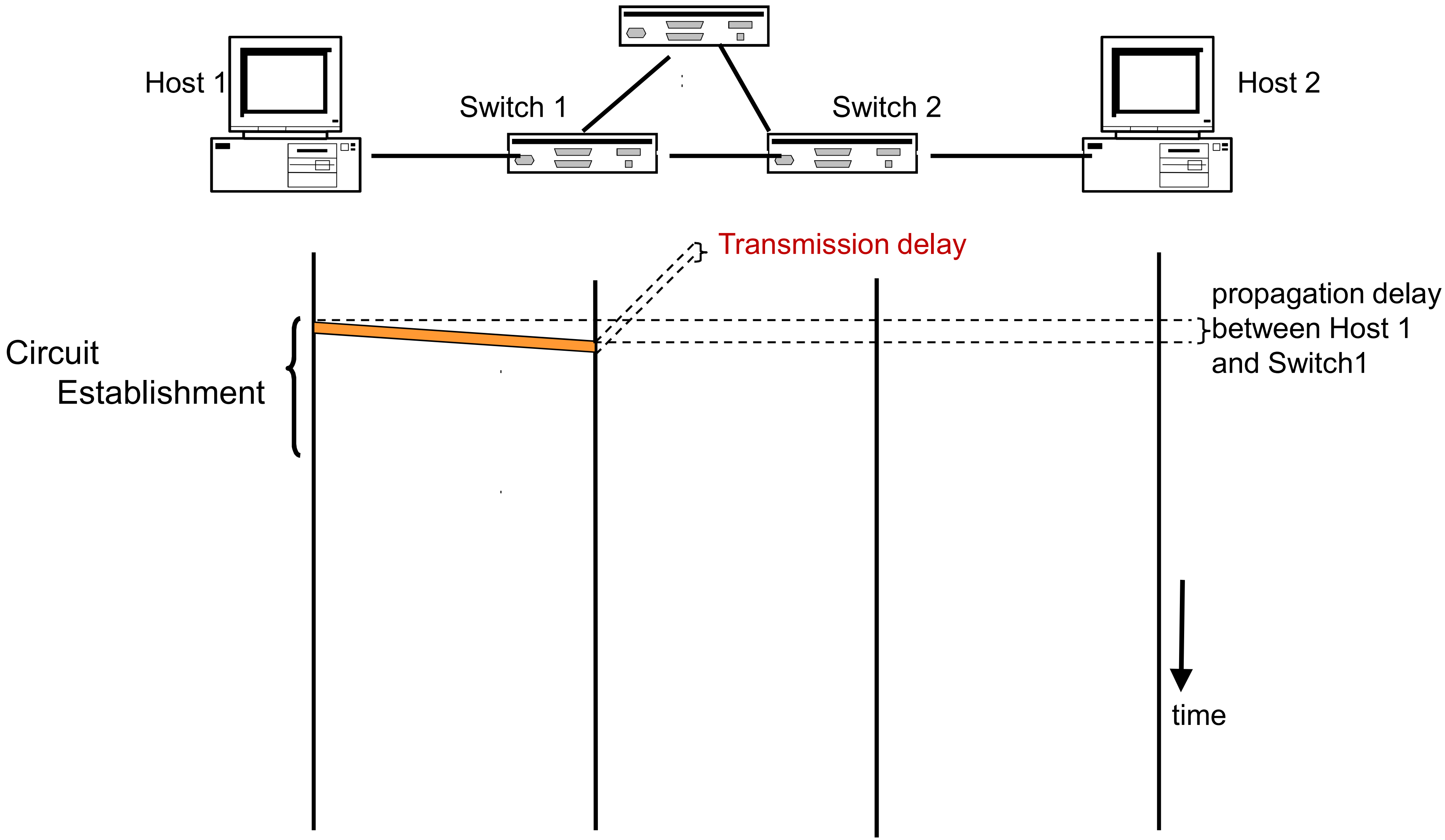

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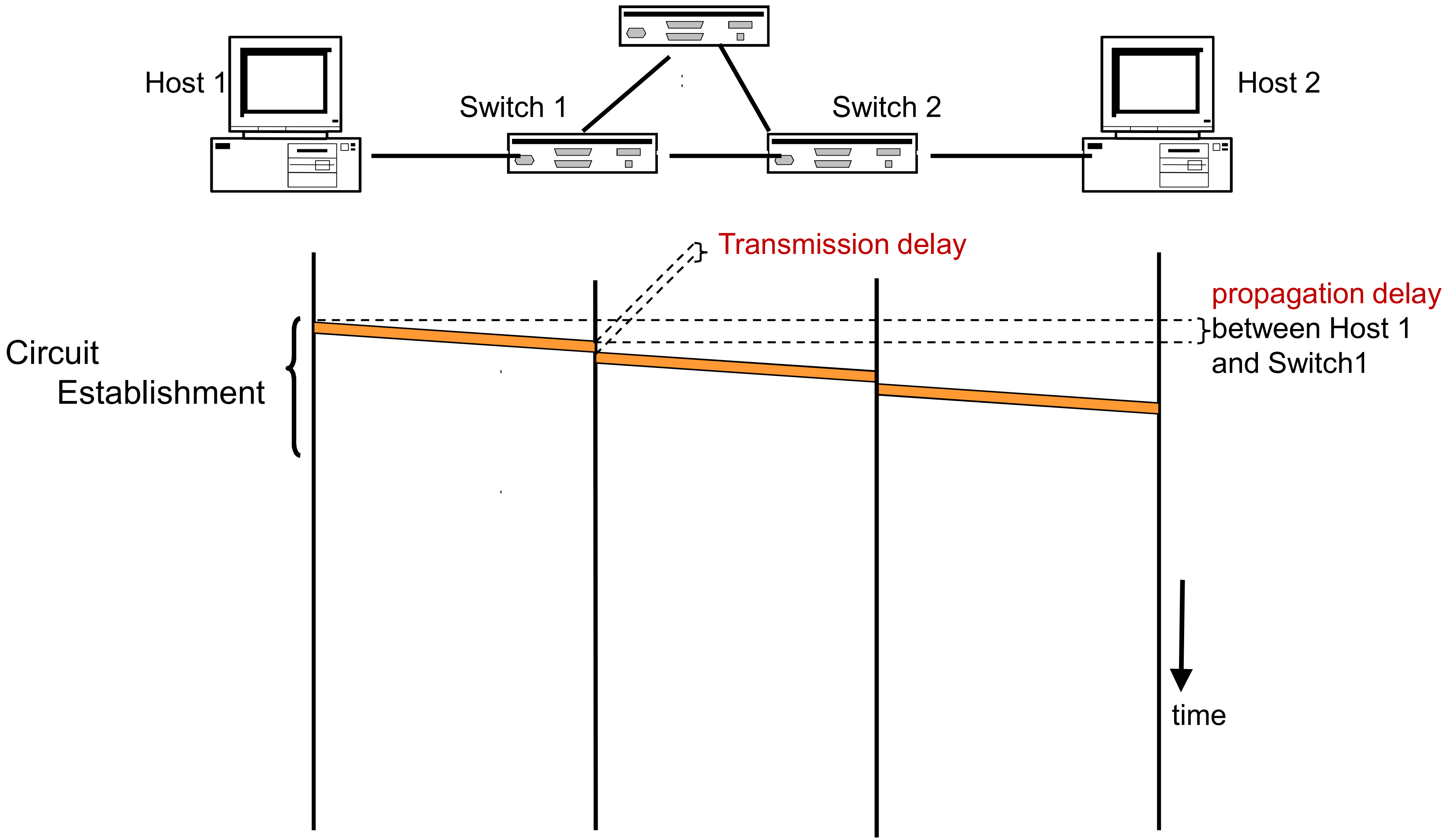

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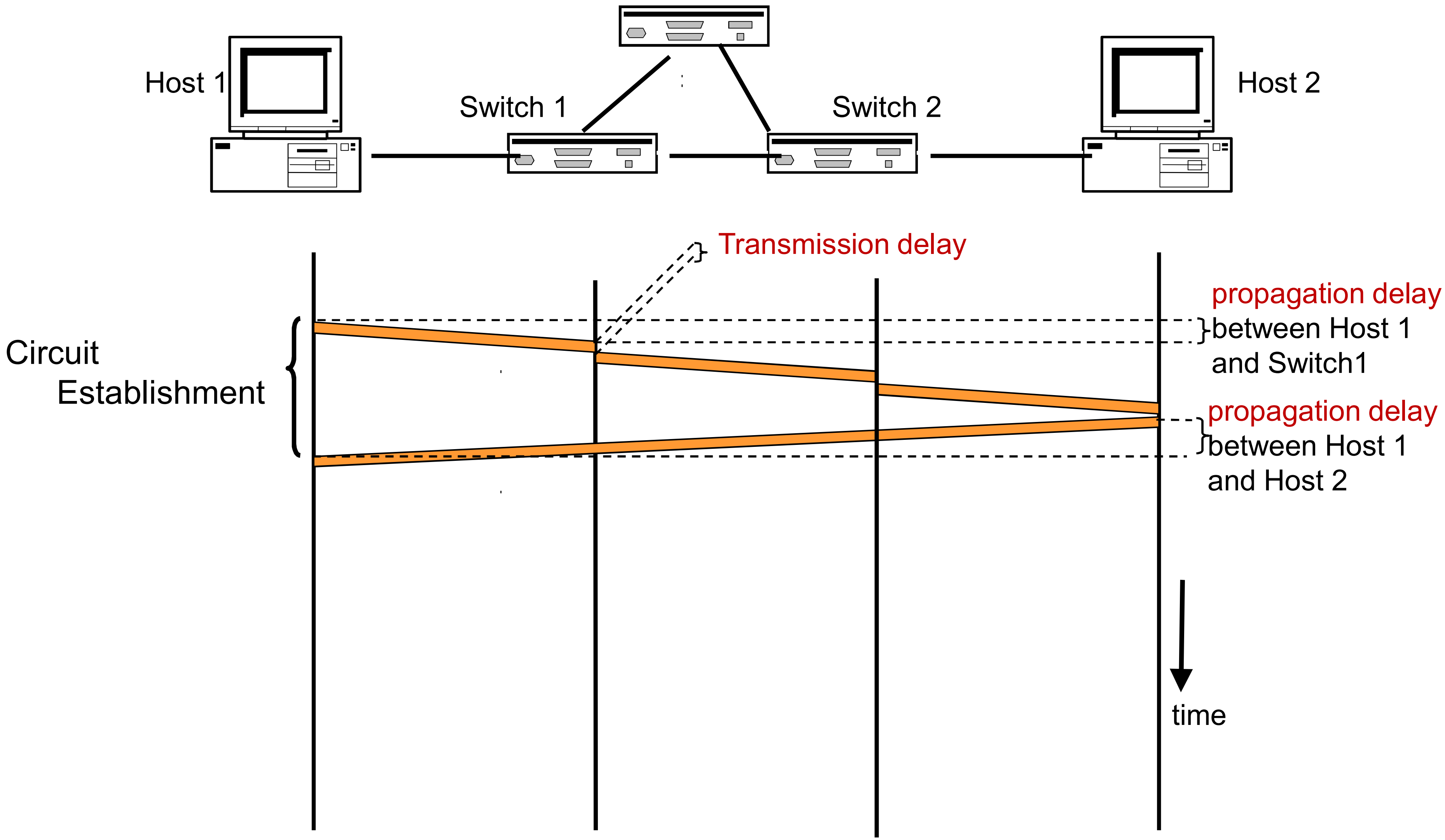
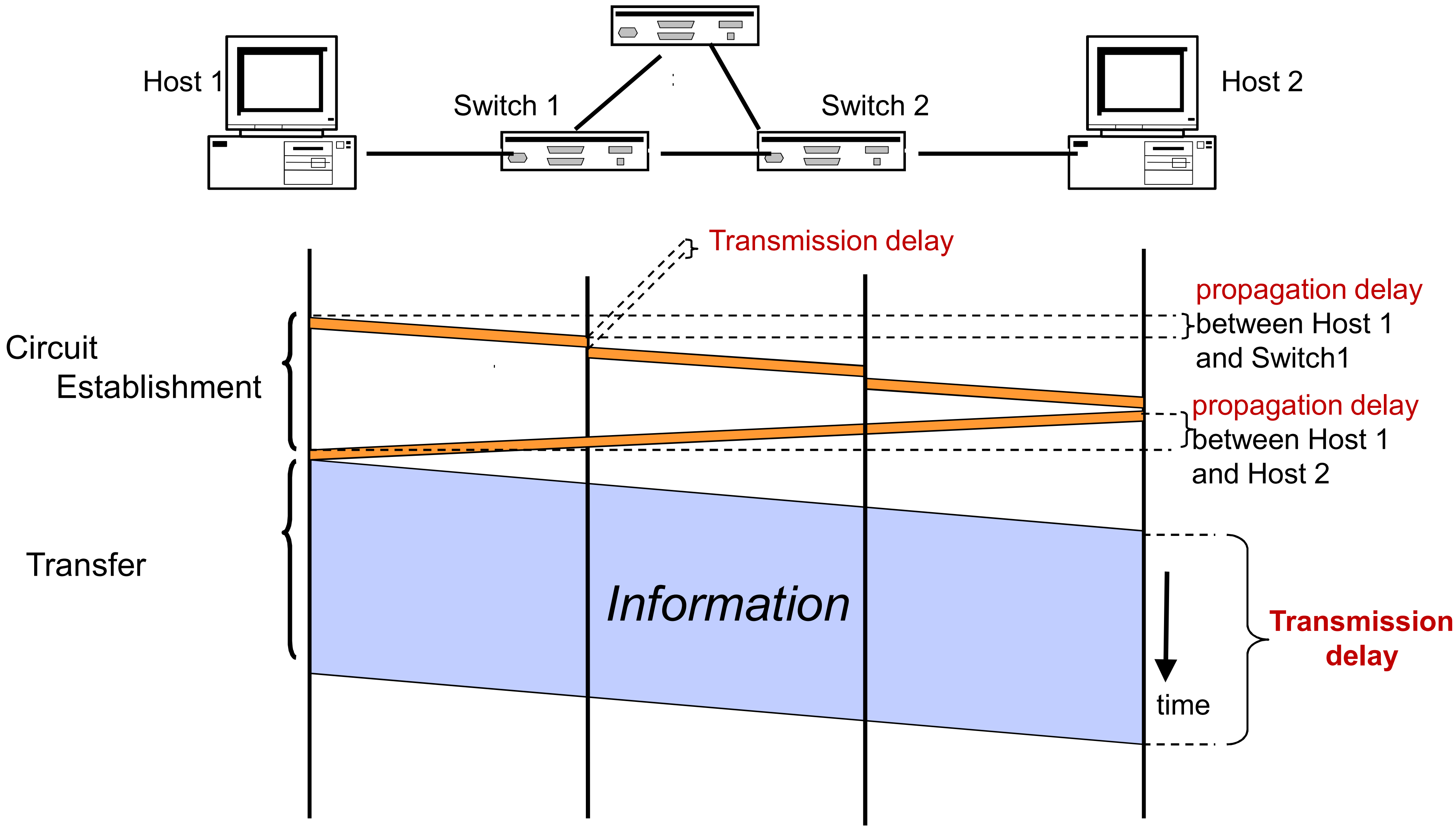
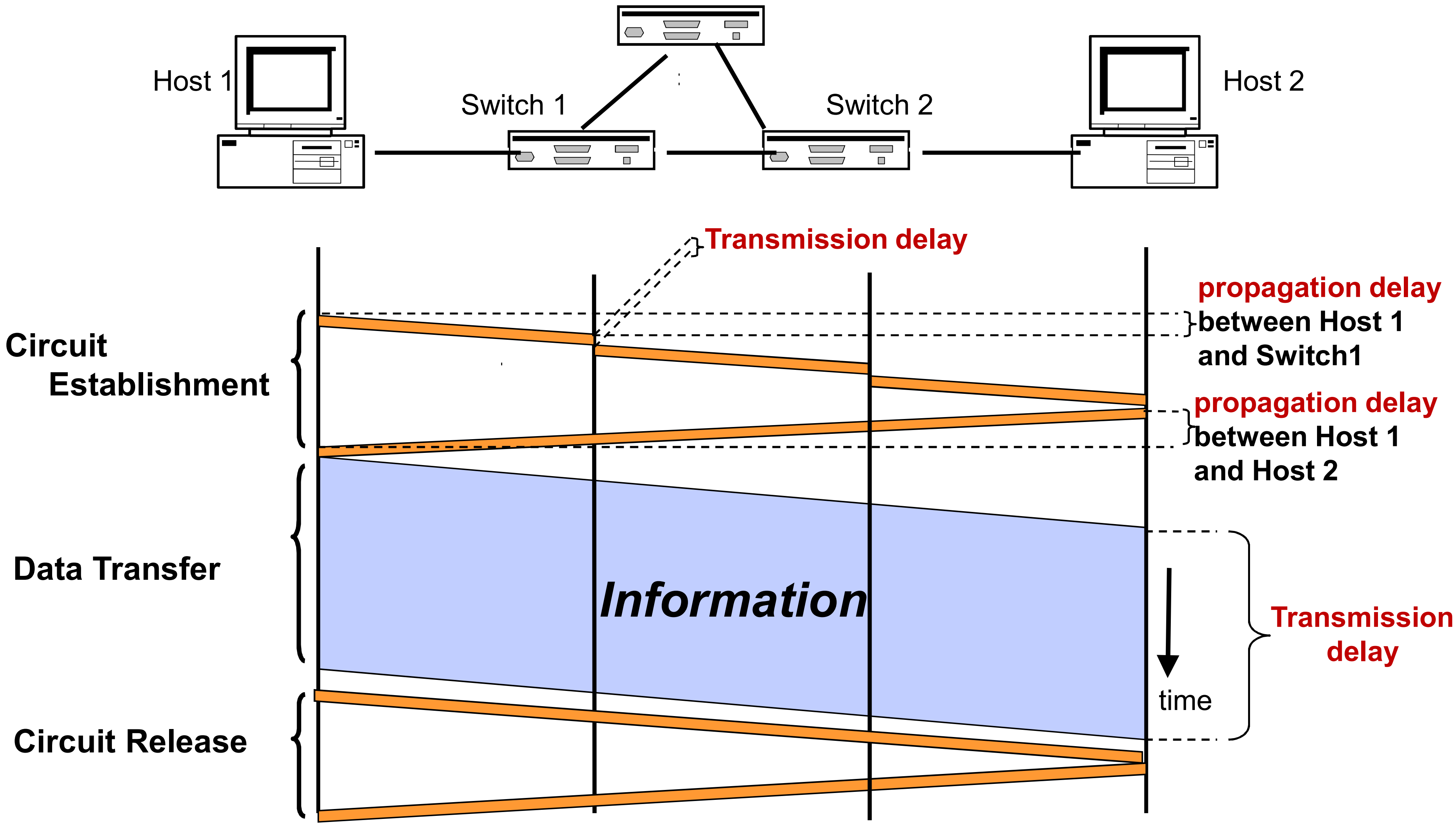


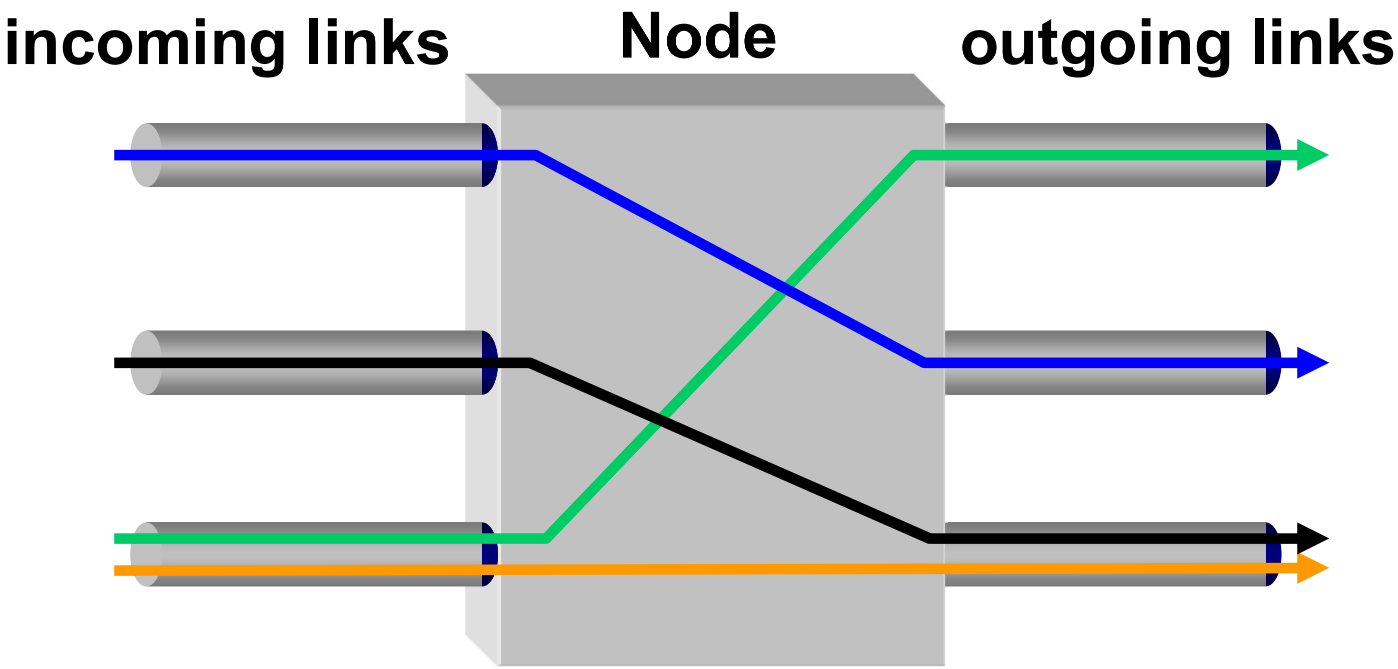
Timing in Circuit Switching



Timing in Circuit Switching



Circuit Switching: Sharing a link

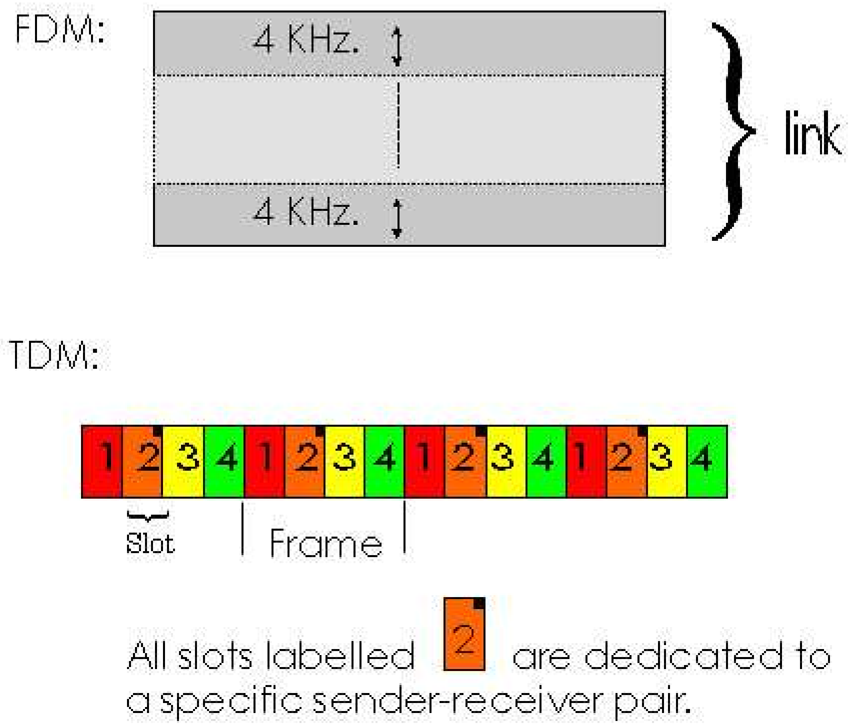


How do the black and orange circuits share the outgoing link?

Circuit Switching: Sharing a link

network resources (e.g., bandwidth) divided into "pieces"

- **pieces allocated to calls**
- **resource piece *idle* if not used by owning call *(no sharing)***
- **dividing link bandwidth into "pieces"**
  - frequency division (FDM)
  - time division (TDM)
  - space division

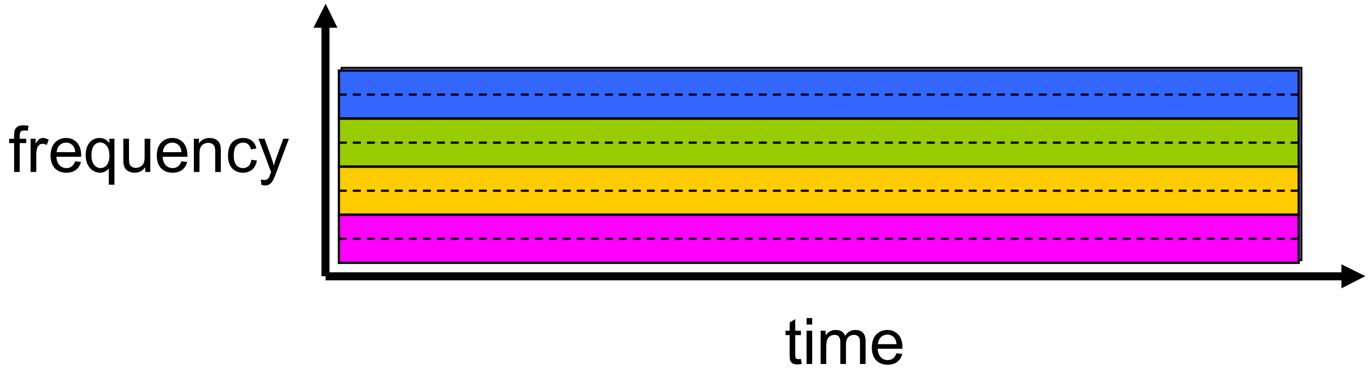


Circuit Switching: Sharing a link

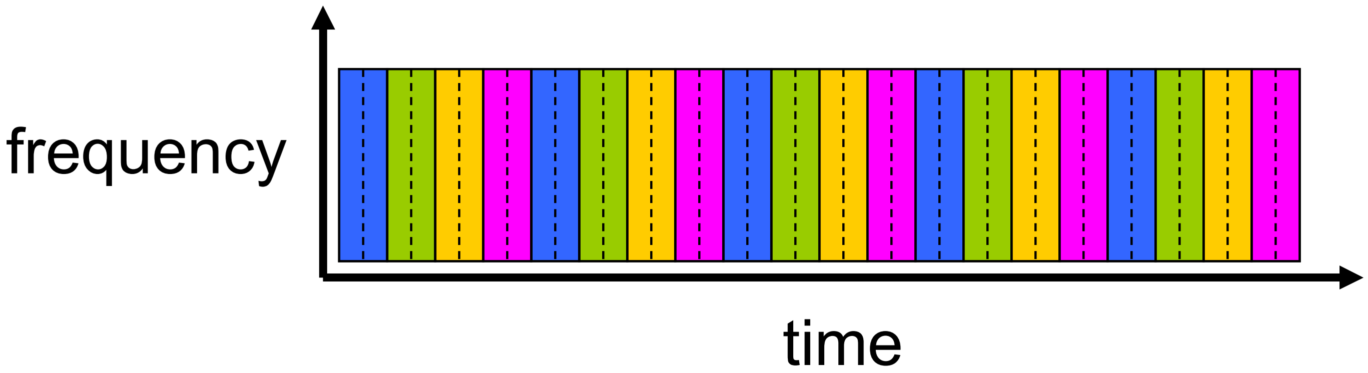
Example:

4 users

FDM



TDM



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 Mb/s**
  - **Each link uses TDM with 24 slots**
  - **500 ms to establish end-to-end circuit**

Work it out!

Another 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 FDM with 24 hannels/frequencies**
  - **500 msec to establish end-to-end circuit**

Work it out!

Network Core: Packet Switching

each end-end data stream divided into packets

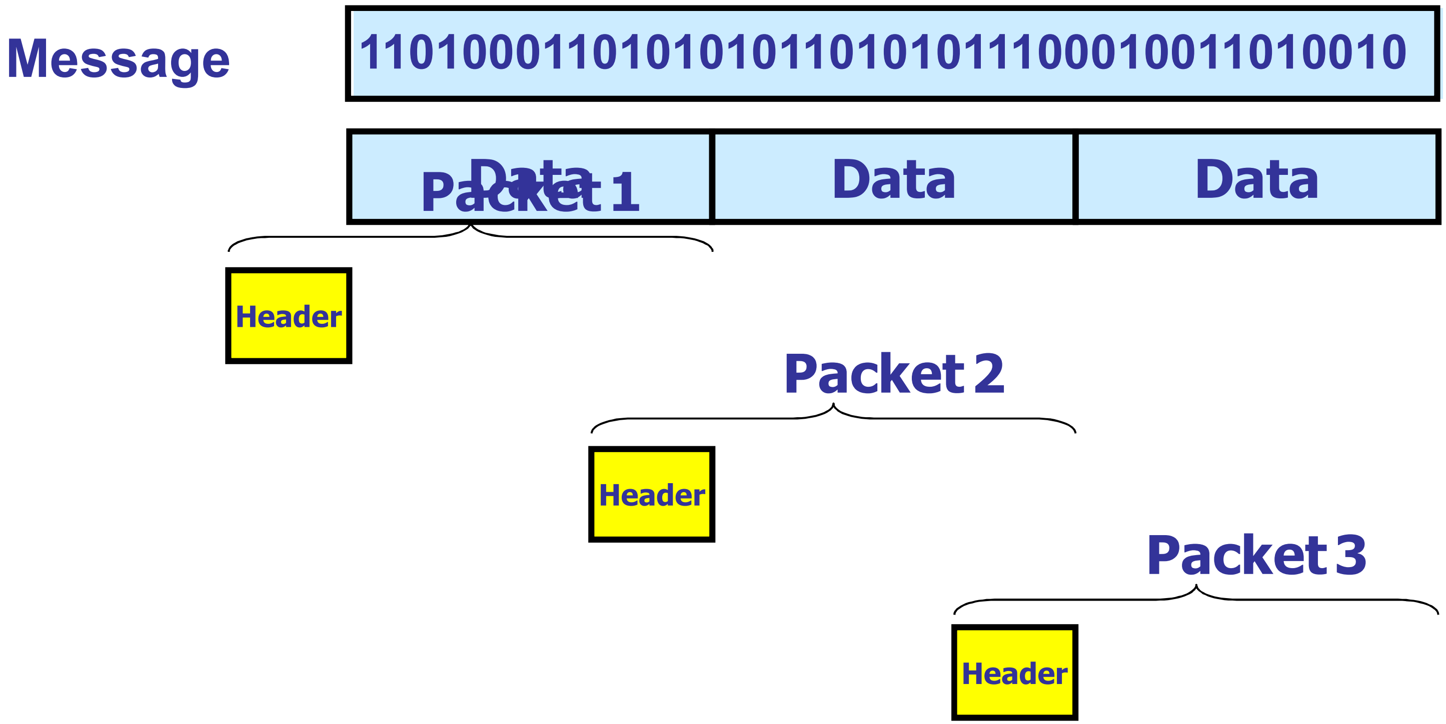
Header and Trailer carry control information (e.g., destination address, checksum)

- Each packet traverses the network from node to node along some path (**Routing**) based on header info.
- Usually, once a node receives the **entire** packet, it stores it (hopefully briefly) and then forwards it to the next node (**Store-and-Forward Networks**)

Build Packets

The sender first divides the message into shorter, fixed-length data segments

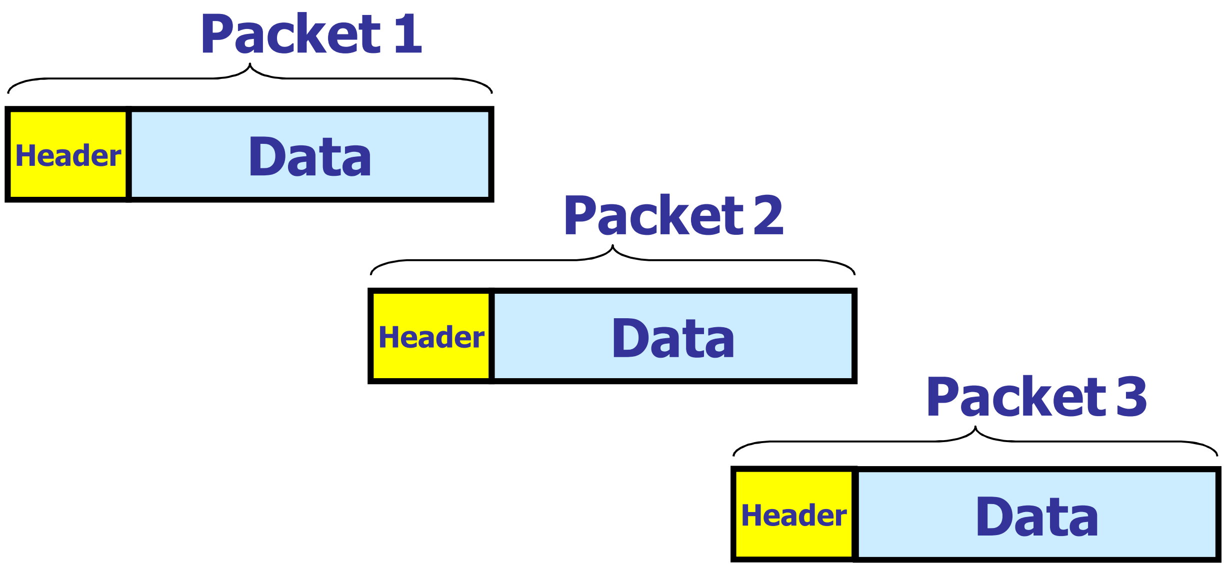
Then a header is added in front of each data segment to form a packet.



Send Packets

Send each packet to the receiver (assuming the receiver is on the left).

Packet-switched networks use "packets" as data transmission units.

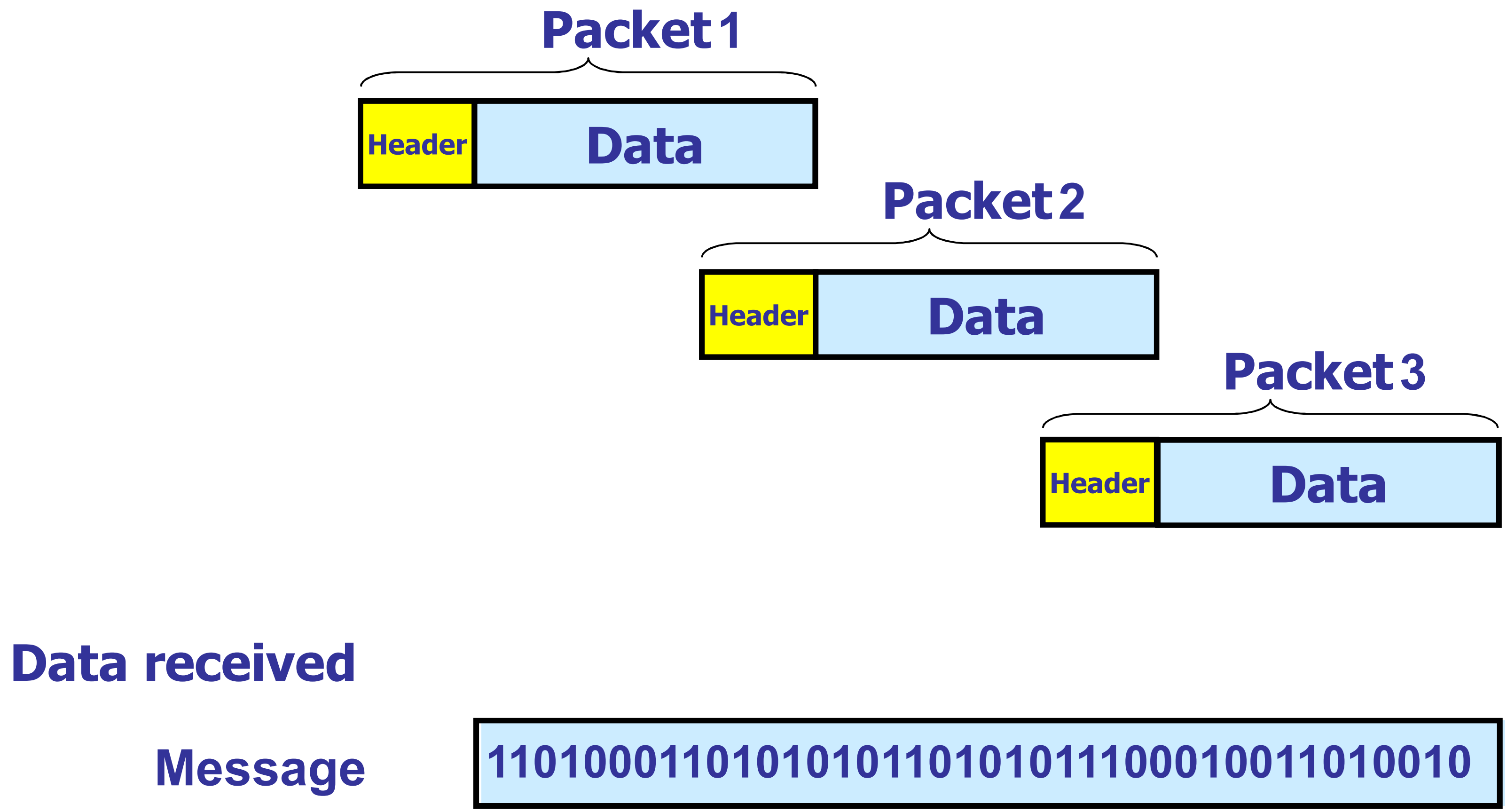


The header is very important

- Headers are used to control the flow of packets through the network or over the communication link.
- The header contains control information, such as:
  - Addresses: source and destination,
  - Sequence number,
  - Protocol version, total length, etc.
- The switch in the packet-switched network forwards the packet to the next switch based on the address information in the header of the received packet.

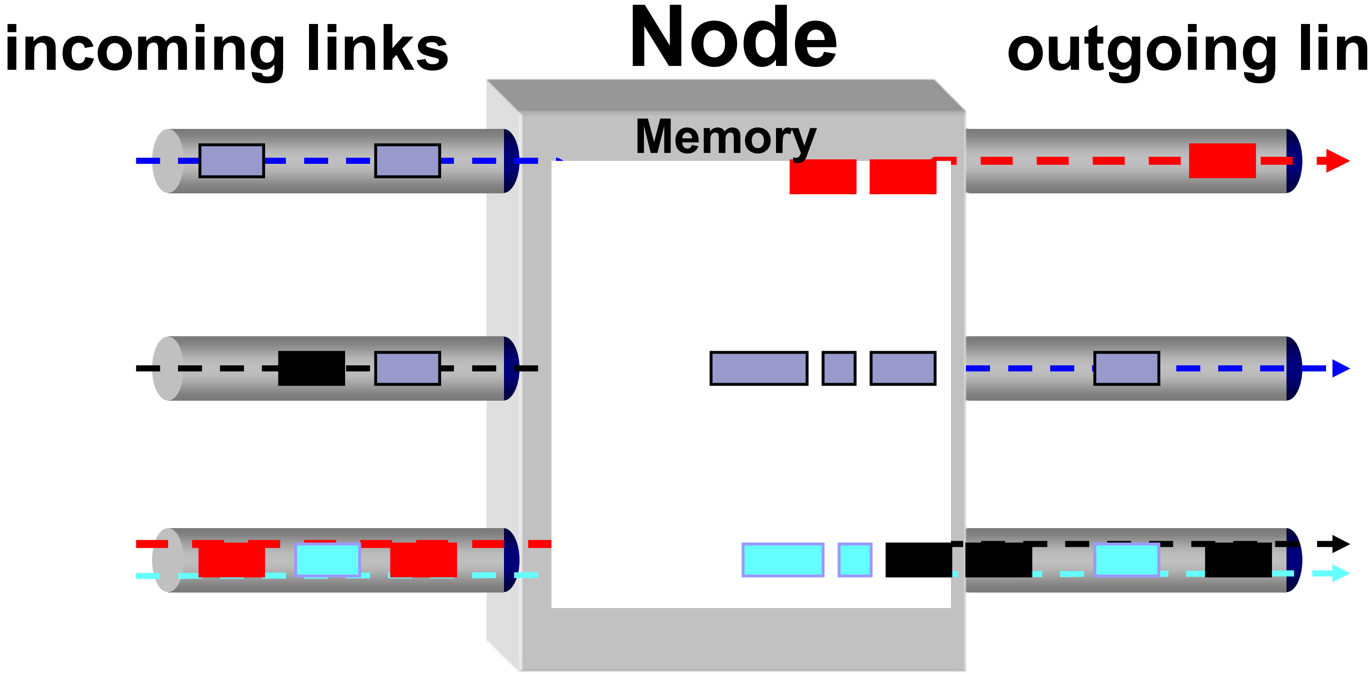
Restore to Message

After receiving the packet, the receiver strips off the header of the packet, and obtains the data, then restores data to a message.



Network Core: Packet Switching

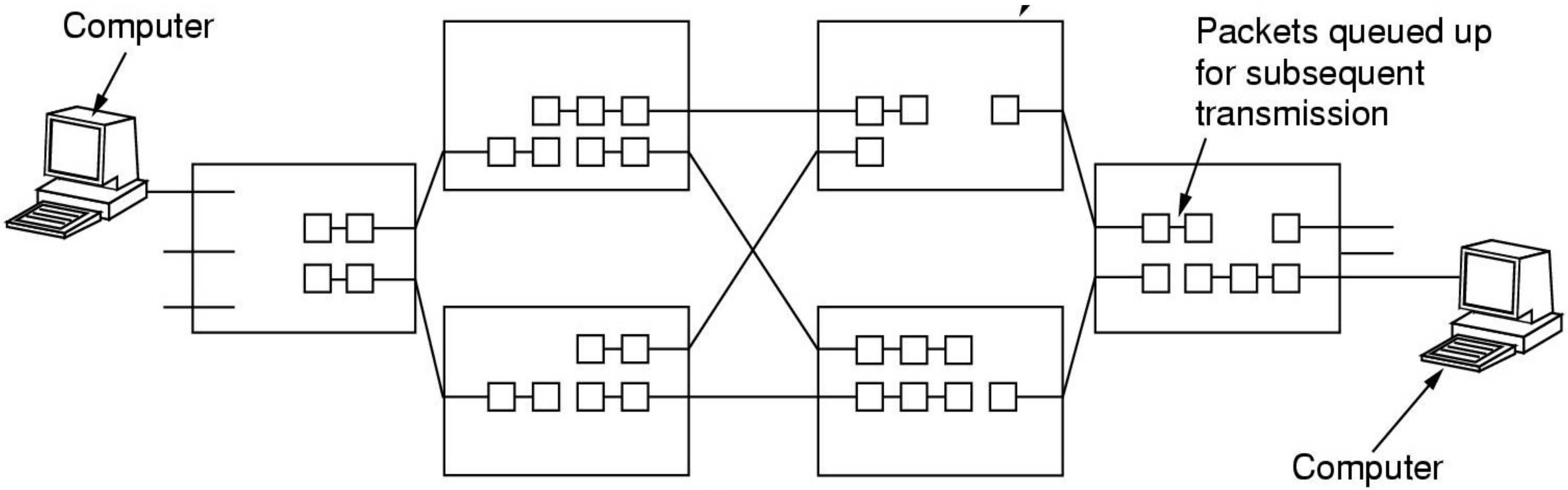
- **Node in a packet switching network**



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

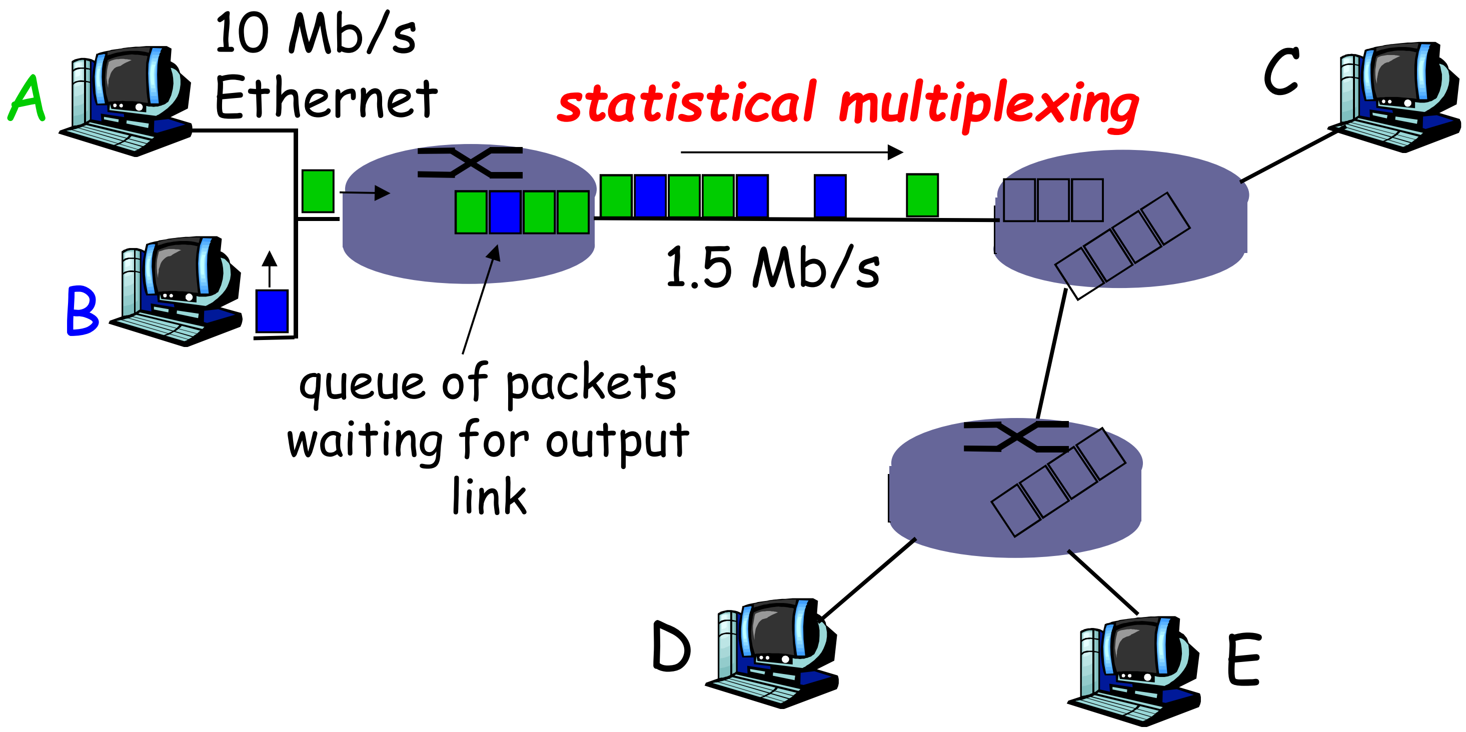
Network Core: Packet Switching

- **Node in a packet switching network**



(b)

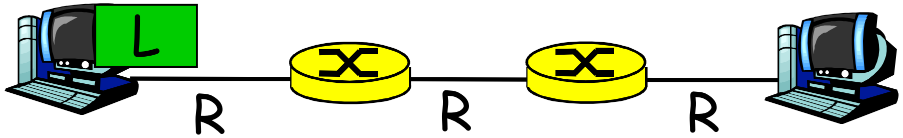
Packet Switching: Statistical Multiplexing



Sequence of A & B packets does not have fixed pattern
➔ ***statistical multiplexing***.

In TDM each host gets same slot in revolving TDM frame.

Packet-switching: store-and-forward

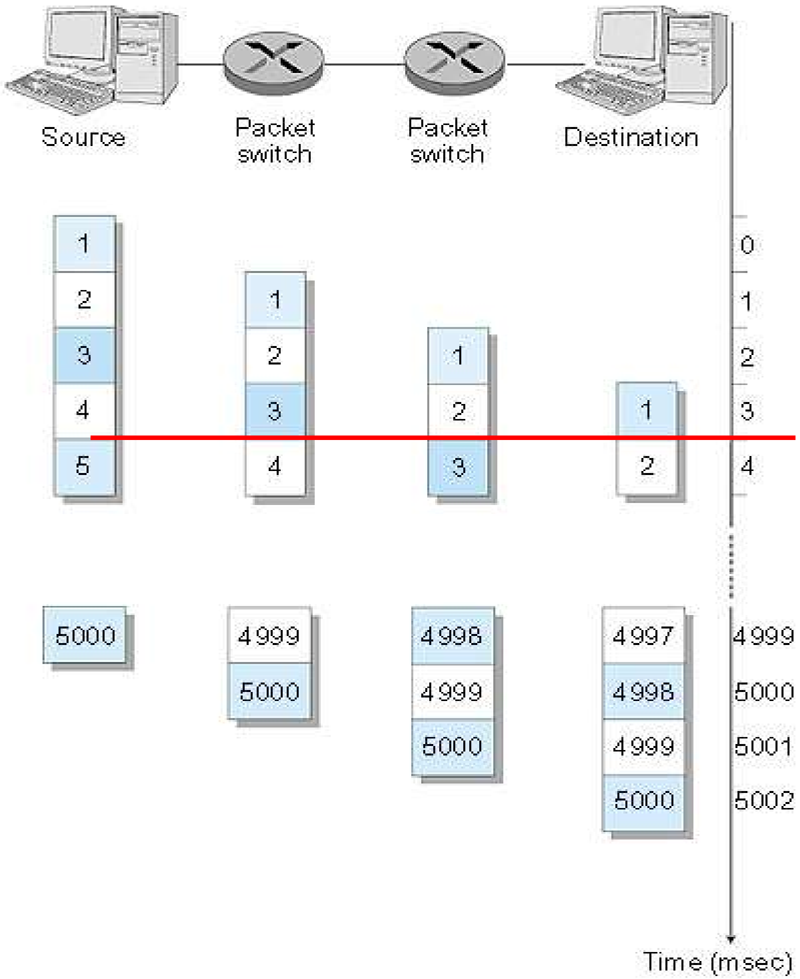


- Takes *L/R* seconds to transmit (push out) packet of *L* bits on to link or *R* b/s
- Entire packet must arrive at router before it can be transmitted on next link: ***store and forward***
- delay = *3*L/R*

Example:

- *L* = 7.5 Mbits
- *R* = 1.5 Mb/s
- delay = 15 sec

Packet Switching: Message Segmenting



Now break up the message into 5000 packets

- Each packet 1,500 bits
- 1 msec to transmit packet on one link
- *pipelining:* each link works in parallel
- Delay reduced from 15 sec to 5.002 sec

If you were building a network….

- **Which would you choose?**
  - Circuit switched?
  - Packet-switched?

- Let's review the strengths and weaknesses

Advantages of Circuit Switching

- **Guaranteed bandwidth**
  - Predictable communication performance
  - Not "best-effort" delivery with no real guarantees
- **Simple abstraction**
  - Reliable communication channel between hosts
  - No worries about lost or out-of-order packets
- **Simple forwarding**
  - Forwarding based on time slot or frequency
  - No need to inspect a packet header
- **Low per-packet overhead**
  - Forwarding based on time slot or frequency
  - No headers on each packet

Disadvantages of Circuit Switching

- **Wasted bandwidth**
  - Bursty traffic leads to idle connection during silent period
  - Unable to achieve gains from “statistical multiplexing”
- **Blocked connections**
  - Connection refused when resources are not sufficient
  - Unable to offer “okay” service to everybody
- **Network state**
  - Network nodes must store per-connection information
  - Unable to avoid per-connection storage and state
  - This makes failures more disruptive!
- **Connection set-up delay**
  - No communication until the connection is set up
  - Unable to avoid extra latency for small data transfers

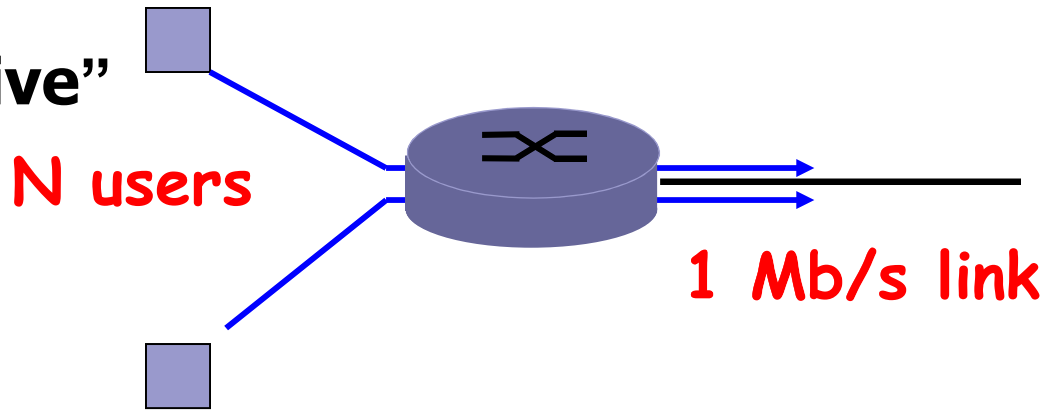
Packet-Switching vs. Circuit-Switching

- **Reliability advantage:** since routers don't know about individual conversations, when a router or link fails, it is easy to fail over to a different path
- **Efficiency advantage** of packet-switching over circuit switching: Exploitation of statistical multiplexing
- **Deployability advantage:** easier for different parties to link their networks together because they're not promising to reserve resources for one another
- **Disadvantage:** packet-switching must handle congestion
  - More complex routers (more buffering, sophisticated dropping)
  - Harder to provide good network services (e.g., delay and bandwidth guarantees)

Packet switching vs. 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 that .004



Packet switching vs. circuit switching

	circuit switching	packet switching
resource	**partitioned**	**not partitioned**
when using resource	**use a single partition bandwidth**	**use whole link bandwidth**
reservation/setup	**need reservation (setup delay)**	**no reservation**
resource contention	**busy signal (session loss)**	**congestion (long delay and packet losses)**
service guarantee	**yes**	**no**
charging	**time**	**packet**
header	**no header**	**per packet header**
fast path processing	**fast**	**per packet processing**

Packet switching vs. circuit switching

Is packet switching a "slam dunk winner?"

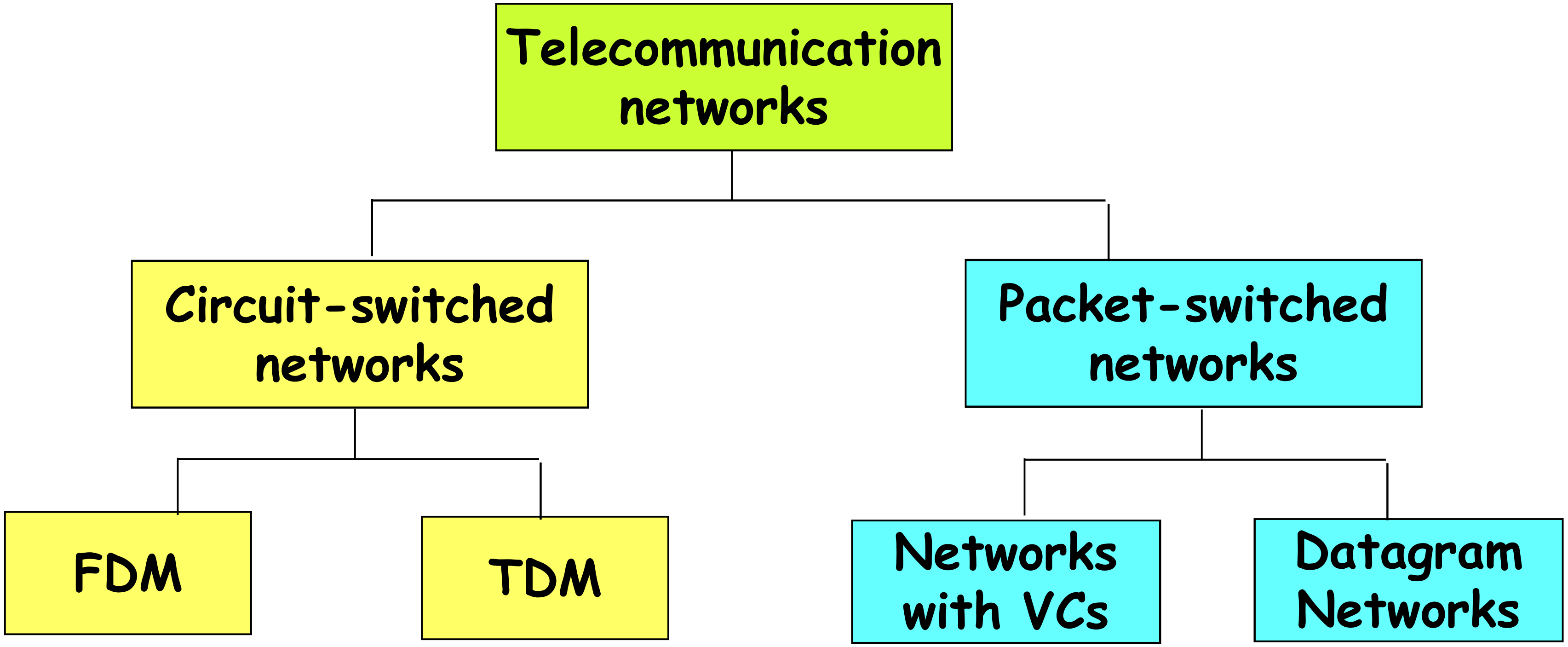
- Great for bursty data
  - resource sharing - go as fast as you can and then get out of the way
  - simpler, no call setup
- **Excessive congestion:** packet delay and loss
  - protocols needed for reliable data transfer, congestion control
- **Q: How to provide circuit-like behavior?**
  - prioritization
  - 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)?

Packet-switched networks: routing & forwarding

- ***Goal:*** move packets among routers from source to destination
  - we'll study several path selection algorithms.
- **datagram network:**
  - ***destination address*** determines next hop
  - **routes may change during session**
  - analogy: driving, asking directions
- **virtual circuit network:**
  - each packet carries tag (virtual circuit ID), *tag* determines next hop
  - **fixed path** determined at *call setup time*, remains fixed thru call
  - **routers maintain per-call state**

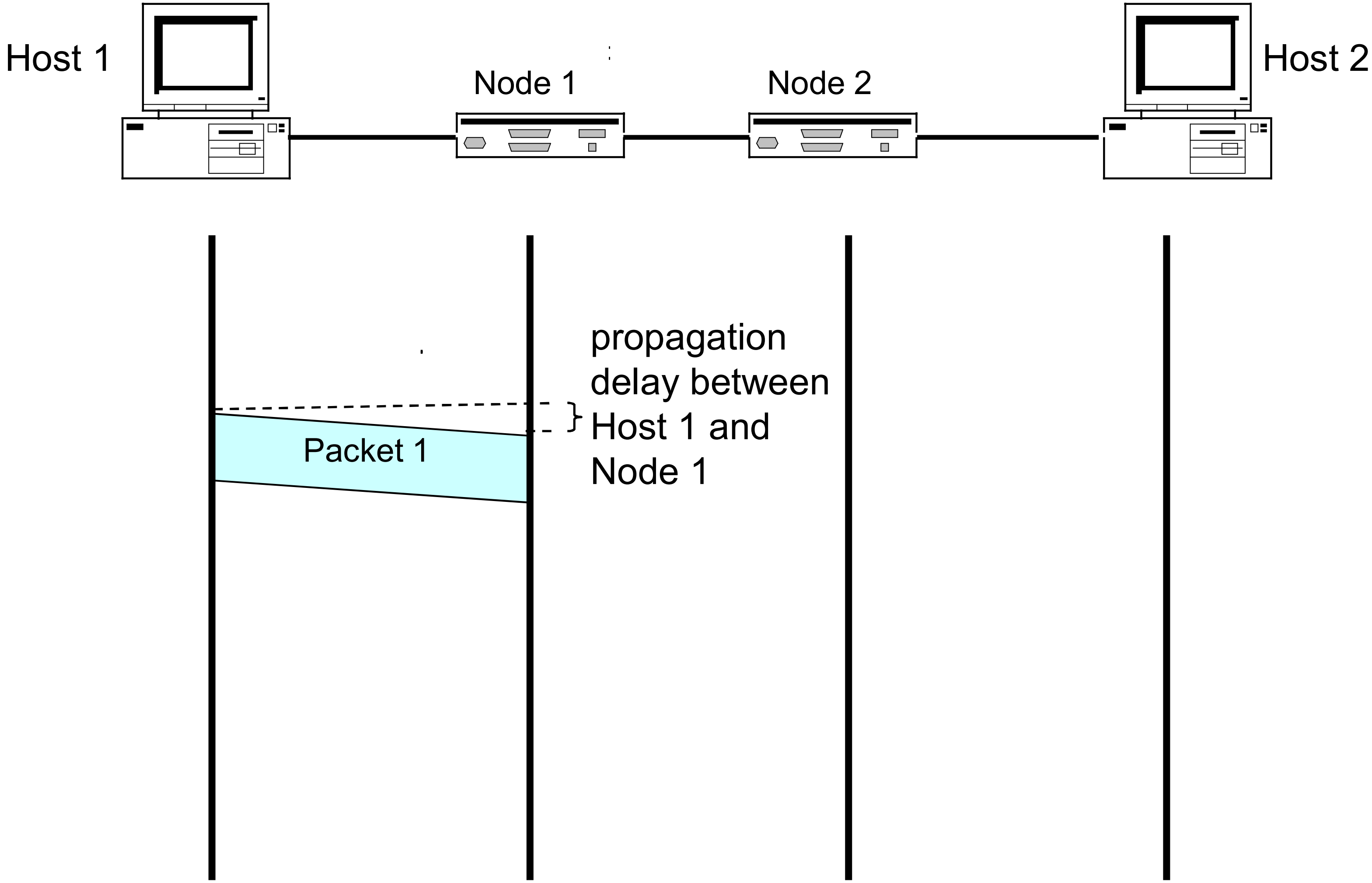
Network Taxonomy



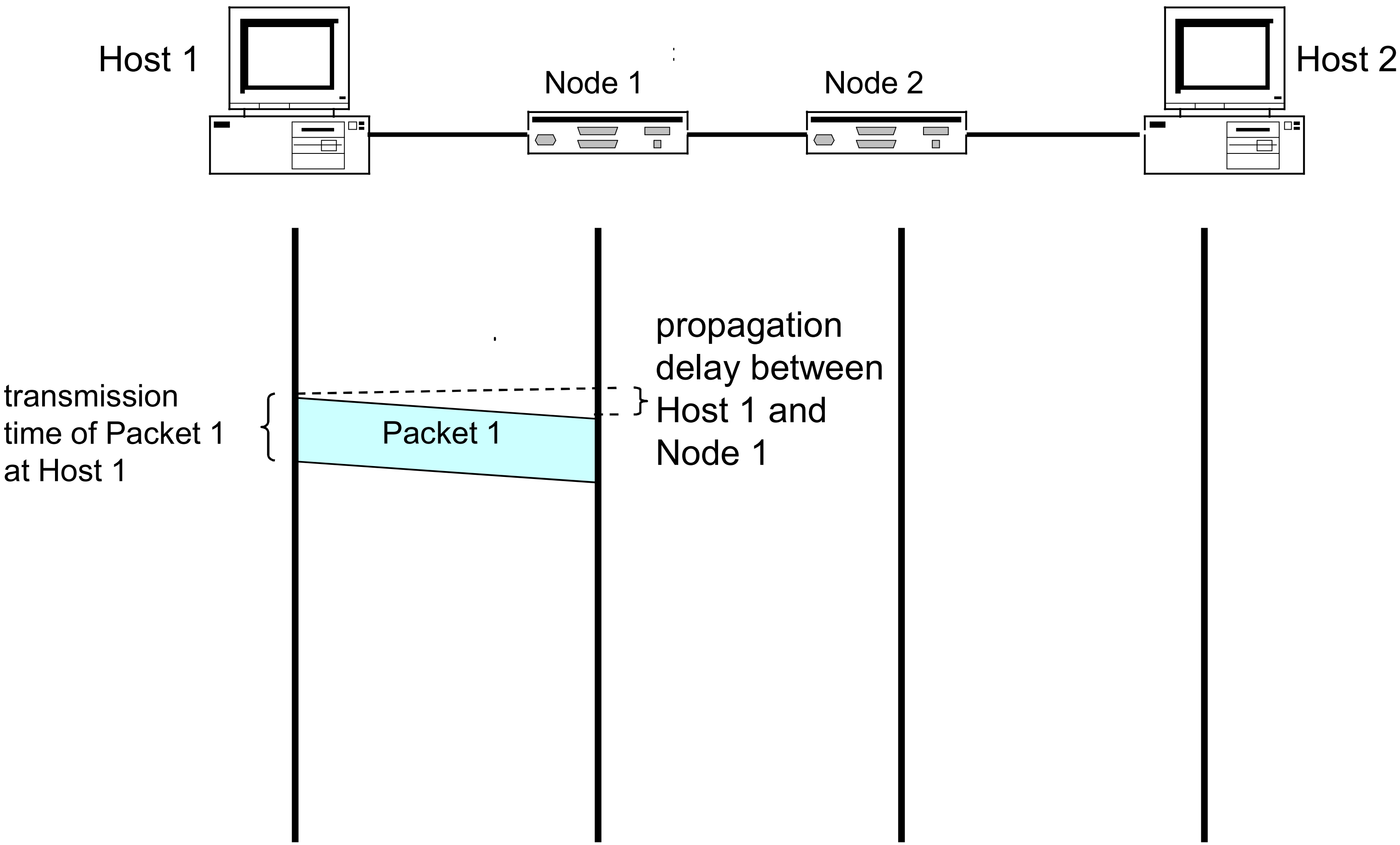
Datagram Packet Switching

- **Each packet is independently switched**
  - Each packet header contains full destination address
- **No resources are pre-allocated (reserved) in advance**
- **Leverages "statistical multiplexing"**
  - Gambling that packets from different conversations won't all arrive at the same time, so we don't need enough capacity for all of them at their peak transmission rate
  - *Assuming independence of traffic sources*, can compute probability that there is enough capacity

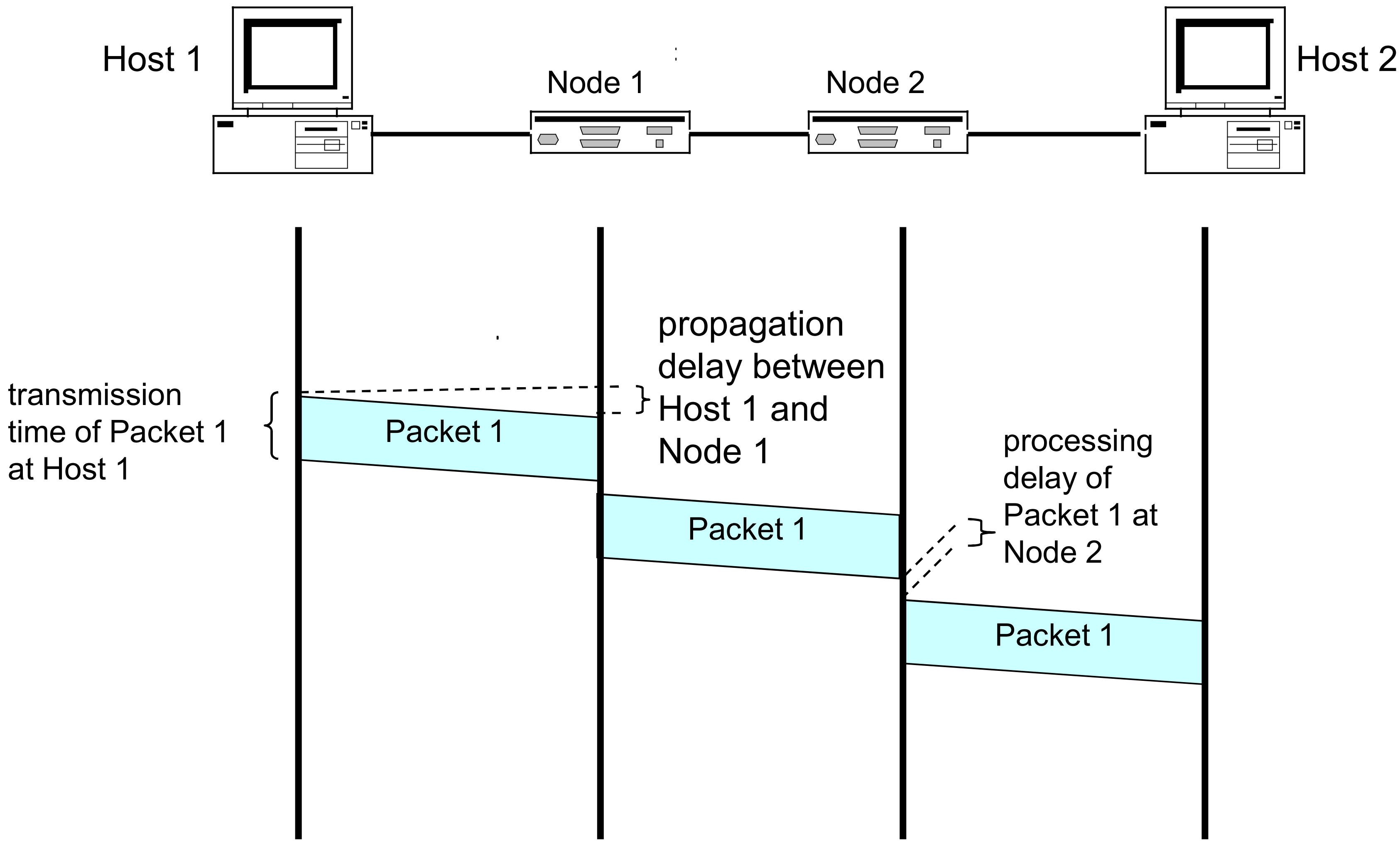
Timing of Datagram Packet Switching



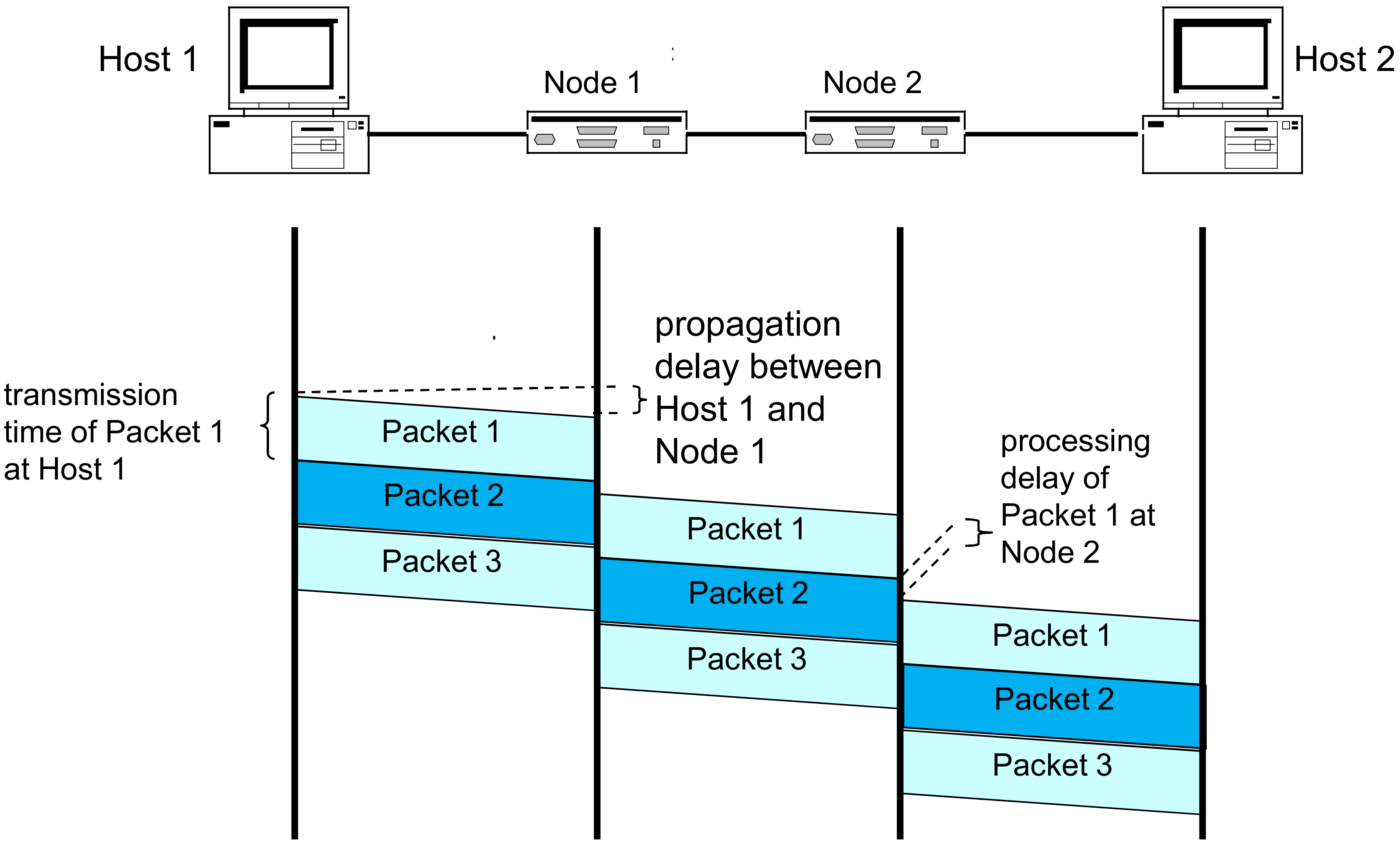
Timing of Datagram Packet Switching



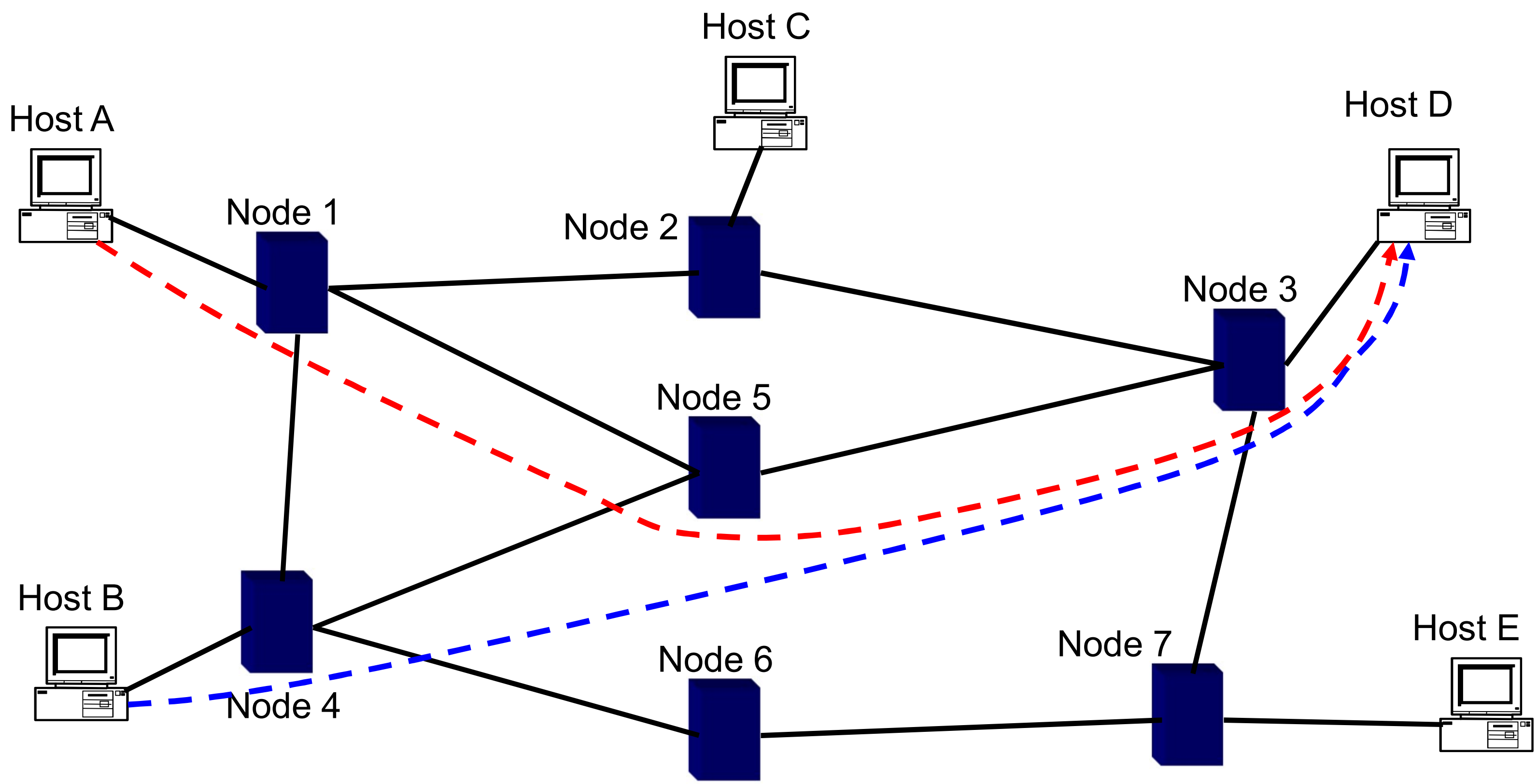
Timing of Datagram Packet Switching



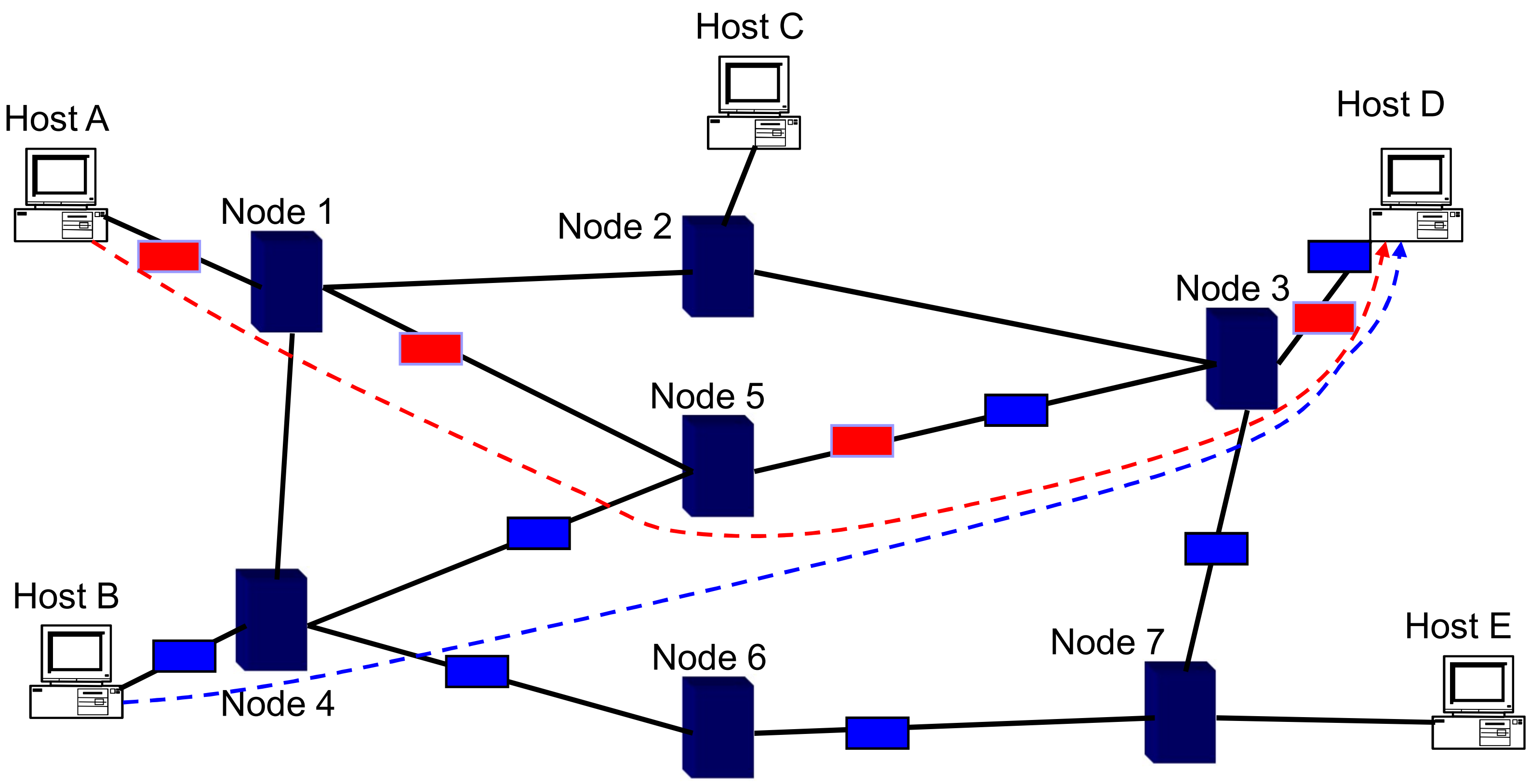
Timing of Datagram Packet Switching



Datagram Packet Switching



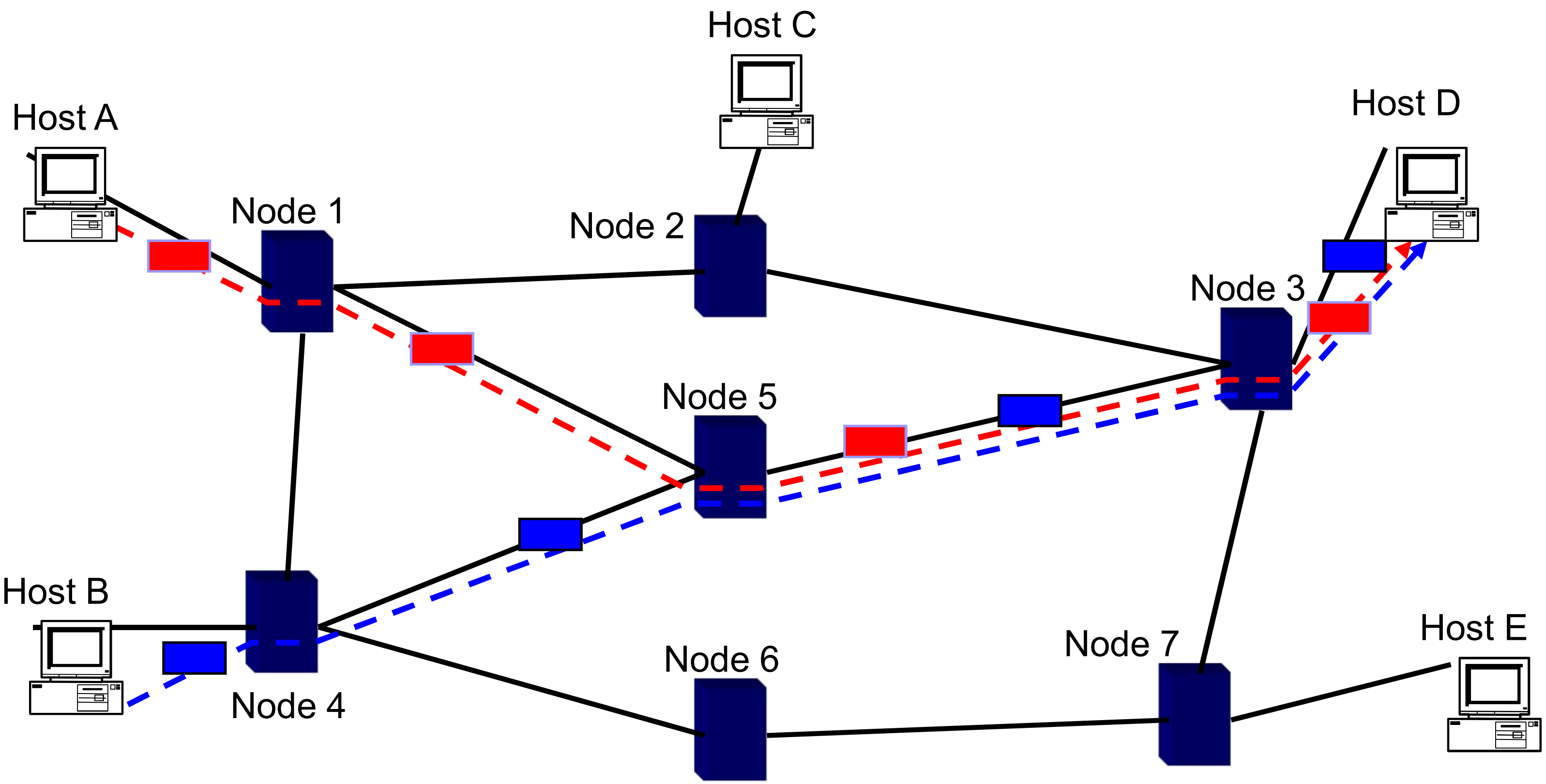
Datagram Packet Switching



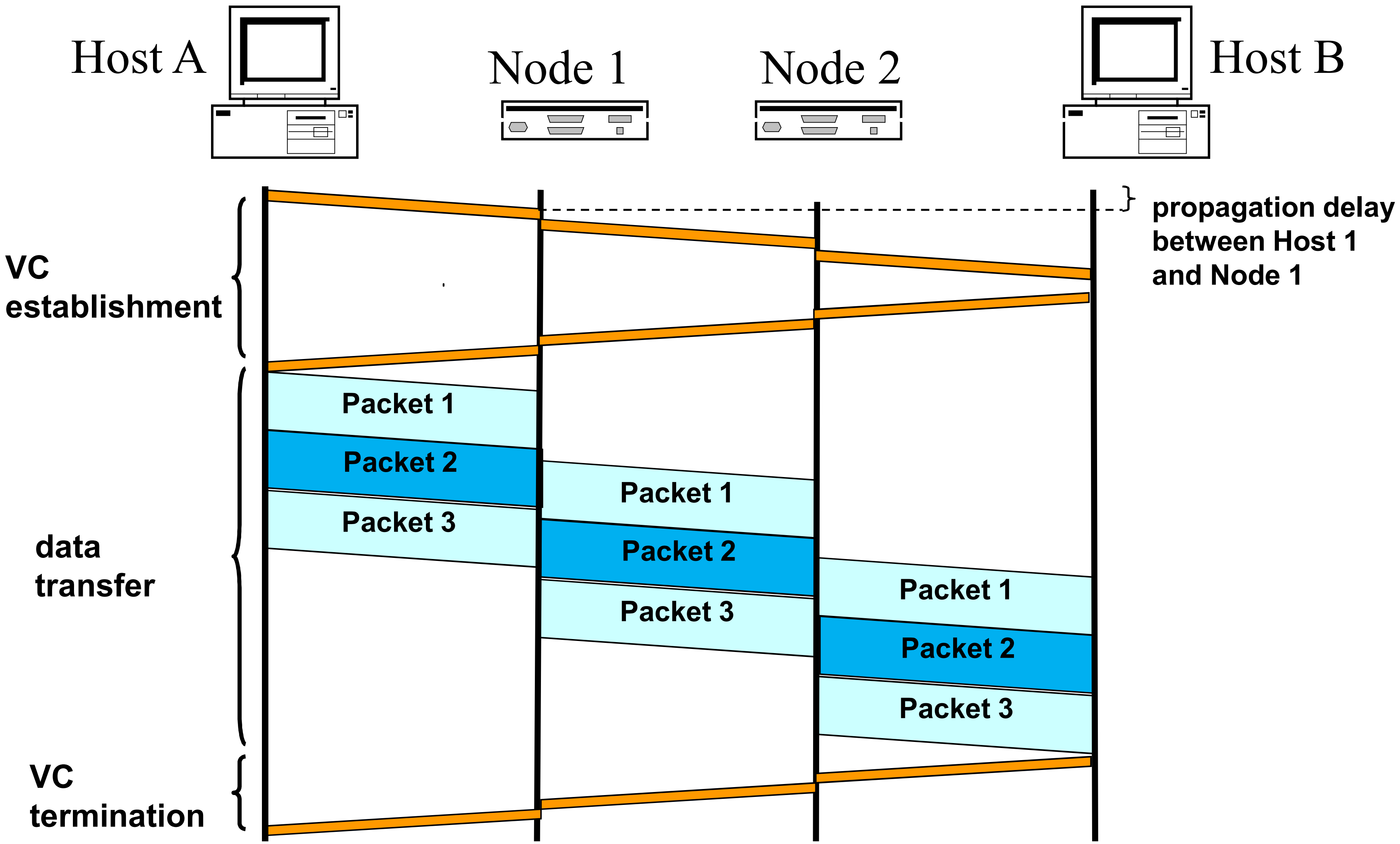
Virtual-Circuit Packet Switching

- **Fixed path** determined at *call setup time*, remains fixed thru call
- **Routers maintain per-call state**
- **3 phases:**
  1. VC establishment
  2. Data transfer
  3. VC disconnect

Virtual-Circuit Packet Switching



Timing Diagram of Virtual-Circuit Switching



Questions

- **Network edge vs. network core: What's the difference?**
- **Network edge vs. edge computing: What's the difference?**

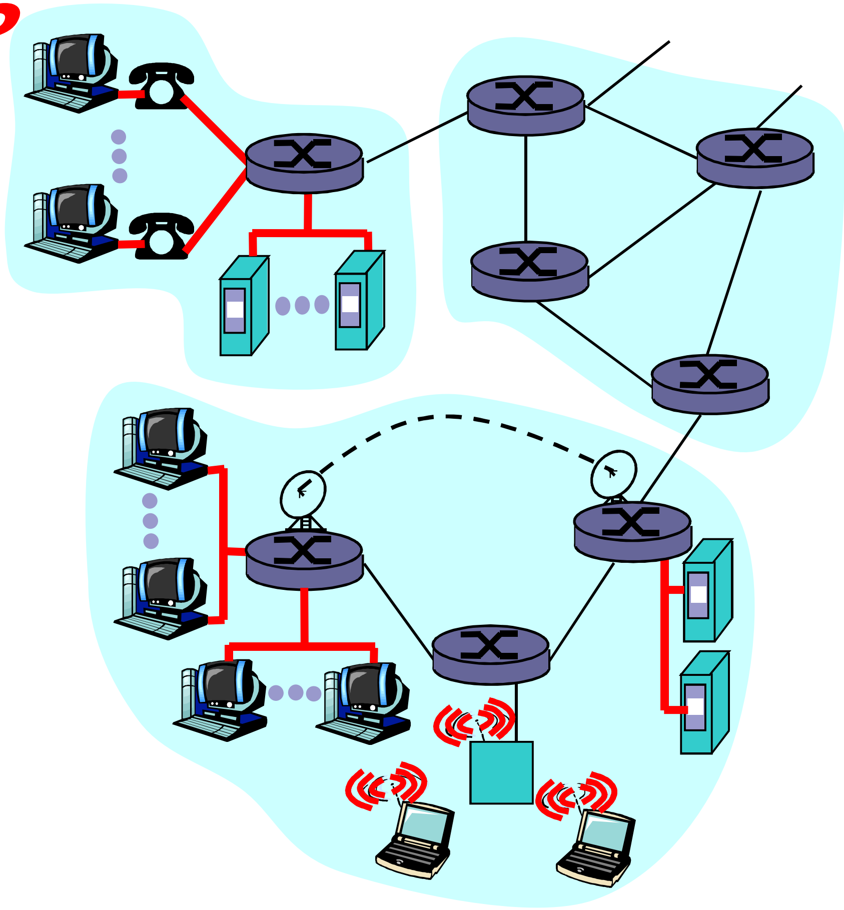
Chapter 1: Roadmap

1.1 Computer network and the Internet
1.2 Network edge and core
1.3 Network access and physical media
1.4 Transmission Technology
1.5 Type and Topology
1.6 Network Performance
1.7 Protocol layers, service models
1.8 Architecture, OSI and TCP/IP Models
1.9 Internet History

Access networks and physical media

Q: How to connect end systems to edge router?

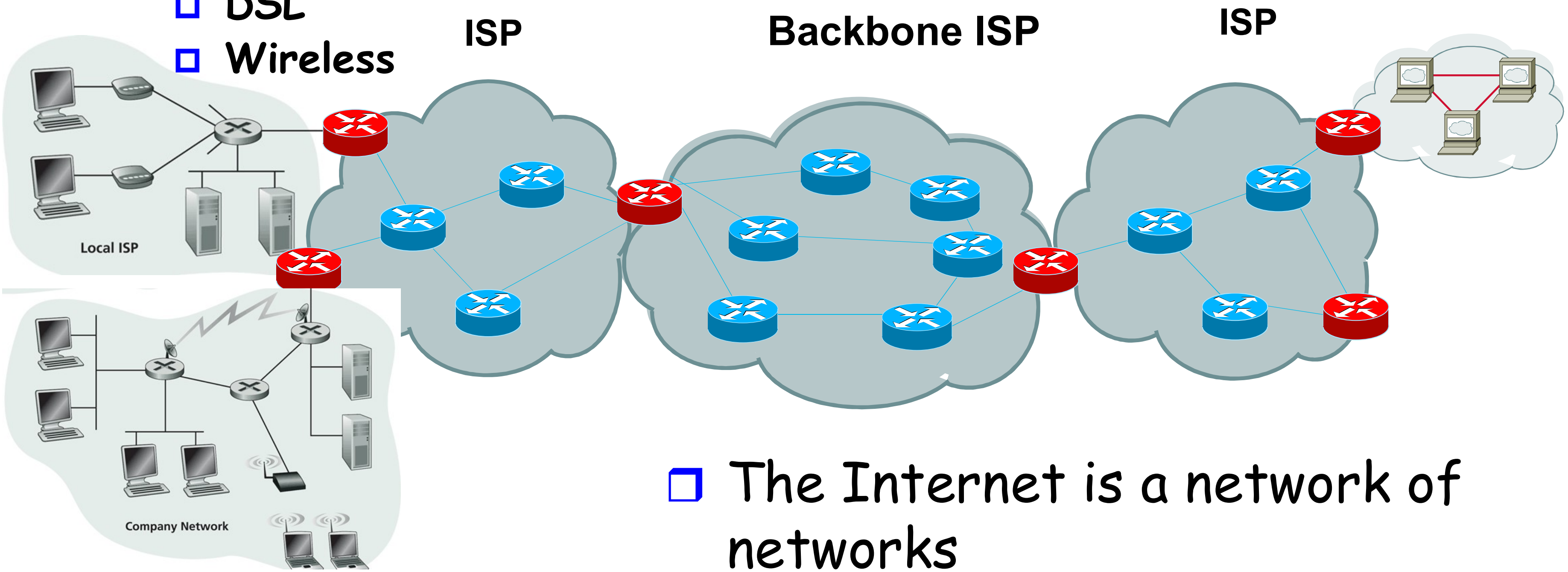
- residential access nets
- institutional access networks (school, company)
- mobile access networks



Internet Physical Infrastructure

Residential access

- Cable
- Fiber
- DSL
- Wireless



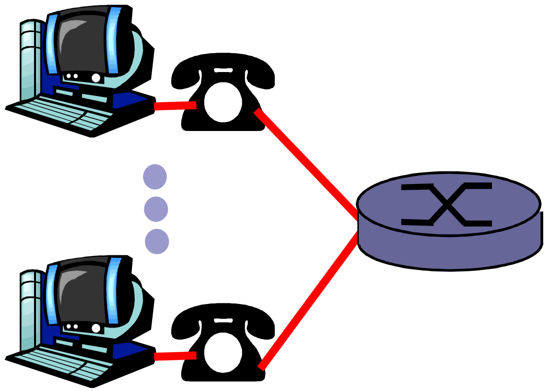
Campus access, e.g.,

- Ethernet
- Wireless

- The Internet is a network of networks
- Each individually administrated network is called an **Autonomous System (AS)**

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"



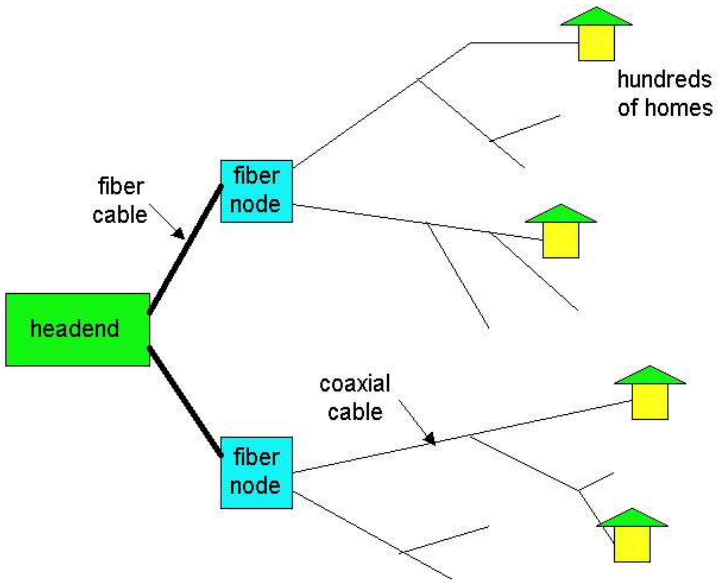
- ADSL: asymmetric digital subscriber line
  - up to 1 Mb/s upstream (today typically < 256 kb/s)
  - up to 8 Mb/s downstream (today typically < 1 Mb/s)
  - FDM: 50 kHz - 1 MHz for downstream

    4 kHz - 50 kHz for upstream

    0 kHz - 4 kHz for ordinary telephone

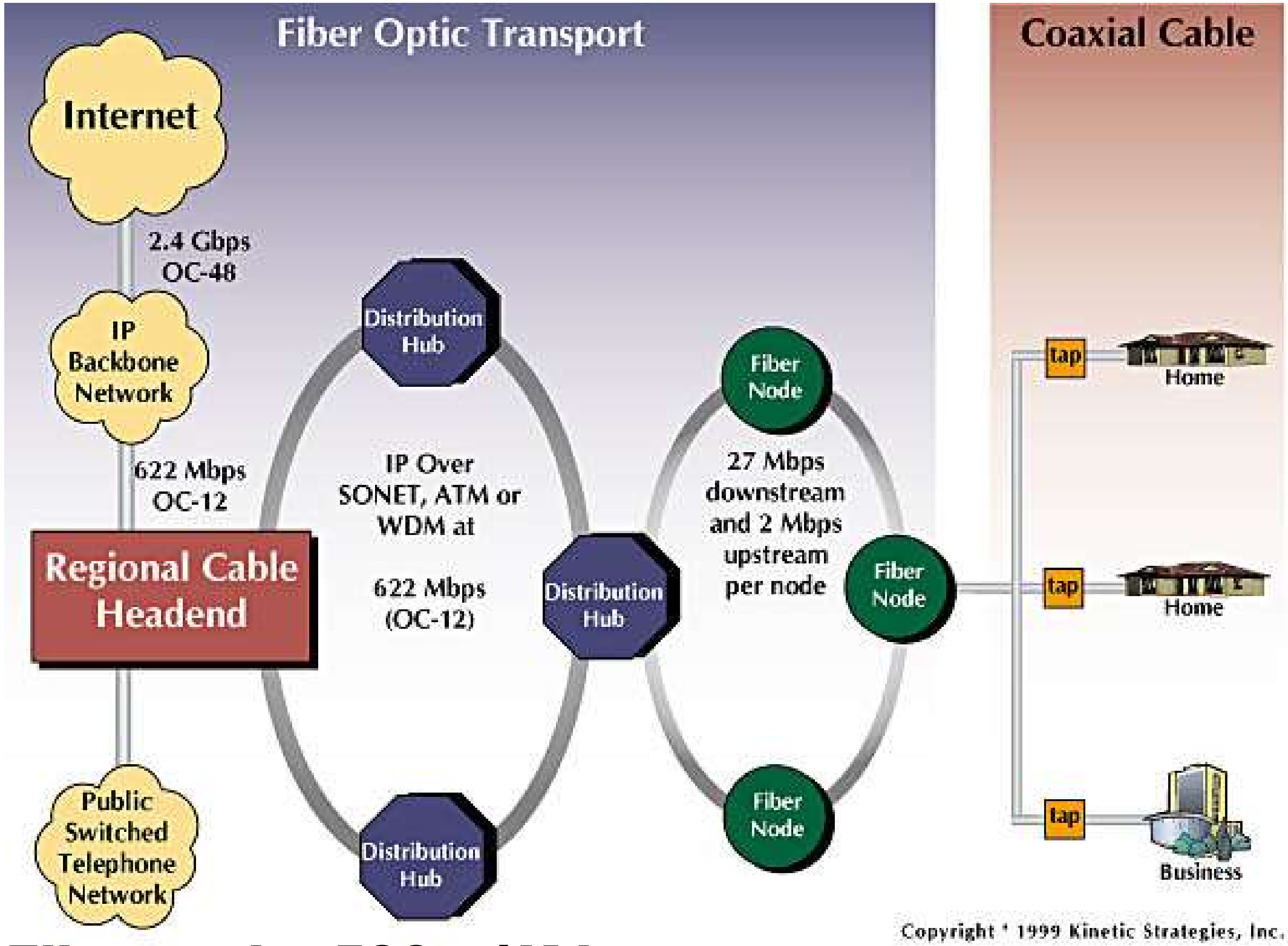
Residential access: Cable modems

- HFC: hybrid fiber coax
  - asymmetric: up to 30Mbps downstream, 2 Mbps upstream
- network of cable and fiber attaches homes to ISP router
  - shared access to router among home
  - issues: congestion, dimensioning



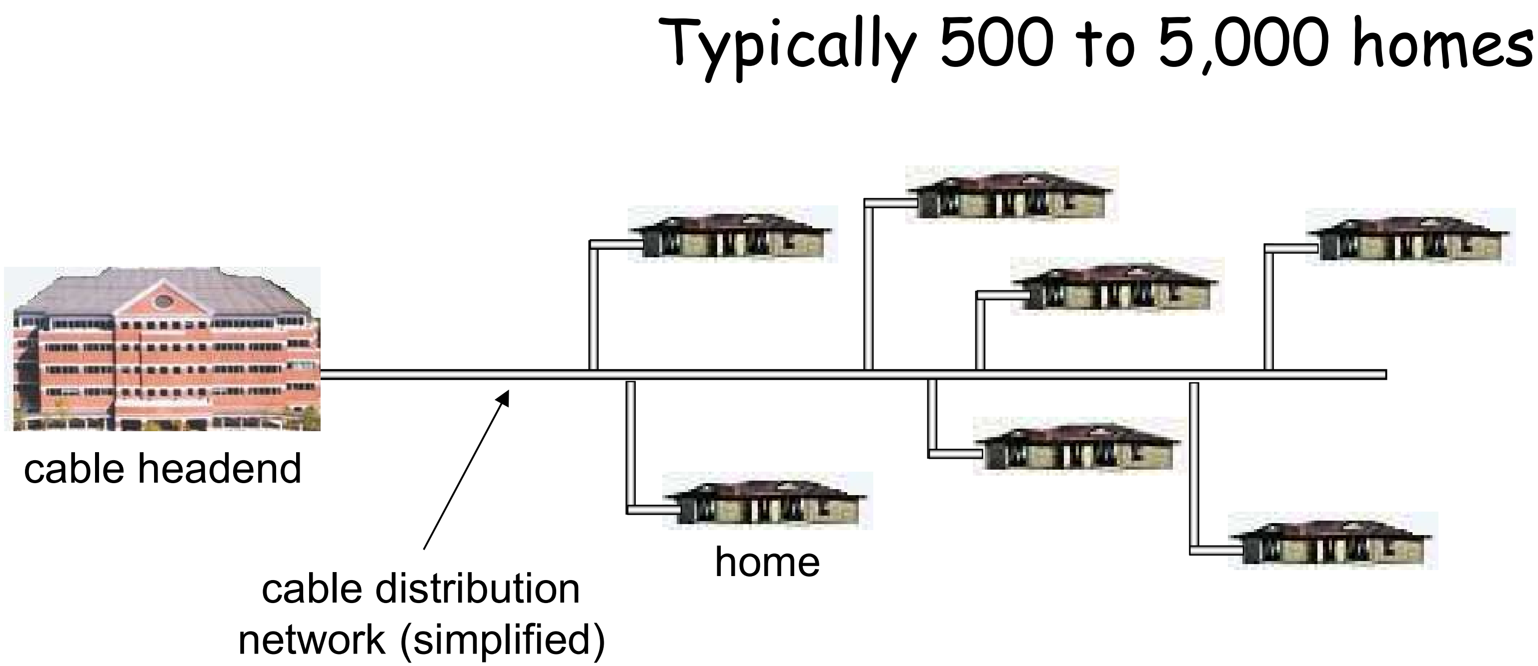
- Deployment: available via cable companies

Residential access: Cable modems

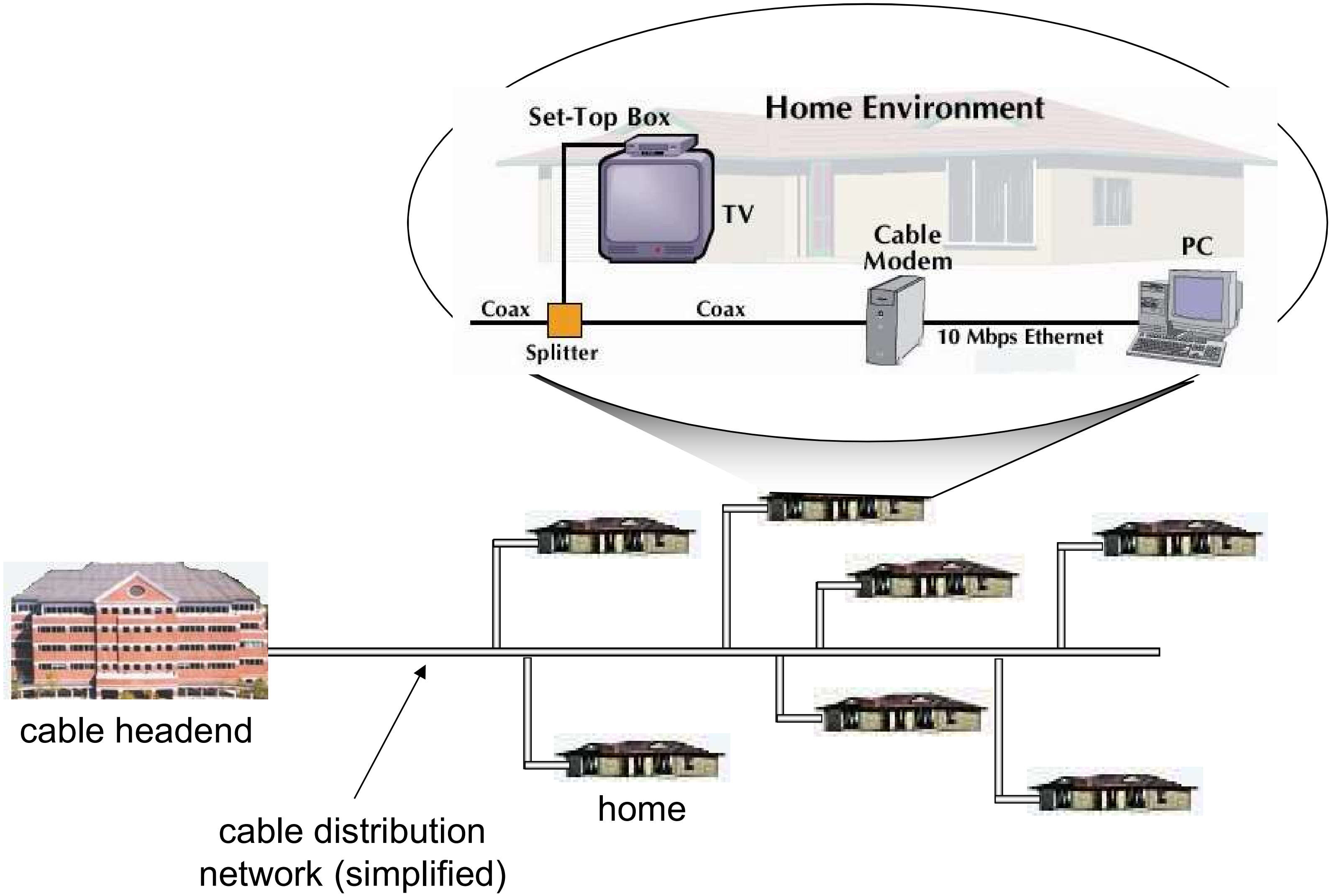


- **Fiber node: 500 - 1K homes**
- **Distribution hub: 20K - 40 K homes**
- **Regional headend: 200 K - 400 K homes**

Cable Network Architecture: Overview



Cable Network Architecture: Overview



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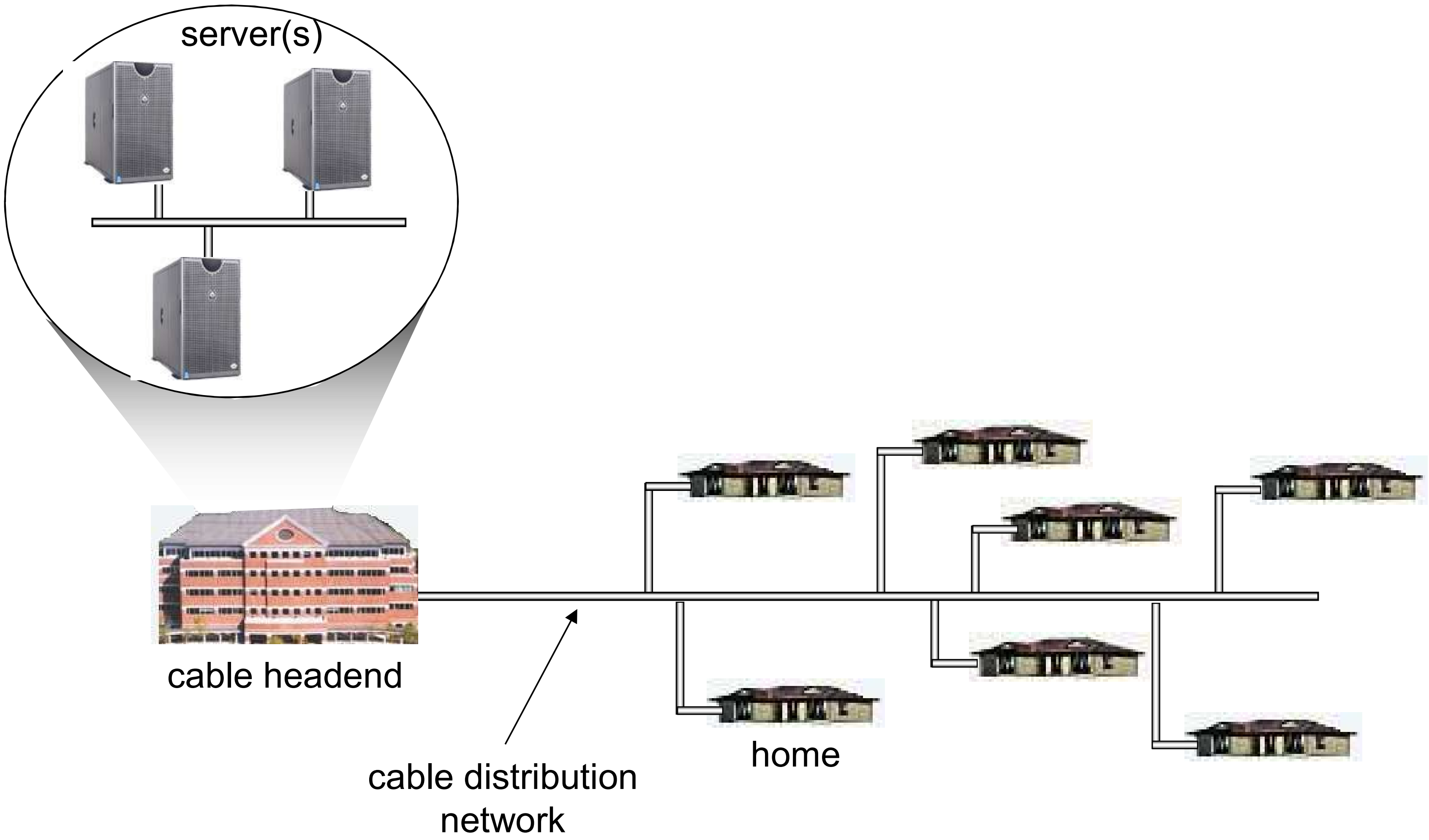

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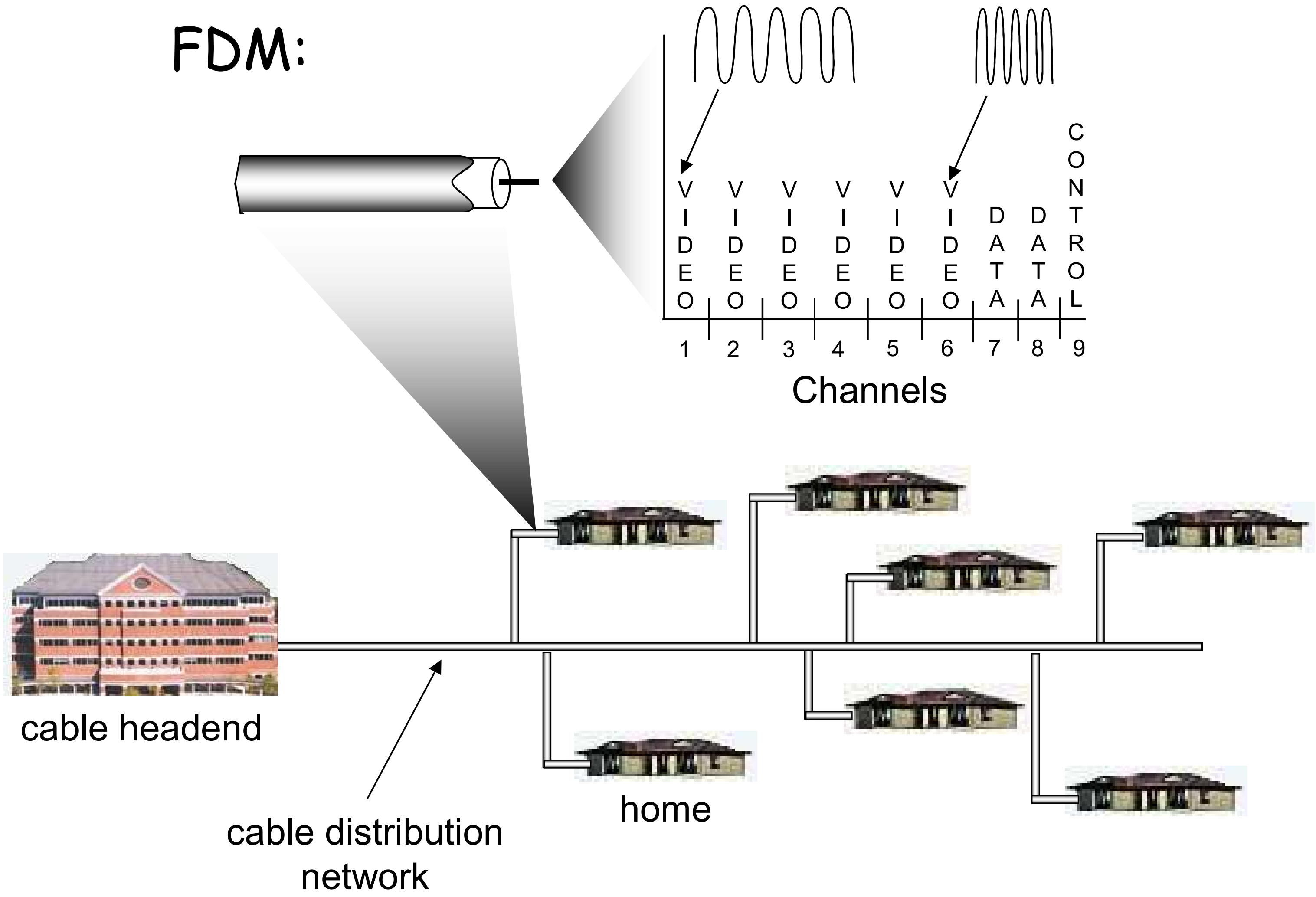
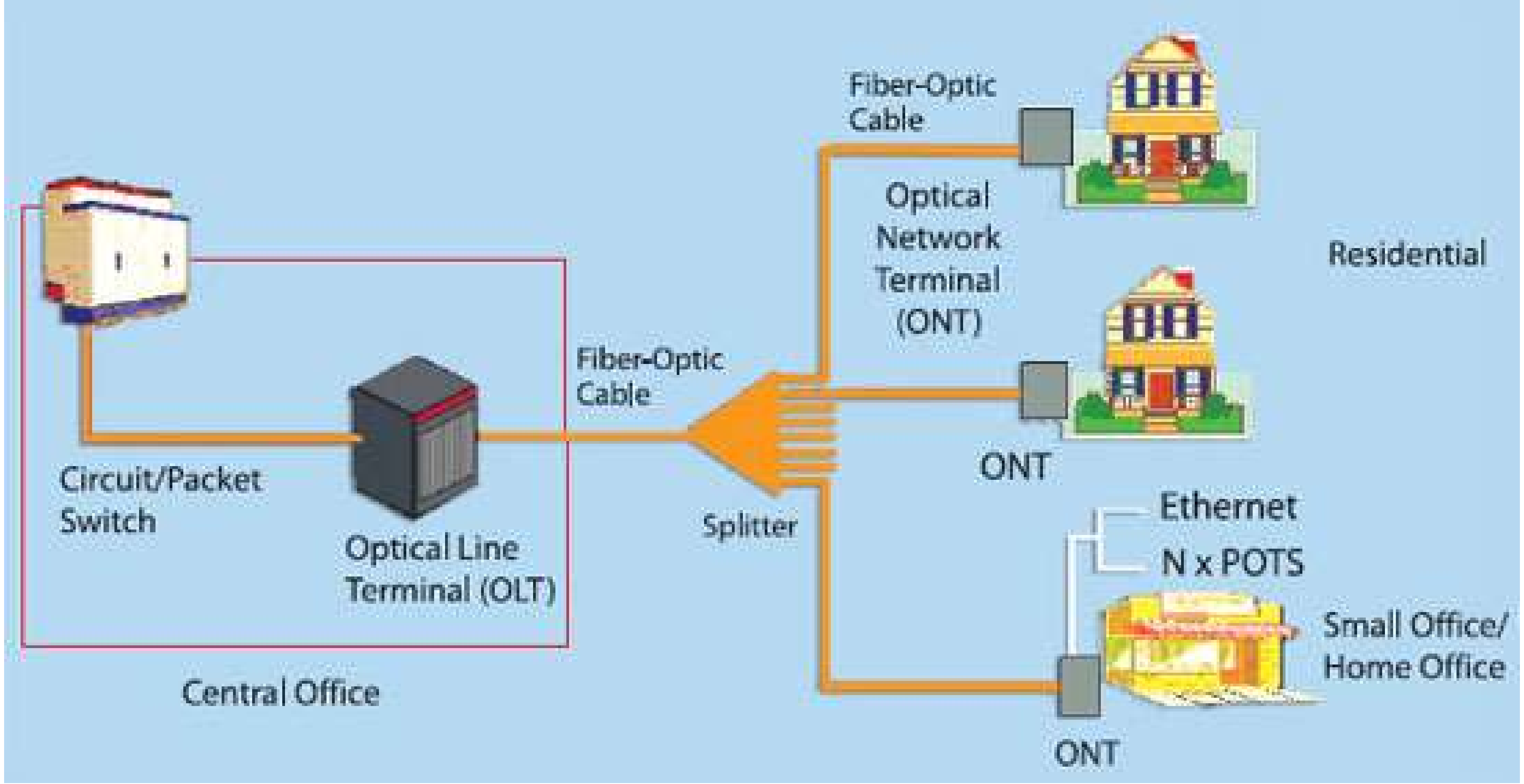


Residential Access: Fiber to the Premises (FTTP)

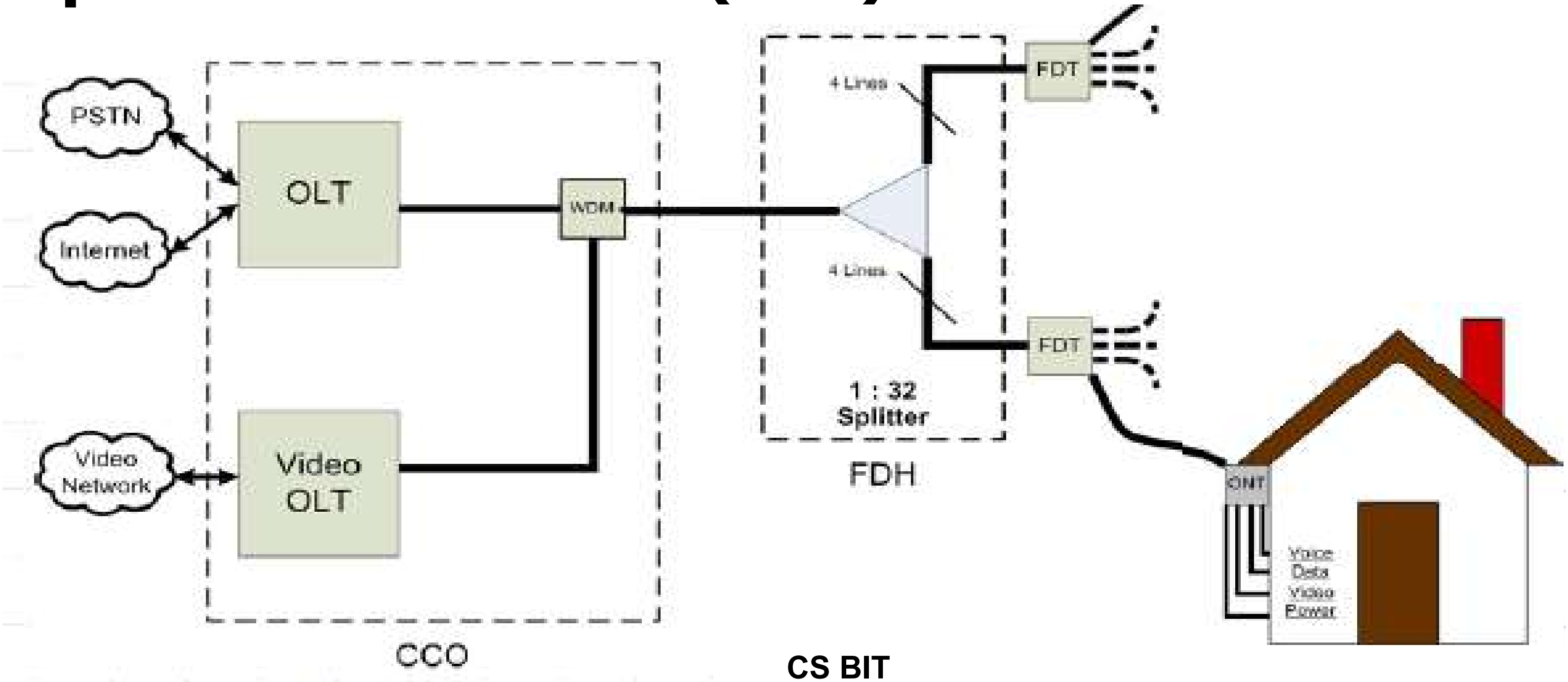
- Deployed by Verizon (all locations) and AT&T (new build areas)
- One of the largest comm. construction projects

FTTP Architecture

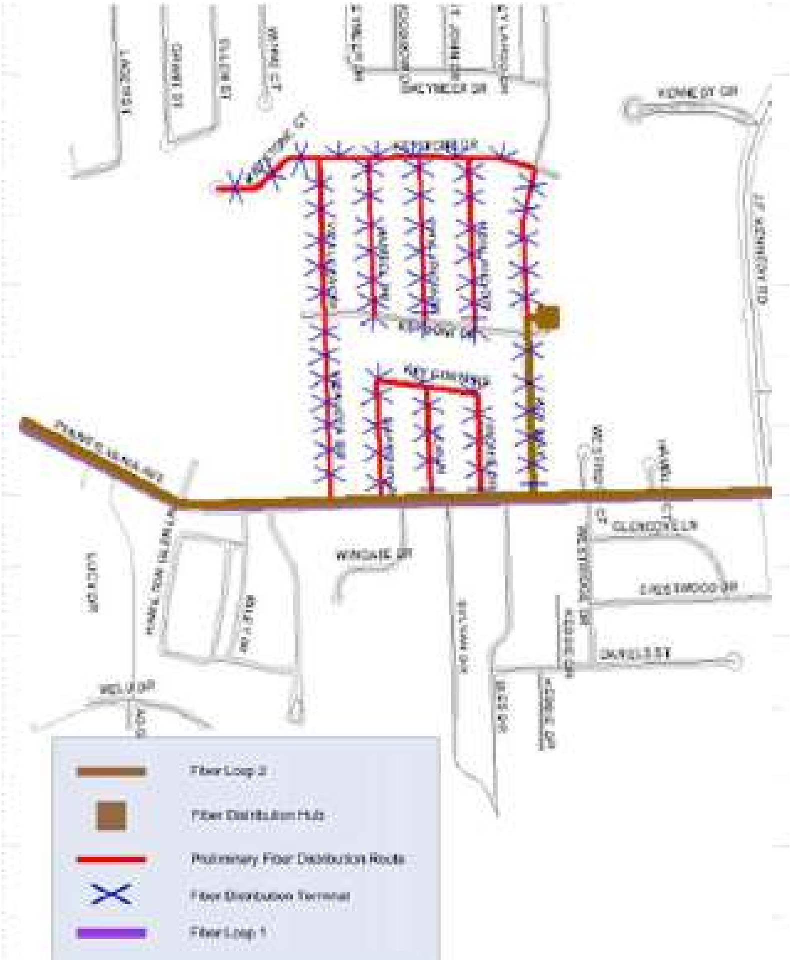


FTTP Architecture

- **Optical Network Terminal box outside dwelling or business**
- **Fiber Distribution Terminal (FDT) in poles or pedestals**
- **Fiber Distribution Hub (FDH) at street cabinet**
- **Optical Line Terminal (OLT) at central office**



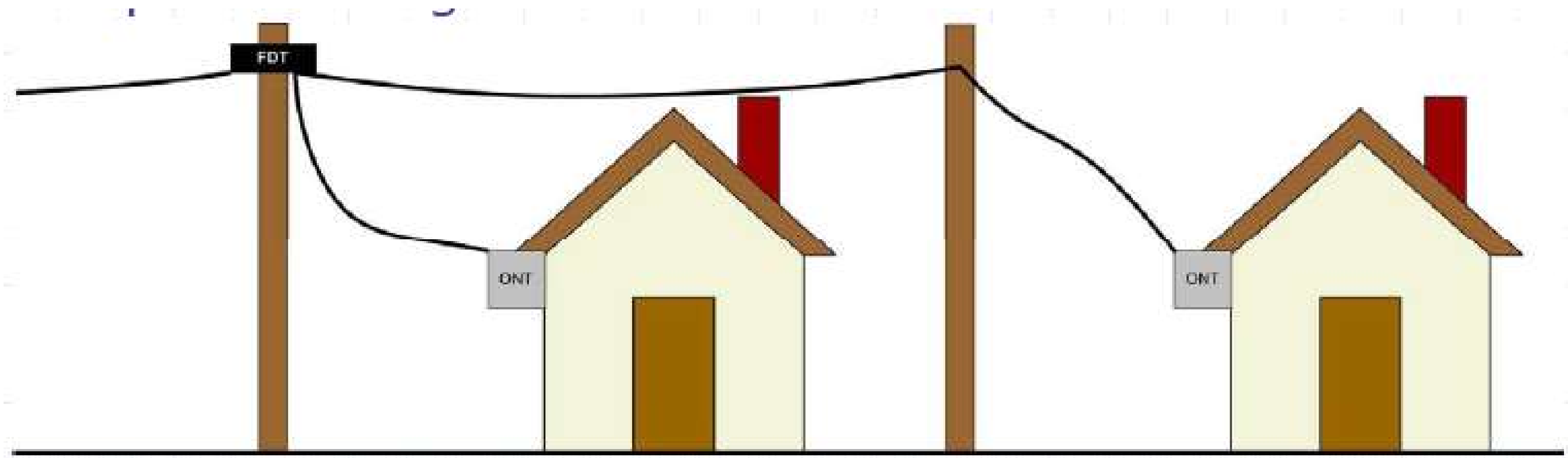
FTTP Architecture: Central to Fiber Distribution Hub (FDH)



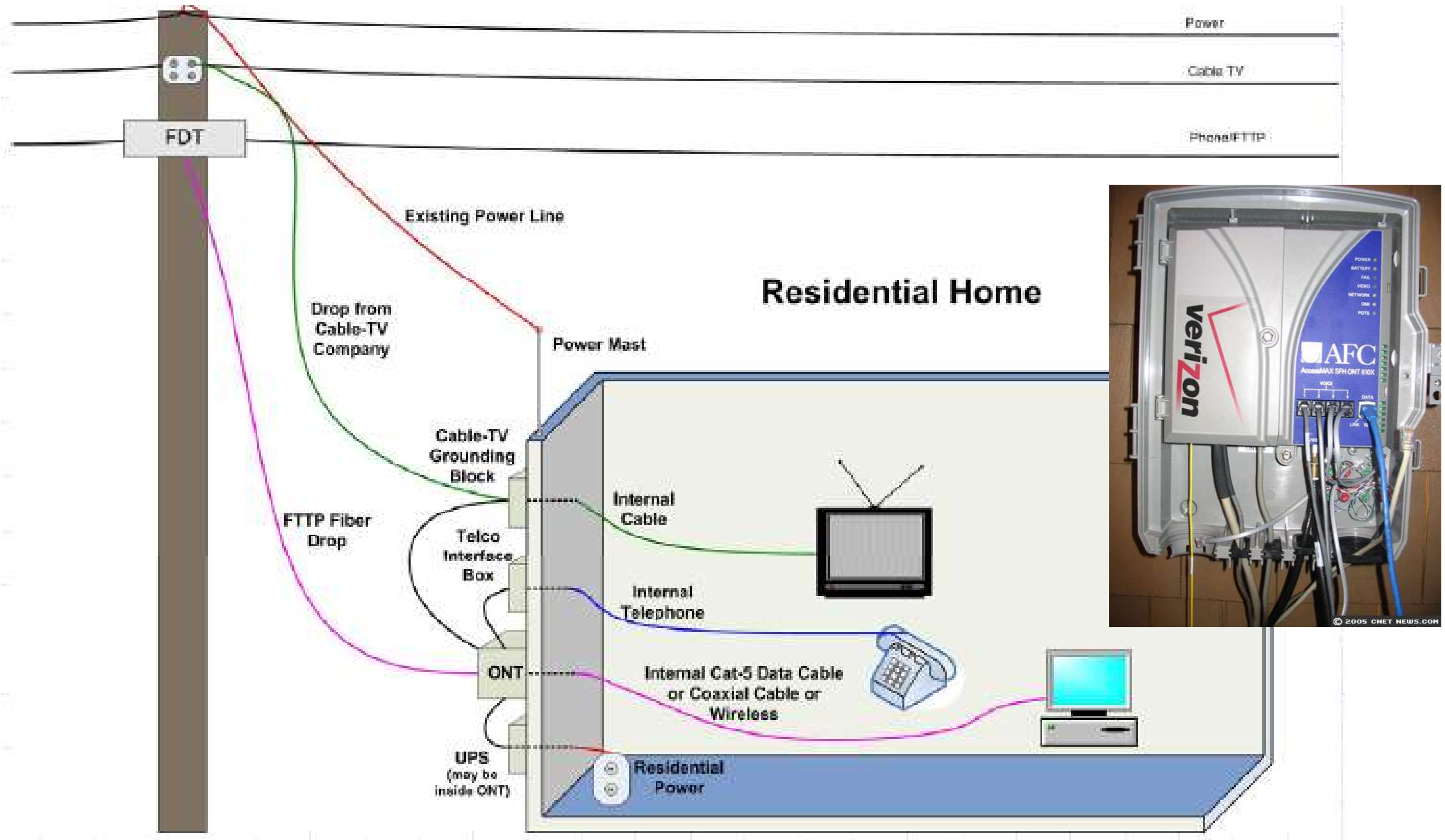
- Backbone fiber ring on primary arterial streets (brown)
- Local distribution fiber plant (red) meets backbone at cabinet

FDH

FTTP Architecture: Fiber Distribution Terminal (FDT)



FTTP Architecture: To Home

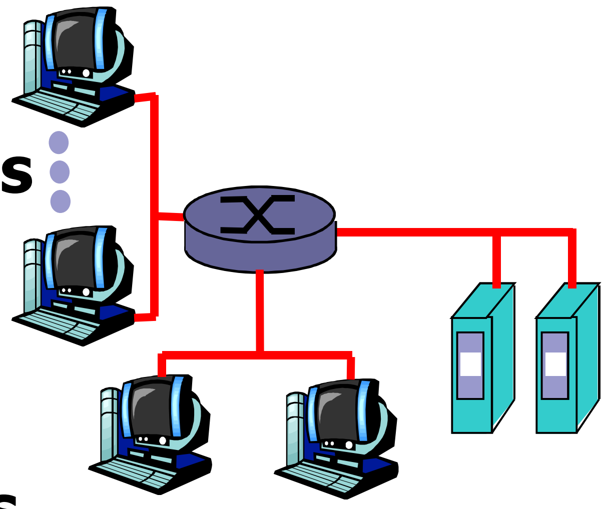


Residential Access: Fiber to the Premises (FTTP)

- **Highest theoretical capacity per user: 1 G bps**
  - currently 5 to 30 Mbps downstream, 2 to 5 Mbps upstream
- **Services**
  - analog and digital video
  - video viewable with and without set-top converter
  - voice
  - interfaces with existing phone, data, video cabling

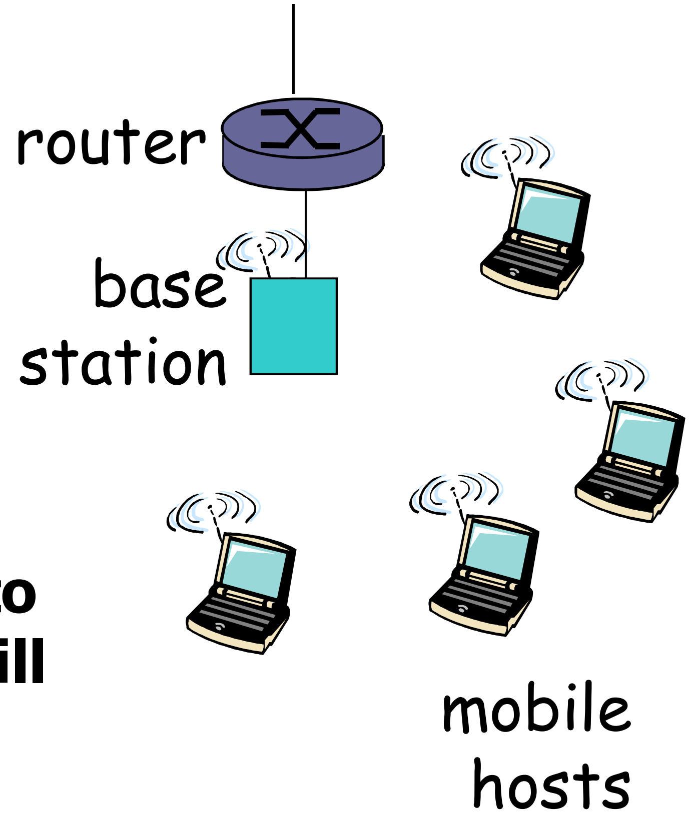
Institutional access: Local Area Networks

- company/university **local area network** (LAN) connects end system to edge router
- **Ethernet:**
  - shared or dedicated cable connects end system and router
  - 10 Mb/s, 100 Mb/s for PCs and enterprise networks
  - Gigabit Ethernet (GigE) for servers
  - 10 Gb/s for servers and backbones
- **deployment:** institutions, home LANs
  - wide area emerging



Wireless access networks

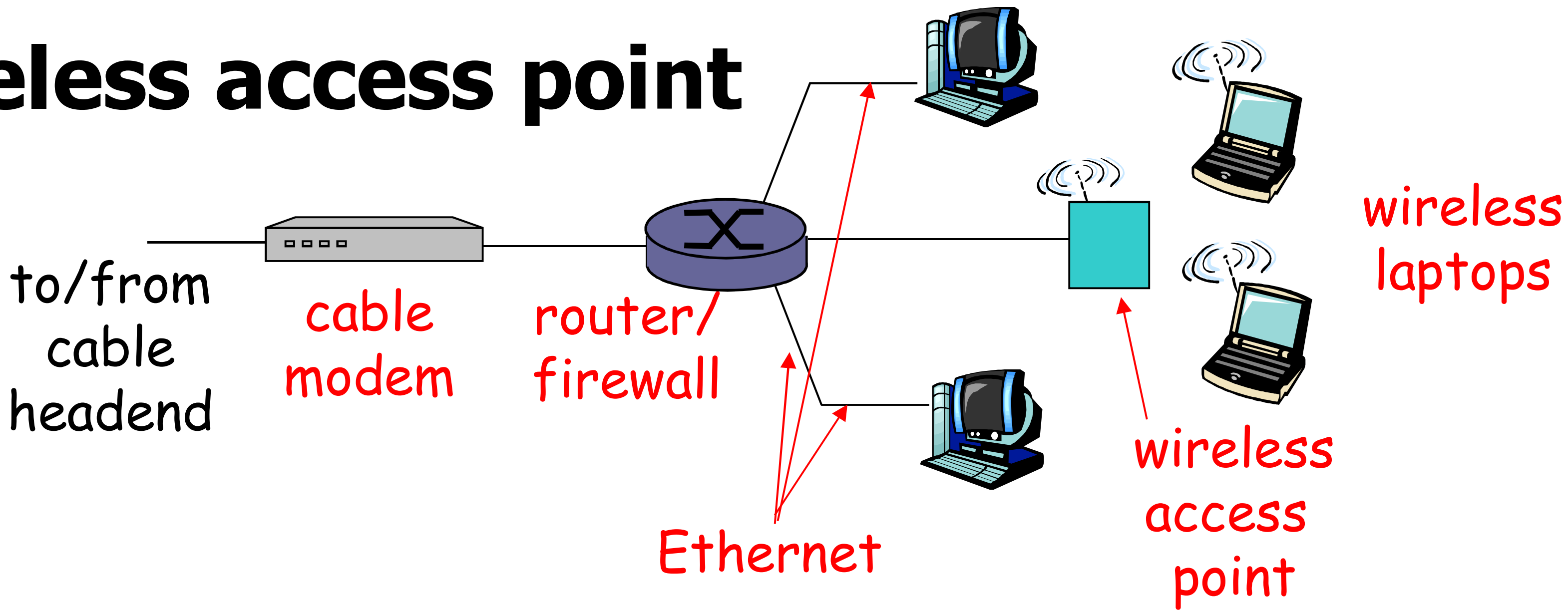
- shared wireless access network connects end system to router
- wireless LANs:
  - radio spectrum replaces wire
  - e.g., 802.11 a/b/g/n
    - nominally, 1 to 100 Mb/s
- wider-area wireless access
  - through cell phone network
  - CDPD: old, slow wireless access to ISP router via cellular network (fill speech gaps) -- obsolete
  - EVDO, 1xRTT: emerging
  - 3G/4G/5G



Home networks

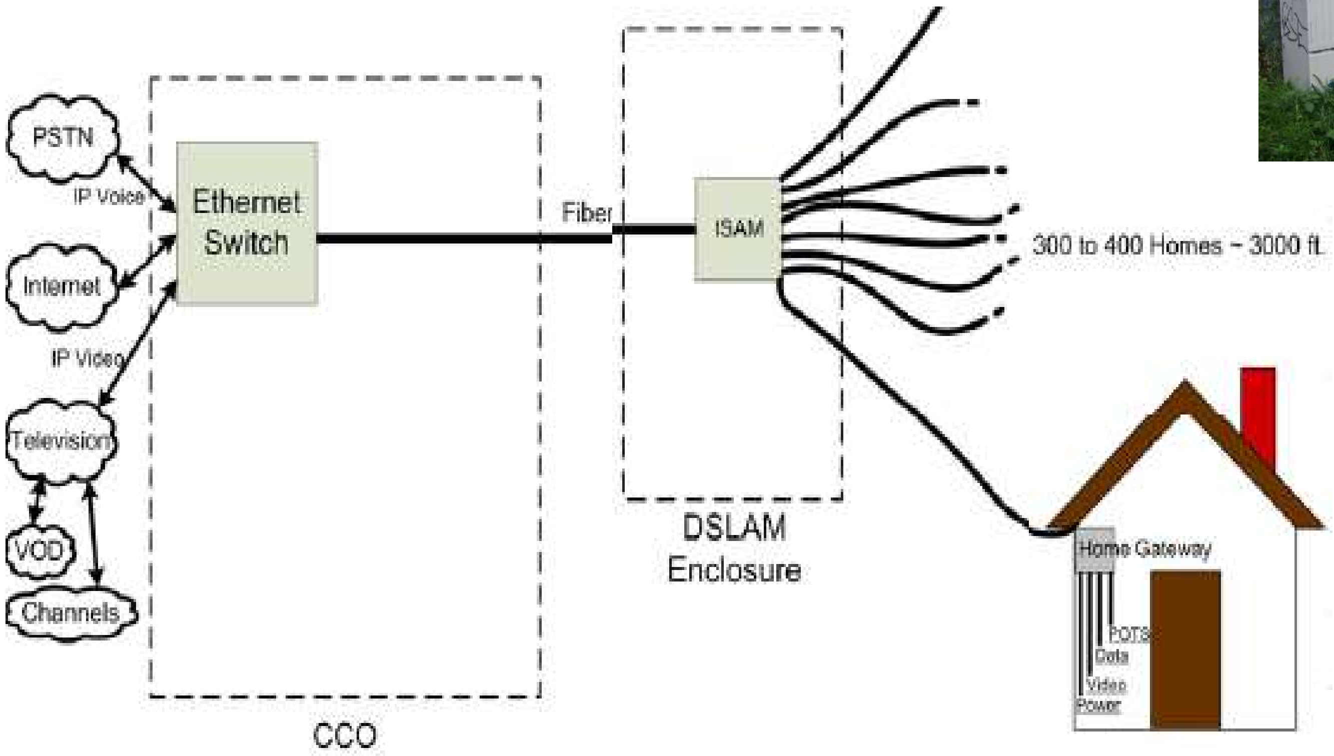
Typical home network components:

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



Access: DSL

- **Compared with FTTP, copper from cabinet (DSLAM) to home**



DSLAM

DSL Services to Customers

- Up to 25 Mbps per customer
- Currently a few Mbps downstream, and a few Mbps upstream
- Voice
  - converted to standard telephone signal at Home Gateway

Physical Media

- **physical link:** transmitted data bit propagates across link
- **guided media:**
  - signals propagate in solid media: copper, fiber
- **unguided media:**
  - signals propagate freely, e.g., radio

Twisted Pair (TP)

- two insulated copper wires
  - **Category 3:** traditional phone wires, 10 Mb/s Ethernet
  - **Category 5** TP: 100 Mb/s Ethernet
  - **Category 6** TP:
    - 1 Gb/s Ethernet

Categories of Unshielded Twisted Pair

The EIA/TIA (Electronic Industry Association/Telecommunication Industry Association) has established standards of UTP.

Type	Use
Category 1	Voice Only (Telephone Wire)
Category 2	Data to 4 Mbps (LocalTalk)
Category 3	Data to 10 Mbps (Ethernet)
Category 4	Data to 20 Mbps (16 Mbps Token Ring)
Category 5	Data to 100 Mbps (Fast Ethernet)
Category 5e	Data to 100 Mbps (Fast Ethernet)
Category 6	Data to 250 MHz (Gigabit Ethernet?)
Category 7	Data to 600 MHz

(a)

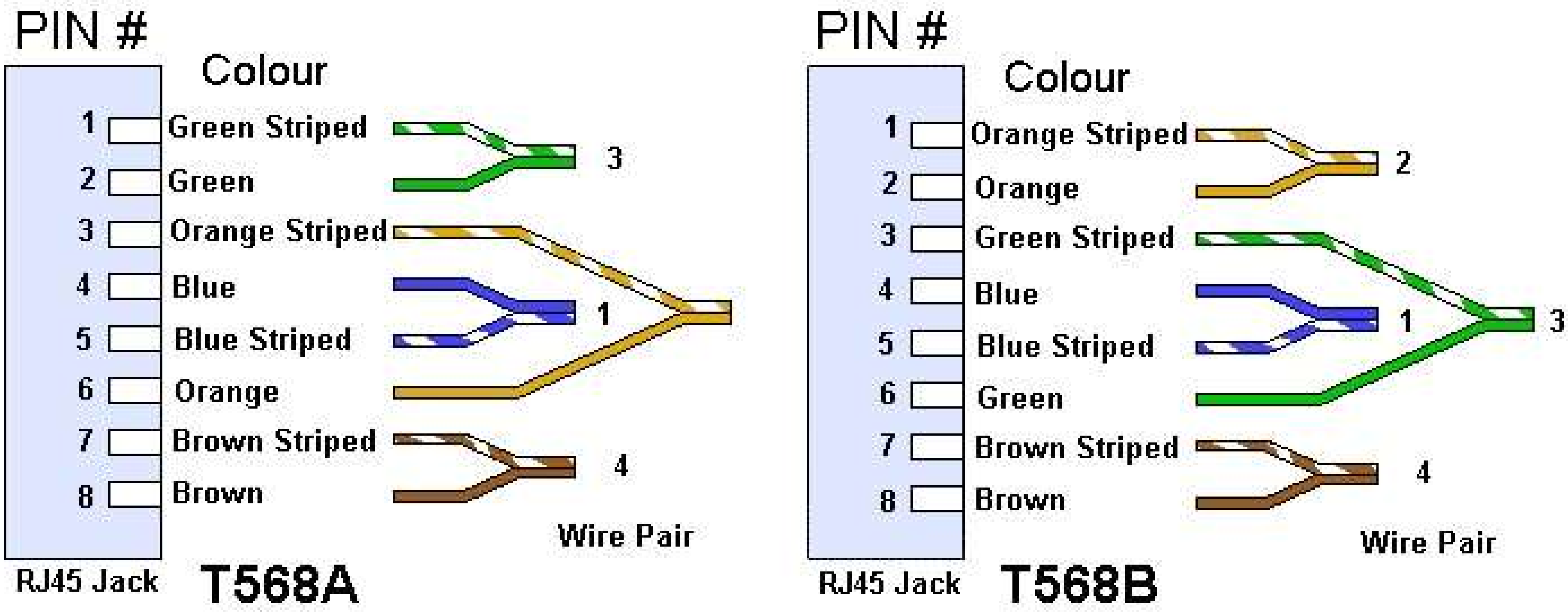
(b)

Twisted Pair Cable

- **RJ45** is a standard type of connector for network cables.
- RJ45 connectors are most commonly seen with Ethernet cables and networks.

How Twisted-Pair Cables and Connectors Are Wired

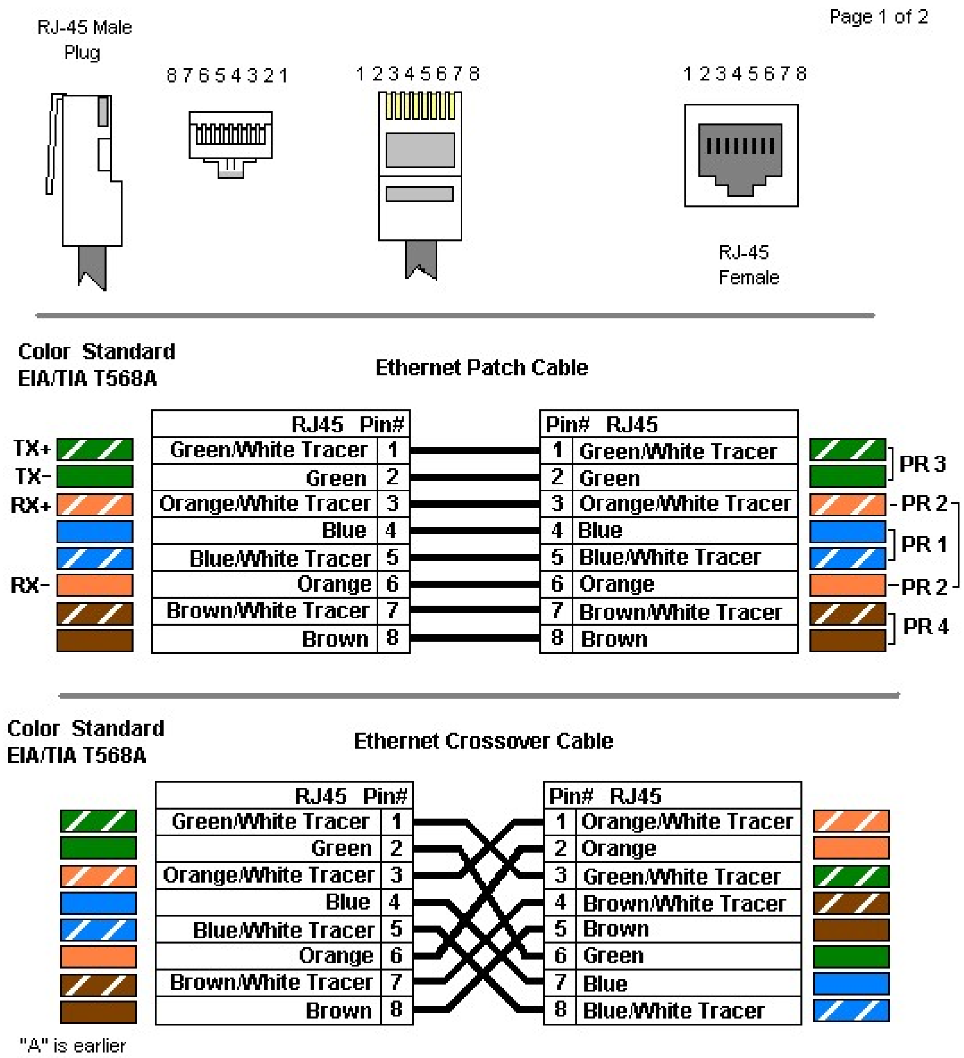
- **The most common standards are T568A and T568B with the second being of the most use.**



How Twisted-Pair Cables and Connectors Are Wired

Pin	100BaseT Purpose	T568A Wiring	T568B Wiring
1	Transmit+	Pair 3: White/green	Pair 2: White/orange
2	Transmit-	Pair 3: Green	Pair 2: Orange
3	Receive+	Pair 2: White/orange	Pair 3: White/green
4	(Used only on Gigabit Ethernet)	Pair 1: Blue	Pair 1: Blue
5	(Used only on Gigabit Ethernet)	Pair 1: White/blue	Pair 1: White/blue
6	Receive-	Pair 2: Orange	Pair 3: Green
7	(Used only on Gigabit Ethernet)	Pair 4: White/brown	Pair 4: White/brown
8	(Used only on Gigabit Ethernet)	Pair 4: Brown	Pair 4: Brown

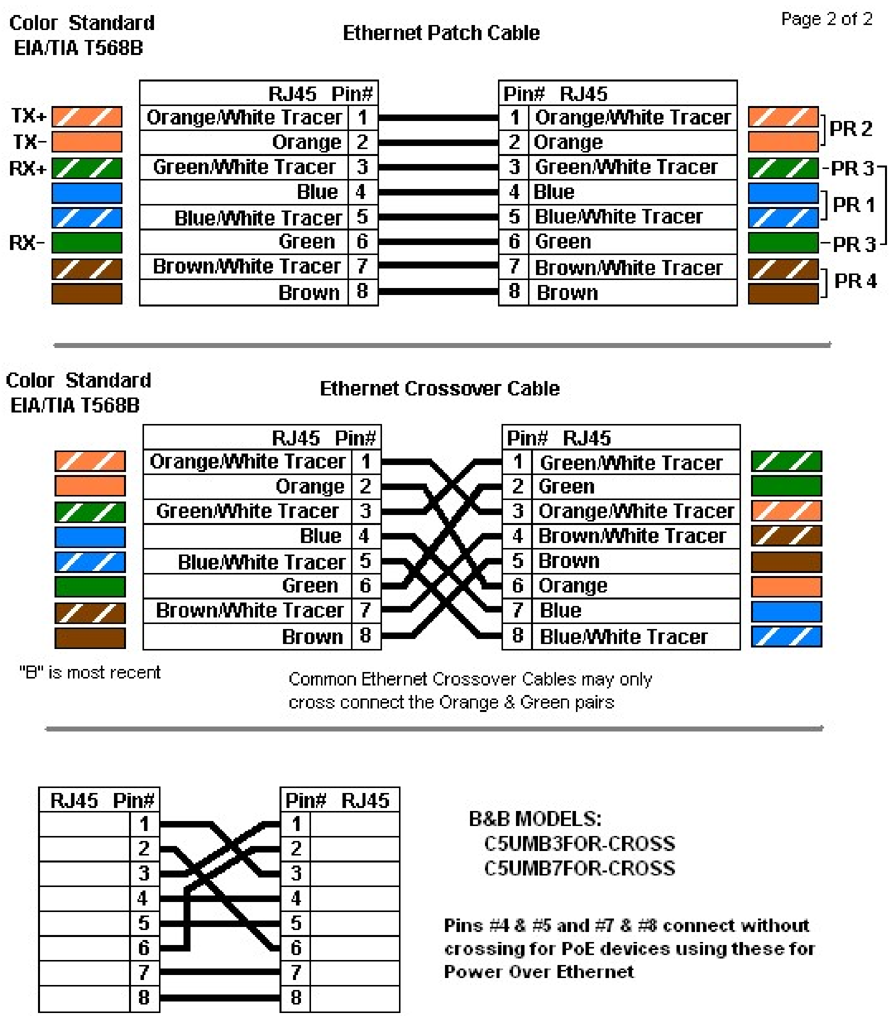
How Twisted-Pair Cables and Connectors Are Wired



Straight-through cable: used to connect a computer to a switch or other network device.
Also called a **patch cable.**

Crossover cable: used to connect two like devices such as a hub to a hub or a PC to a PC.
Transmit and receive lines are reversed

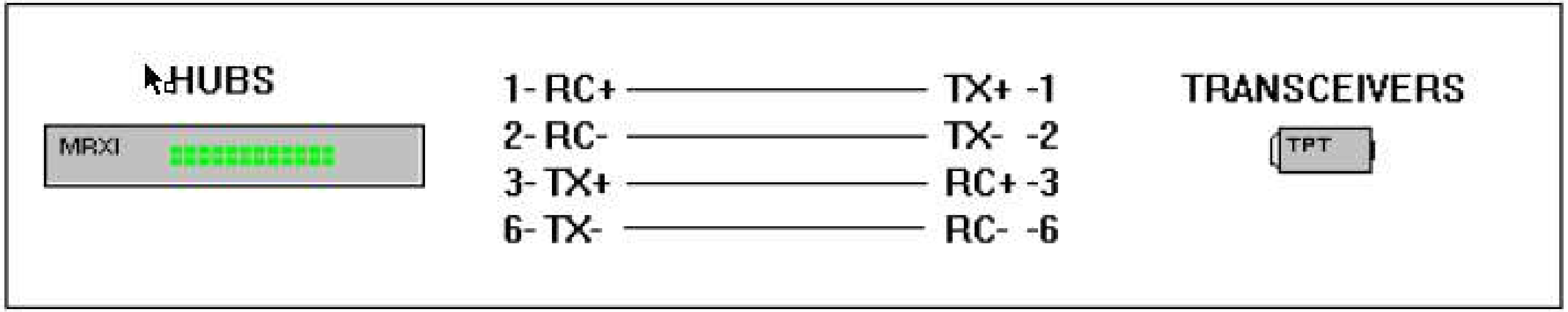
How Twisted-Pair Cables and Connectors Are Wired



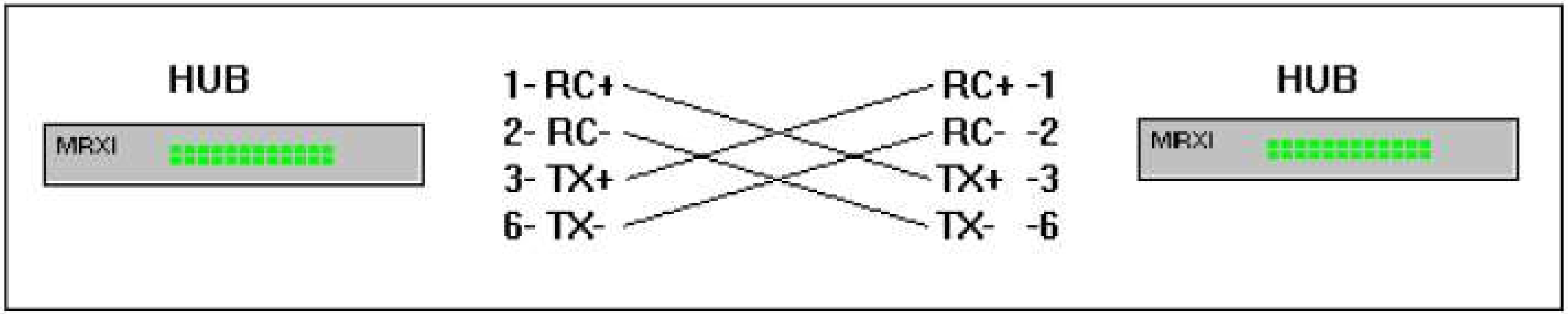
Straight-through cable:
used to connect a computer to a switch or other network device.
Also called a **patch cable.**

Crossover cable:
used to connect two like devices such as a hub to a hub or a PC to a PC.
Transmit and receive lines are reversed

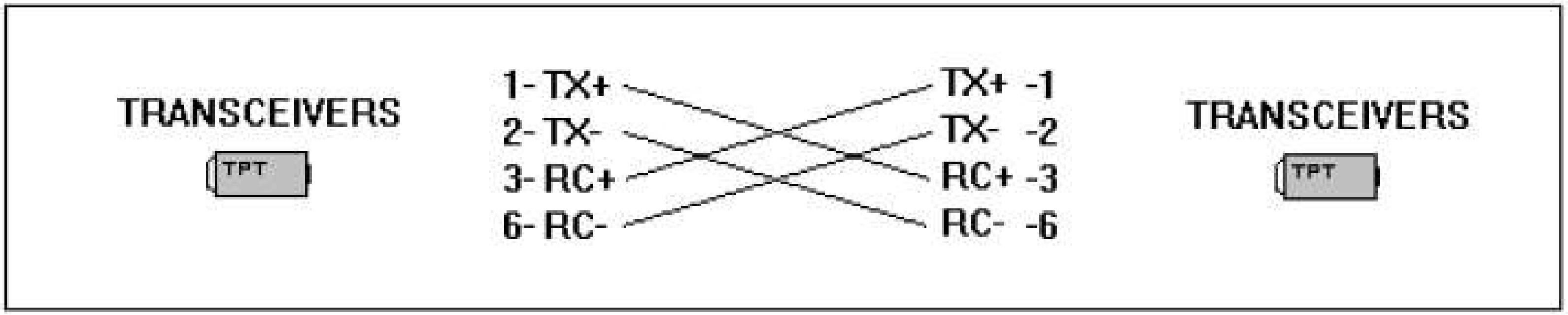
Hub-to-Transceiver



Hub-to-Hub

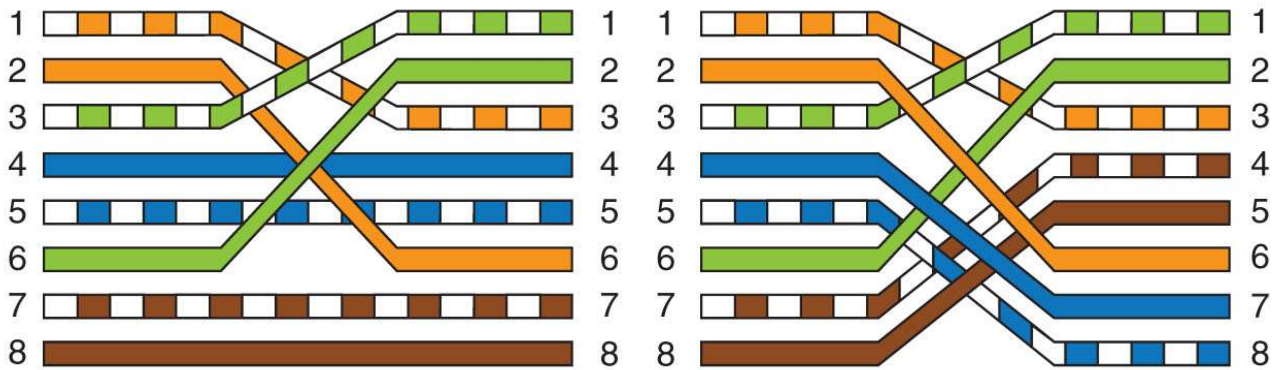


Transceiver-to-Transceiver



How Twisted-Pair Cables and Connectors Are Wired

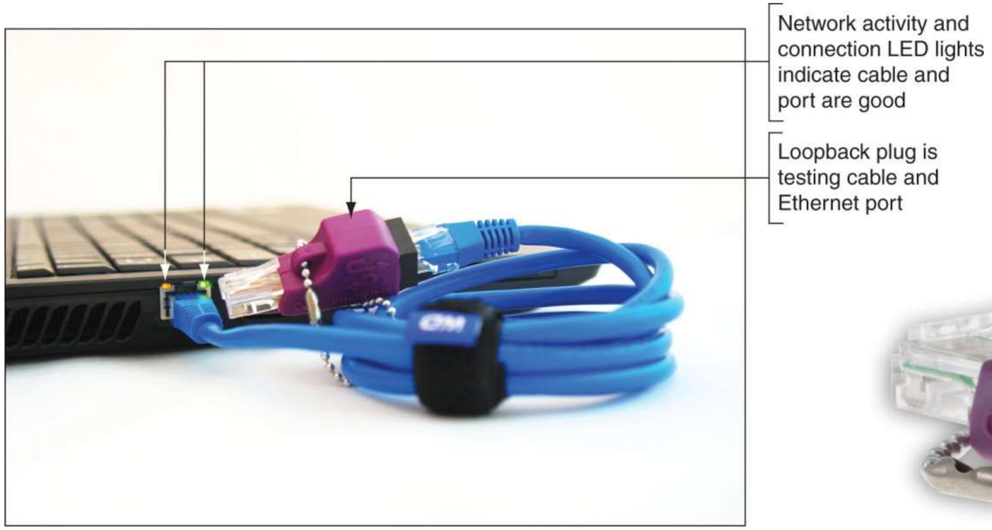
- **When working with existing wiring be sure to find out if wiring is using T568A or T568B**
  - **If not sure, use T568B because it is most common**

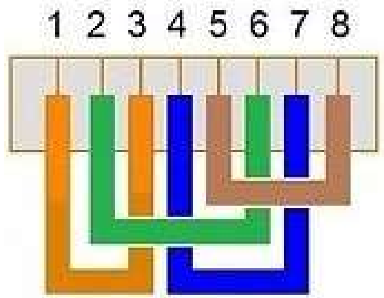


Two crossed pairs in a crossover cable is compatible with 10BaseT or 100BaseT Ethernet; four crossed pairs in a crossover cable is compatible with Gigabit Ethernet

Tools Used By Network Technicians

- **Loopback plug:** **used to test a network cable or port**
  - **Also used to find out which port on a switch matches up with a wall jack**





A loopback plug verifies the cable and network port are good

Tools Used By Network Technicians

- **Cable tester:** used to test a cable
  - Can also find out what type of cable it is if it is not labeled and to locate the ends of a network cable in a building
  - Has two components: remote and the base

Use a cable tester pair to determine the type of cable and/or if the cable is good

Tools Used By Network Technicians

- **Network multimeter: can test cables, ports, and network adapters**
  - **Can detect Ethernet speed, duplex status, default router on a network, length of a cable, voltage levels of PoE, and other network statistics**
  - **Many can document test results and upload results to a PC**

Tools Used By Network Technicians

- **Toner probe:** two-part kit used to find cables in walls
  - Toner connects to one end of cable and puts out a continuous tone while a probe is used to search the walls for the tone

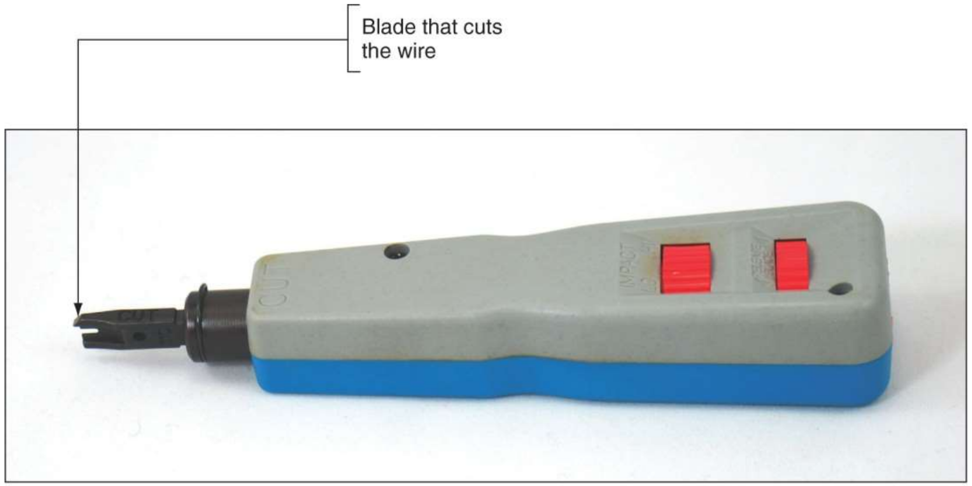
A toner probe kit by Fluke Corporation

Tools Used By Network Technicians

- **Wire stripper:** used to build your own network cable
  - Cuts away the plastic jacket or coating around wires
- **Crimper:** used to attach a terminator or connector to the end of a cable
  - Can serve double-duty as a wire cutter and stripper

Tools Used By Network Technicians

- **Punchdown tool:** **also called an impact tool**
  - **Used to punch individual wires into slots in a keystone RJ-45 jack that is used in an RJ-45 wall jack**



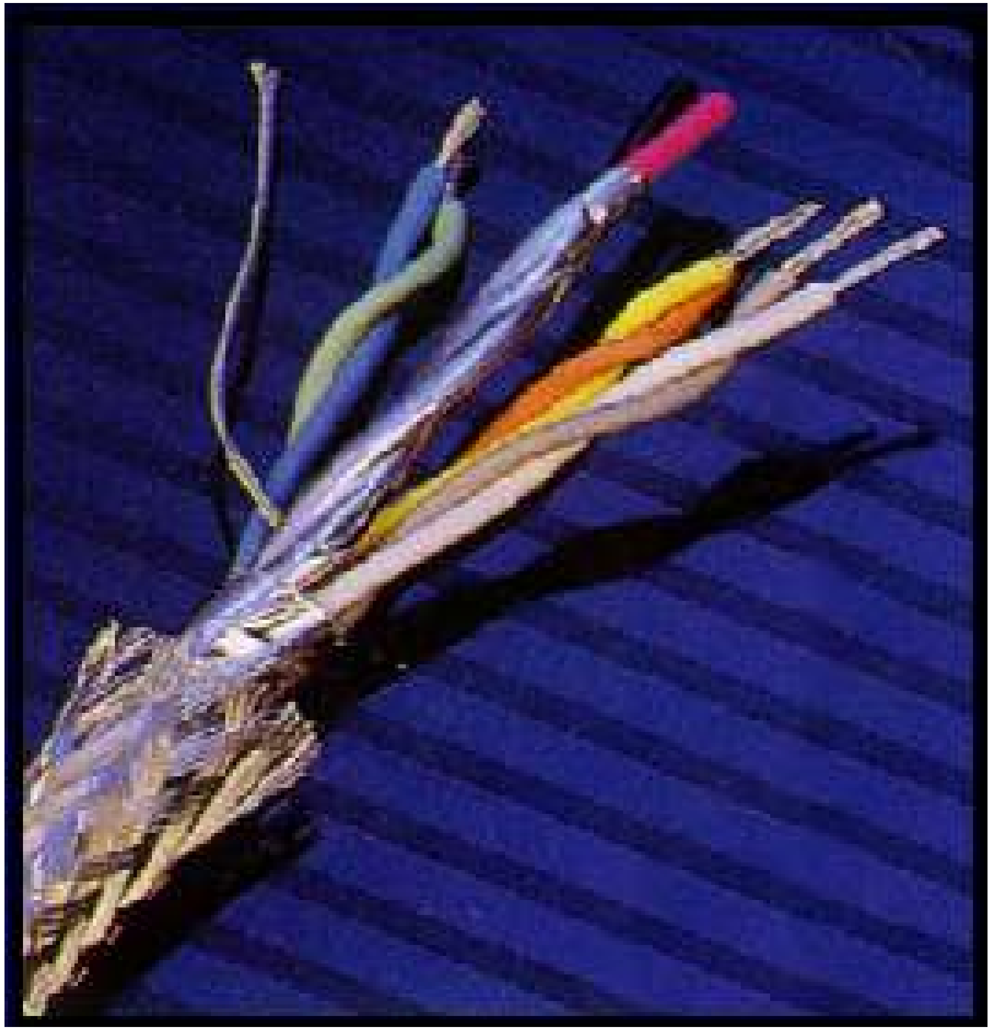
A punchdown tool forces a wire into a slot and cuts off the wire

Tools Used By Network Technicians

- **Patch panel:** provides multiple network ports for cables that converge in one location
  - Each port is numbered on the front of the panel
  - Keystone jacks are color-coded for the wires to be inserted on the back of the panel
  - Punchdown tool is used to terminate

A patch panel provides Ethernet ports for cables converging in an electrical closet

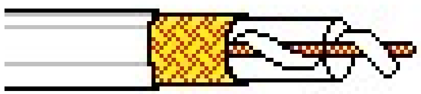
STP



Physical Media: coax, fiber

Coaxial cable:

- wire (signal carrier) within a wire (shield)
  - baseband: single channel on cable
  - broadband: multiple channel on cable
- bidirectional
- formerly common use in 10 Mb/s Ethernet

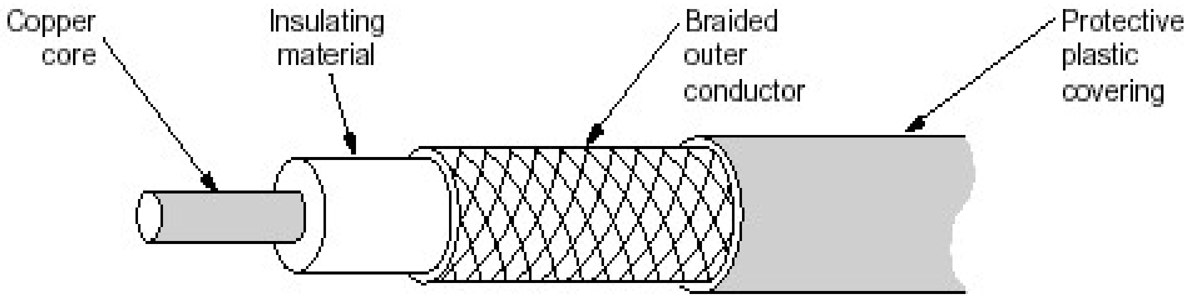


Fiber optic cable:

- glass fiber carrying light pulses
- typically dozens bundled into one cable
- high-speed operation:
  - 100 Mb/s Ethernet
  - high-speed point-to-point transmission (e.g., 40 Gb/s)
- low error rate: repeaters spaced far apart; immune to electromagnetic noise

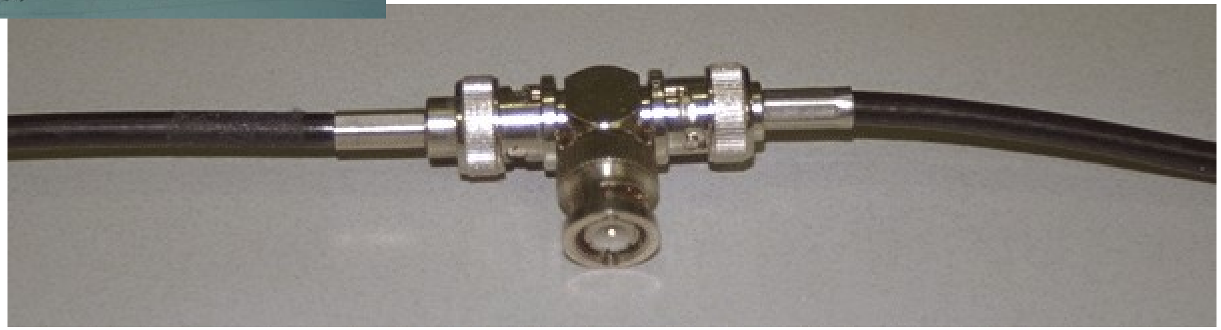
Coaxial Cable

- **Exactly like the one you use for your TV Set:**



- **Baseband Coax**
  - **50-ohm cable for digital transmission**
  - **10Base-2, BNC, Thin-LAN, 185m/per segment**
  - **10Base-5, AUI, Thick-LAN, 500m/ per segment**
  - **At most 5 segments, up to 945m/2500m.**
- **Broadband Coax**
  - **75-ohm cable for analog transmission, like cable TV.**


2002 9 10




D-Link
Ethernet Transceiver
DE-850 Piercing Tap
2002 9 10

S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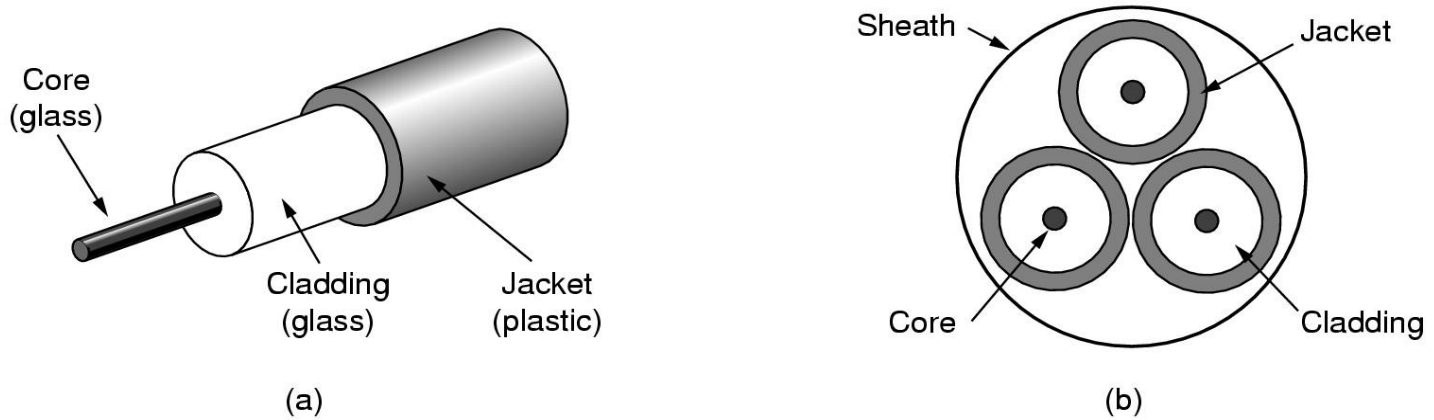
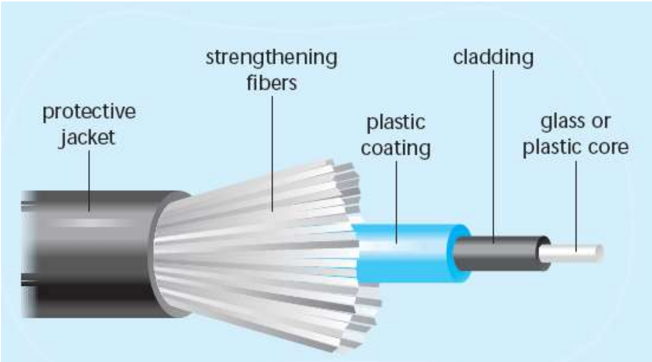
Fiber Optics

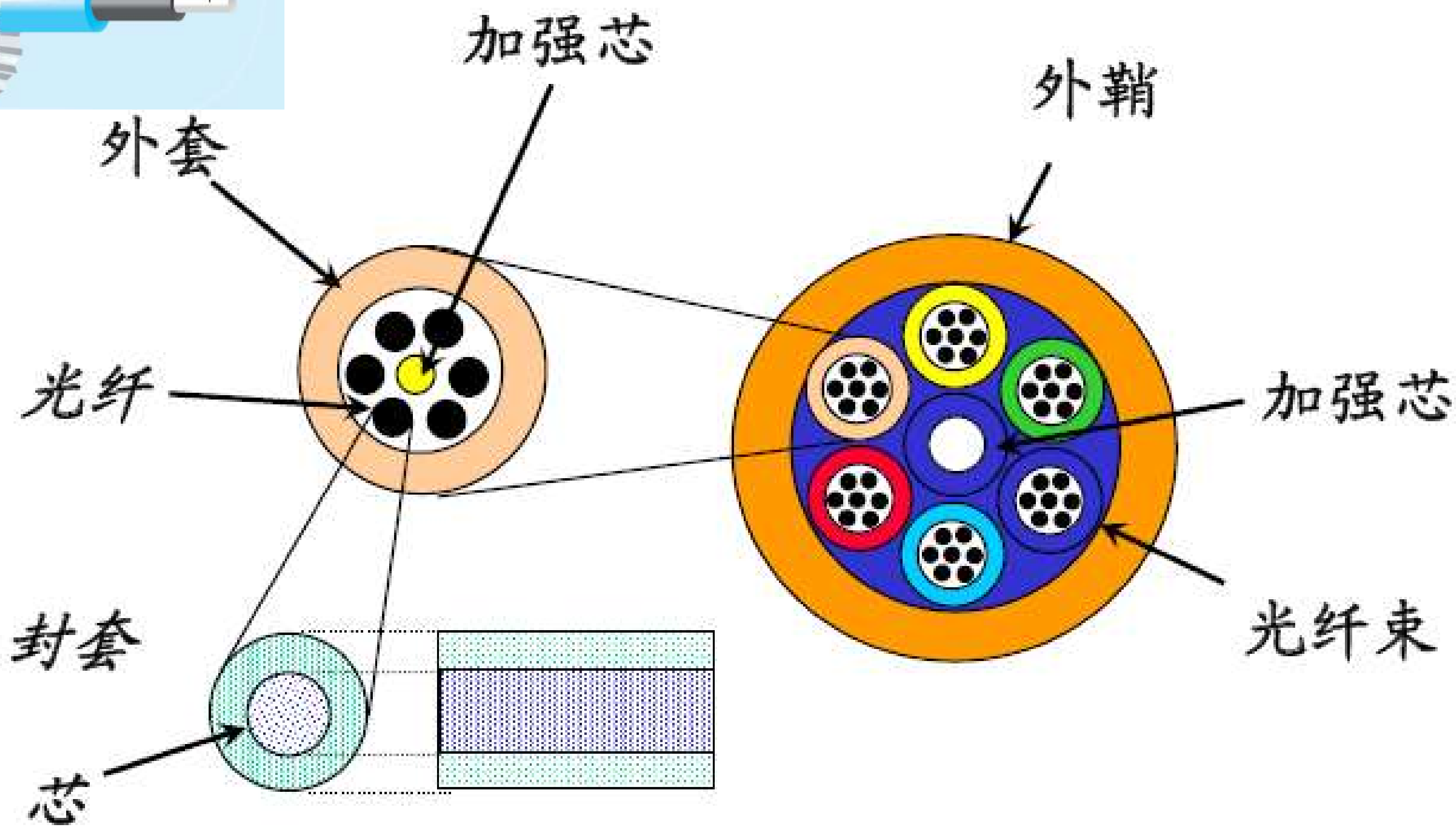


Item	LED	Semiconductor Laser
Data rate	Low	High
Mode	Multimode	Multimode or single mode
Distance	Short	Long
Lifetime	Long life	Short life
Temperature sensitivity	Minor	Substantial
Cost	Low cost	Expensive

Fiber Optics

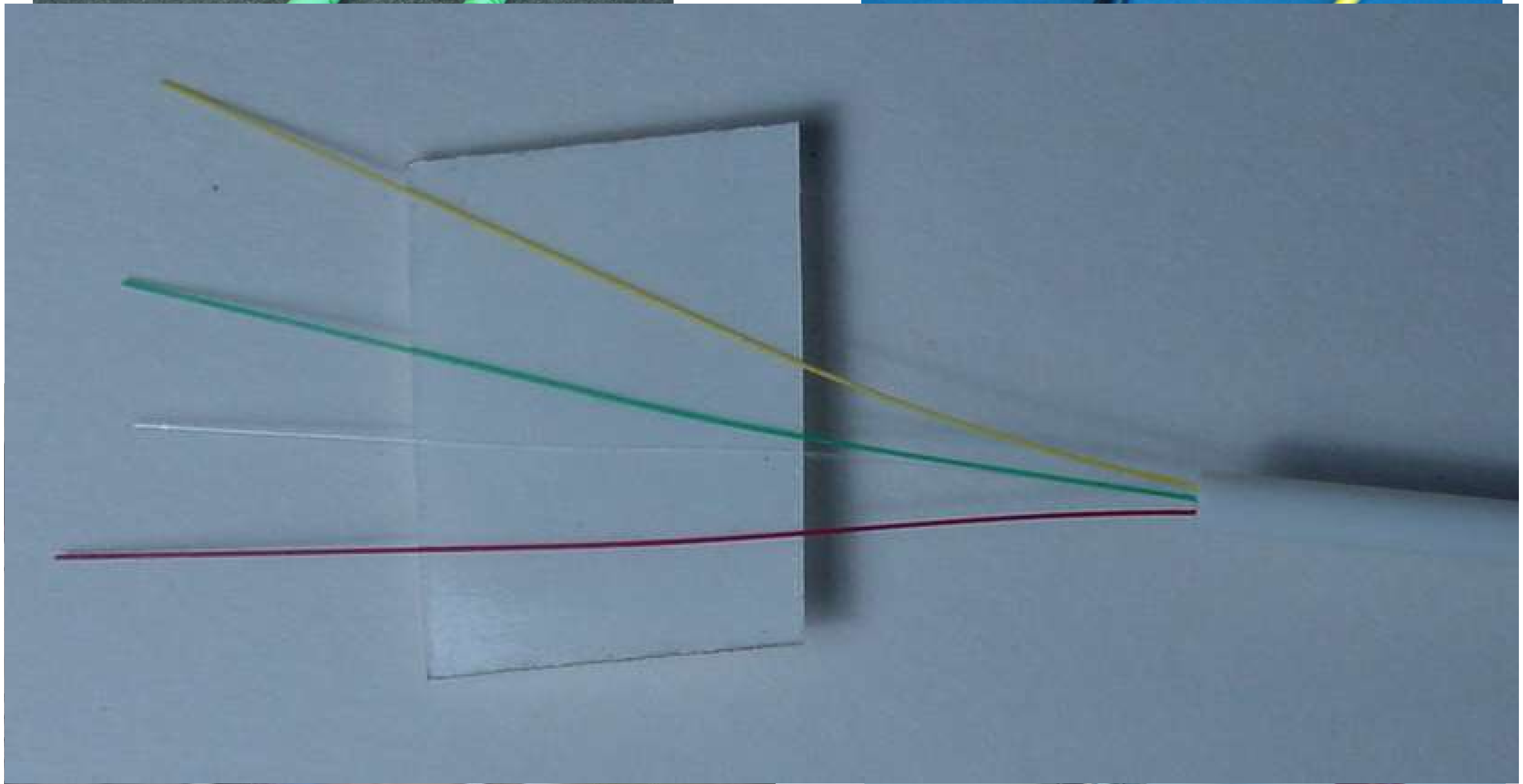


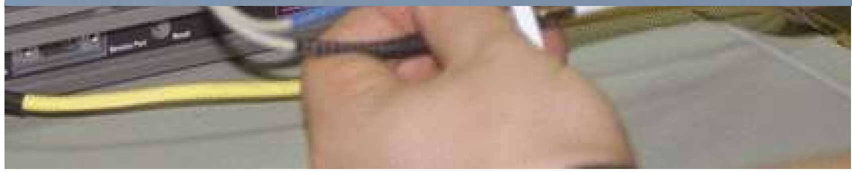
高密度多芯光缆剖面结构



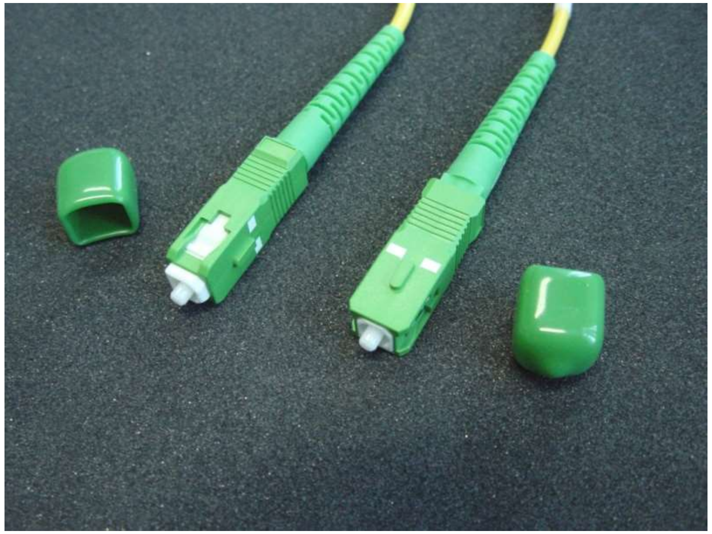
SC：568A标准，方形，插入锁定

ST：插入锁定

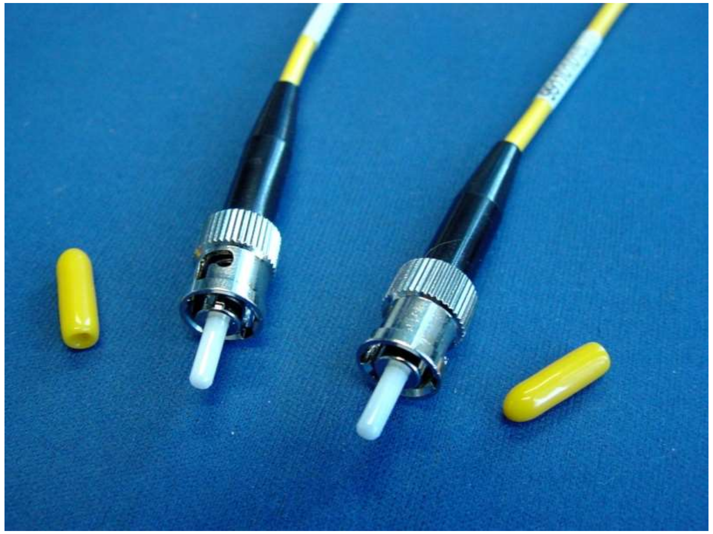


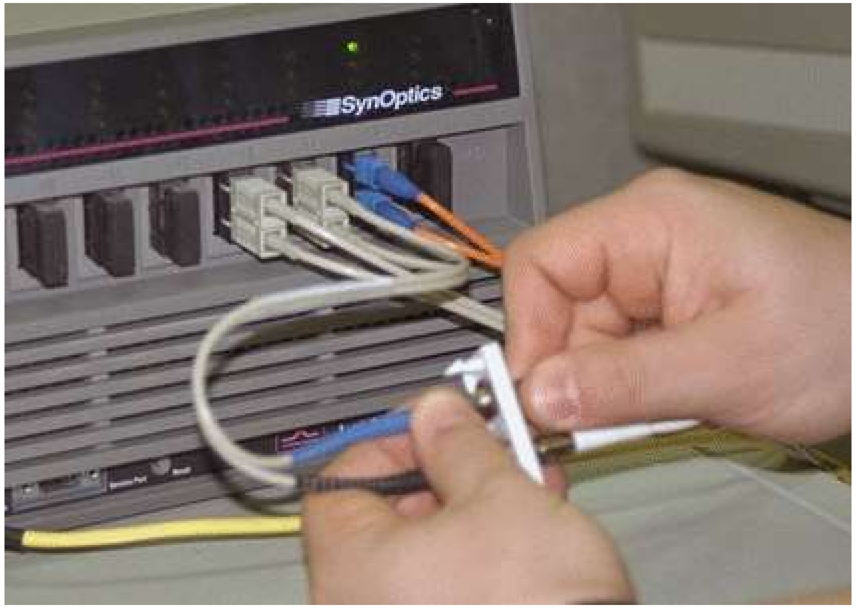


SC：568A标准，方形，插入锁定



ST：插入锁定





光耦合器（ST）

- **Attenuation in decibels = $10\log_{10}$(transmitted power/received power)**

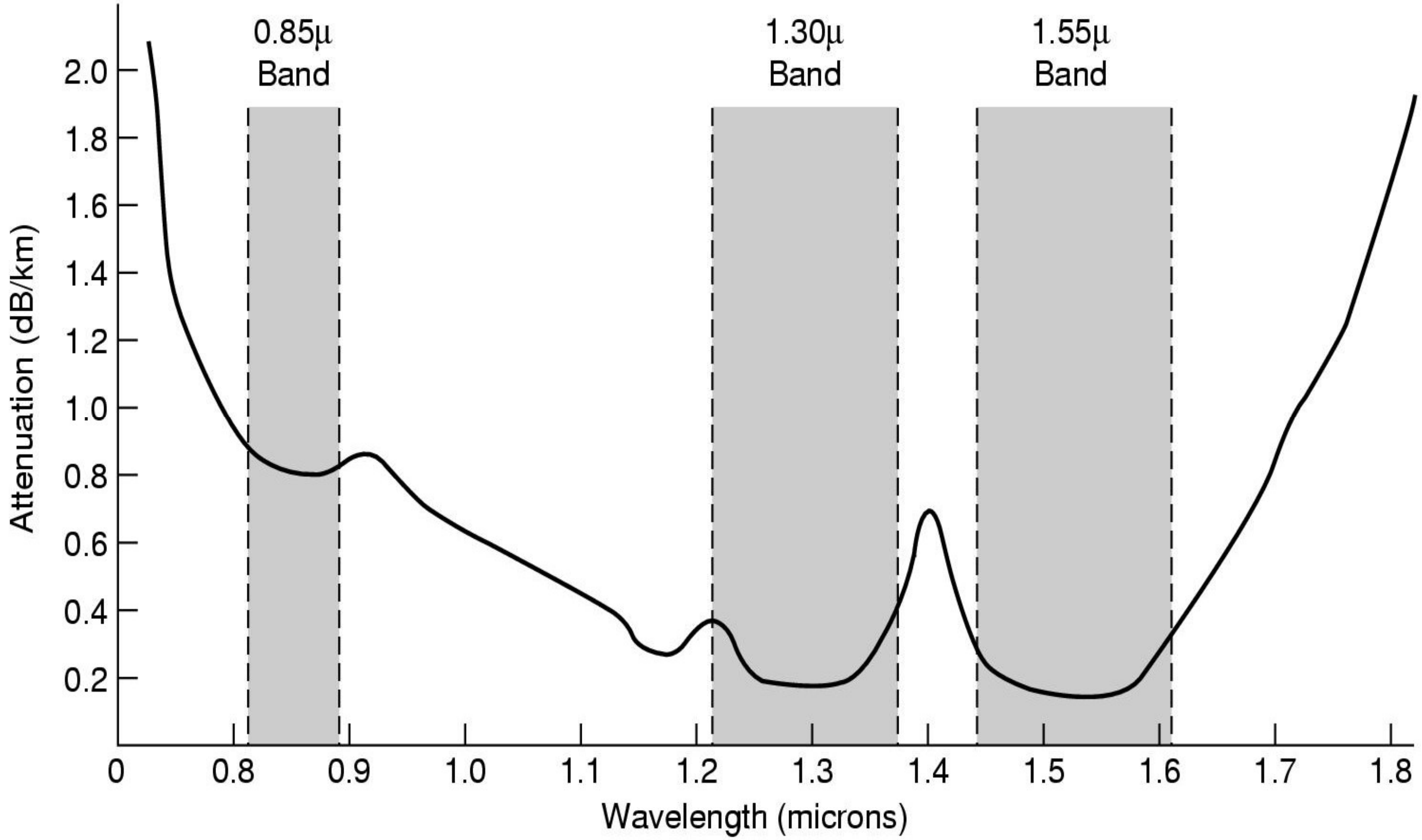


Fig. 2-6 Attenuation of light through fiber in the infrared region.

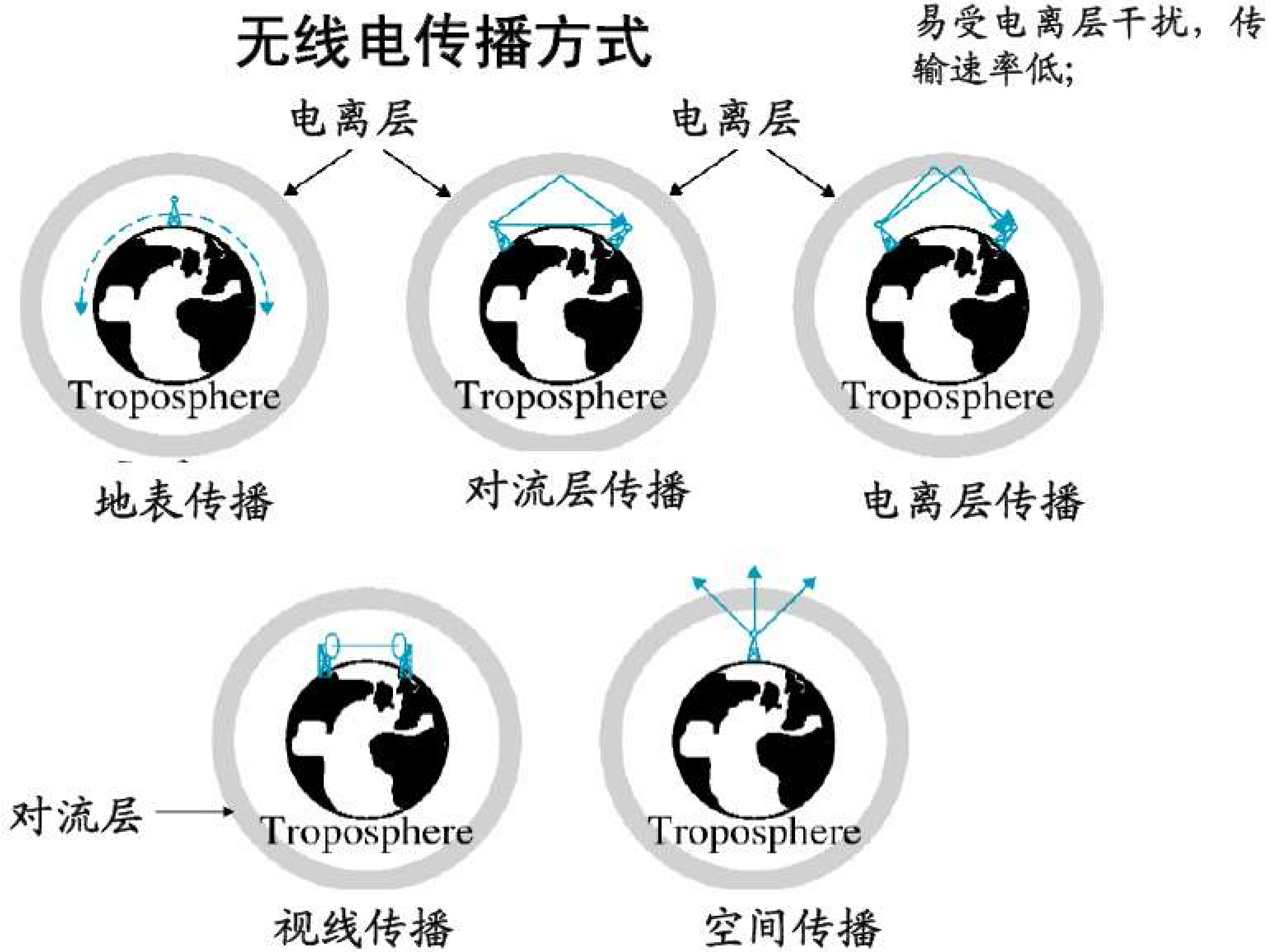
Physical media: radio

- 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 Mb/s channels
- **LAN** (e.g., WiFi)
  - 2Mbps, 11Mb/s, 54Mbps
- **wide-area** (e.g., cellular)
  - e.g. 3G: hundreds of kb/s
- **satellite**
  - up to 50 Mb/s channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus low altitude (Iridium)

Physical media: radio

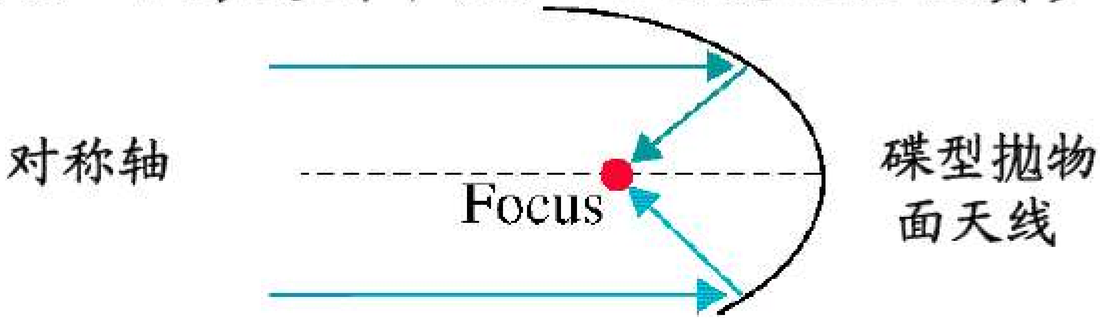


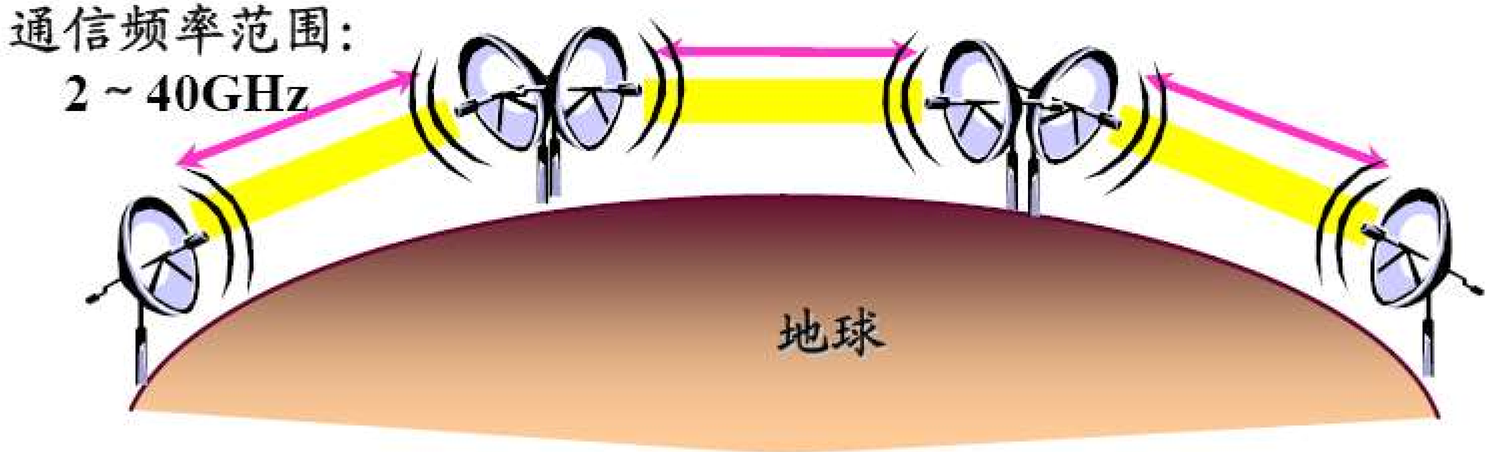
Physical media: radio

微 波

直线传播，需中继转发（塔高100m，站距100km）；

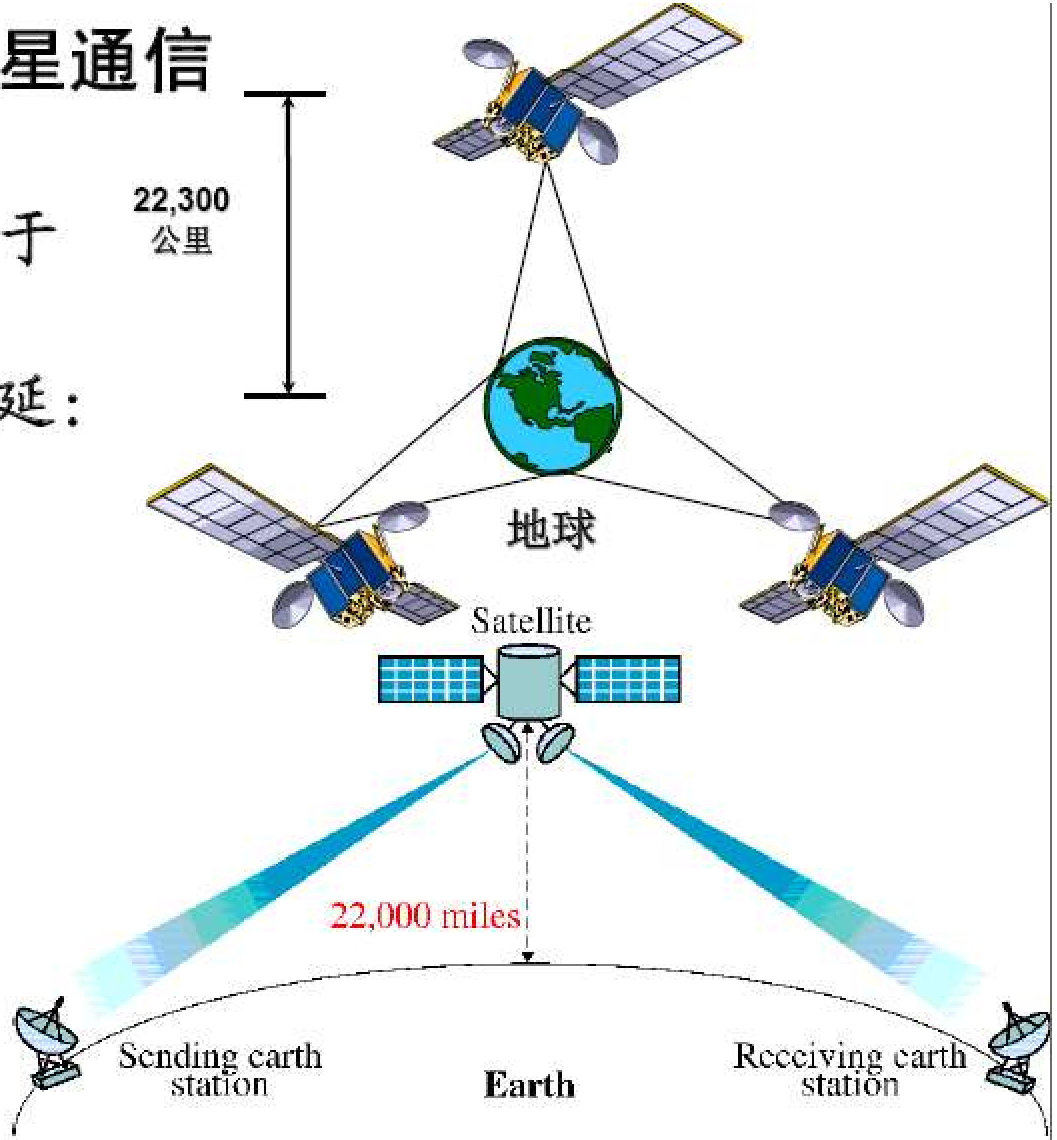
频带宽，容量大，不易受到干扰，比电缆通信投资少。





Physical media: radio

卫星通信



覆盖面广，适合于广播通信；

存在较大传播时延：250ms

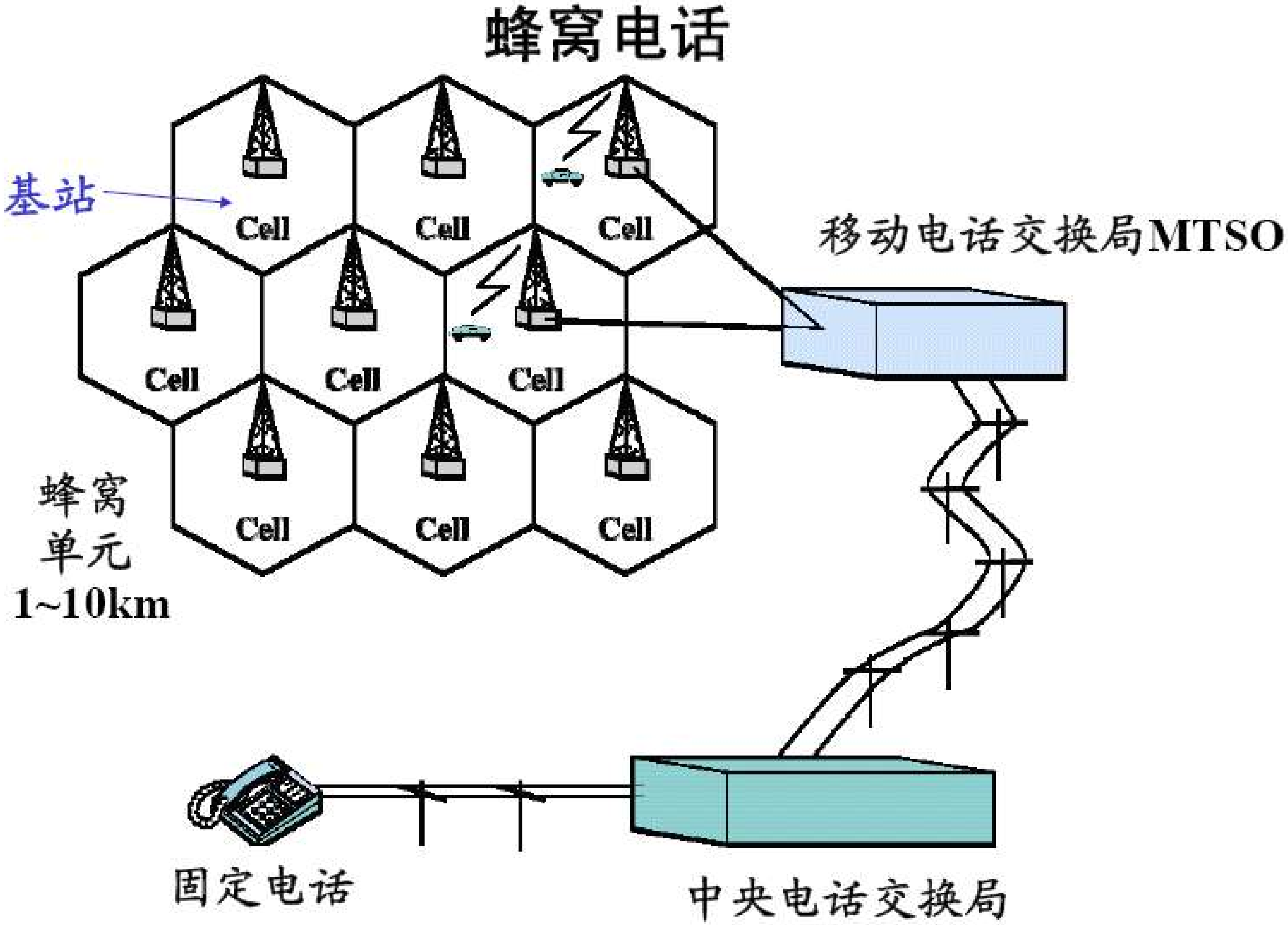
传送数据的总时延

=传播时延

+发送时延

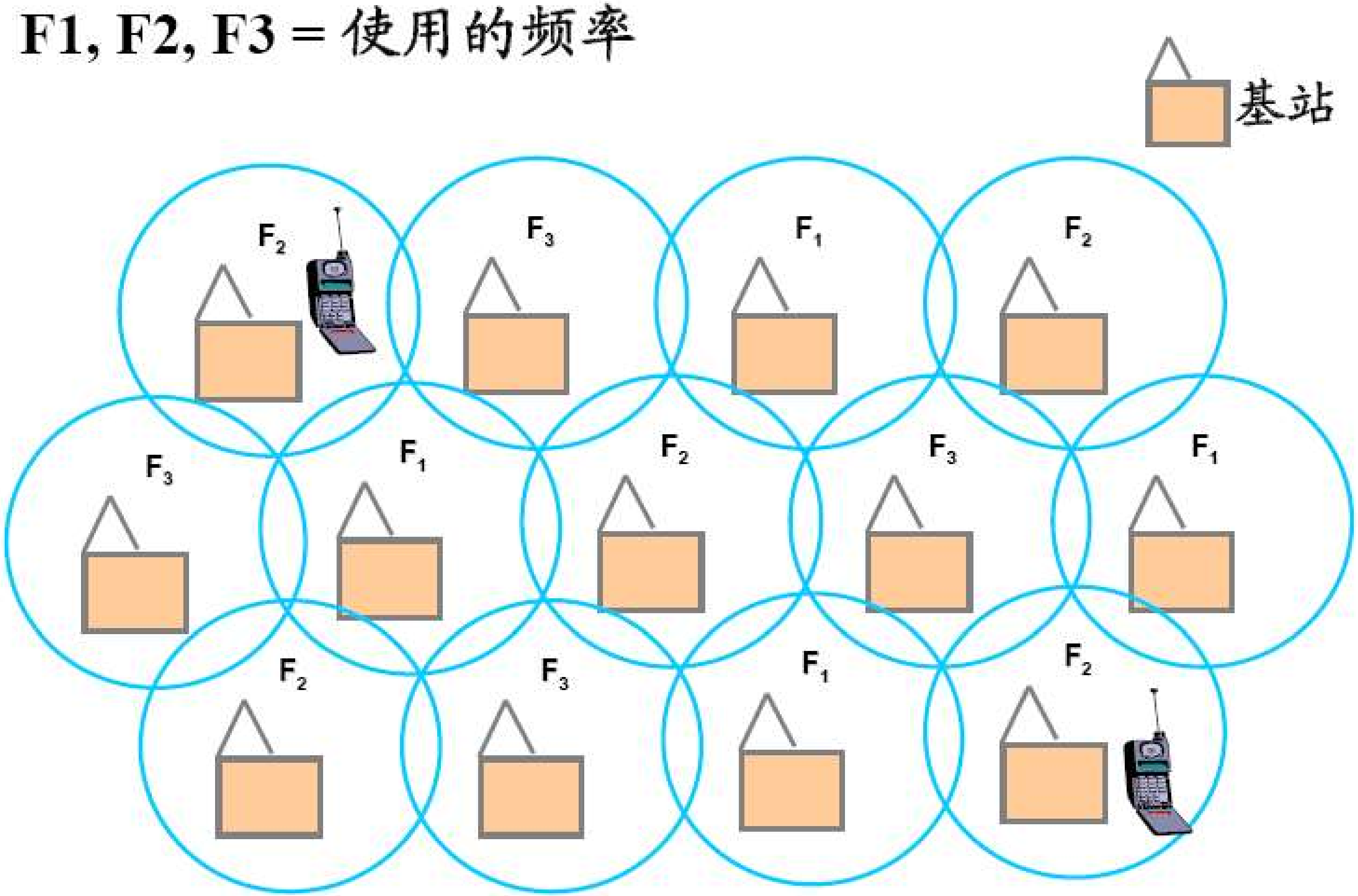
+重发时延

Physical media: radio



Physical media: radio

蜂窝电话



Other network media

- **Power lines**
- **Home phone lines – bus vs. star**
- **Infrared (IR)**
- **BlueTooth – *piconet***
- **Serial lines (RS232, RS485)**
- **Firewire (IEEE 1394)**

Comparison

传输媒体	速率	传输距离	性能(抗干扰性)	价格	应用
双绞线	10-1000Mb/s	几十 kM	可以	低	模拟/数字传输
50Ω同轴电缆	10Mb/s	3kM 内	较好	略高于双绞线	基带数字信号
75Ω同轴电缆	300-450MHz	100kM	较好	较高	模拟传输电视、数据及音频
光纤	几十 Gbps	30kM up	很好	较高	远距离传输
短波	<50MHz	全球	较差	较低	远程低速通信
地面微波接力	4-6GHz	几百 kM	好	中等	远程通信
卫星	500MHz	18000kM	很好	与距离无关	远程通信

Physical media: capacity

- **Capacity has theoretical limit**
  - **Shannon's Law:** capacity limit given by
  - $C = B \log_2 (1 + S/N)$ with spectral bandwidth B
  - E.g., phone has $B = 3000$ Hz, S/N = 35 dB, $C = 34.8$ kb/s
  - dB = $10 \log_{10} S/N$ （称为信噪比）
  - E.g., 25 dB = $10^{2.5} = 316$
  - Radio: typically 1 b/s per Hz of bandwidth
- **Speed has physical limits:**

  c in free space, 0.66 *c* in fiber

Chapter 1: Roadmap

1.1 Computer network and the Internet

1.2 Network edge and core

1.3 Network access and physical media

1.4 Transmission Technology

1.5 Type and Topology

1.6 Network Performance

1.7 Protocol layers, service models

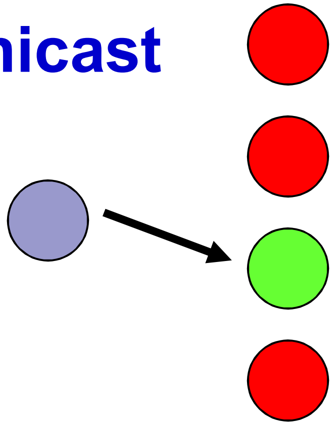
1.8 Architecture, OSI and TCP/IP Models

1.9 Internet History

Transmission Technology

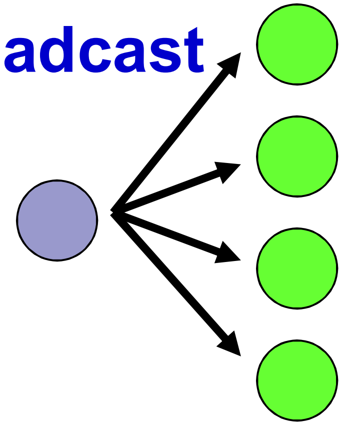
- A message can be unicast, multicast, or broadcast.

Unicast



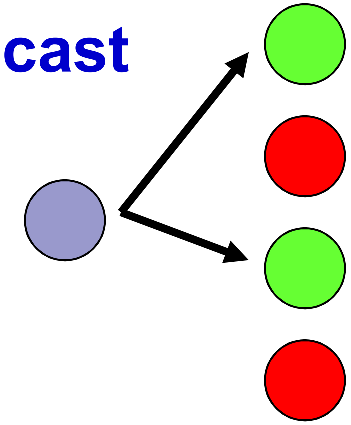
one source to one destination

Broadcast



One source to all nodes on (small, local) network

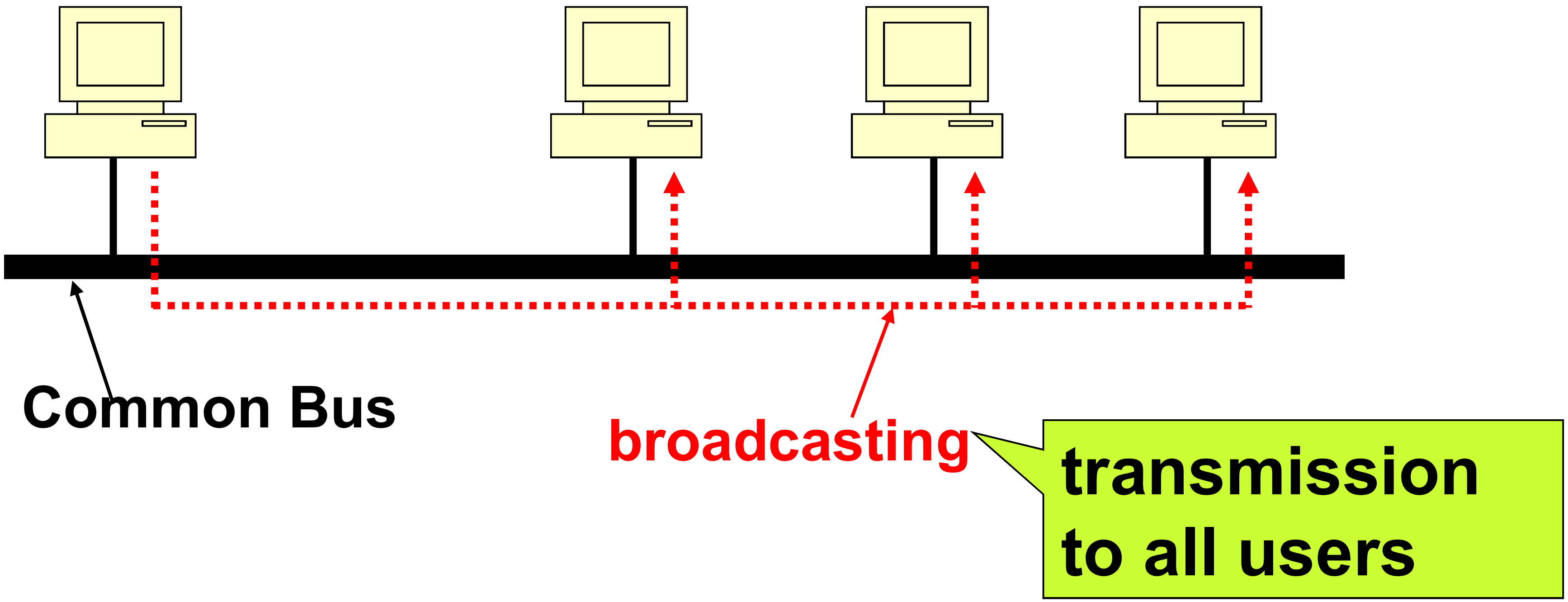
Multicast



one source (potentially many sources) to many destinations

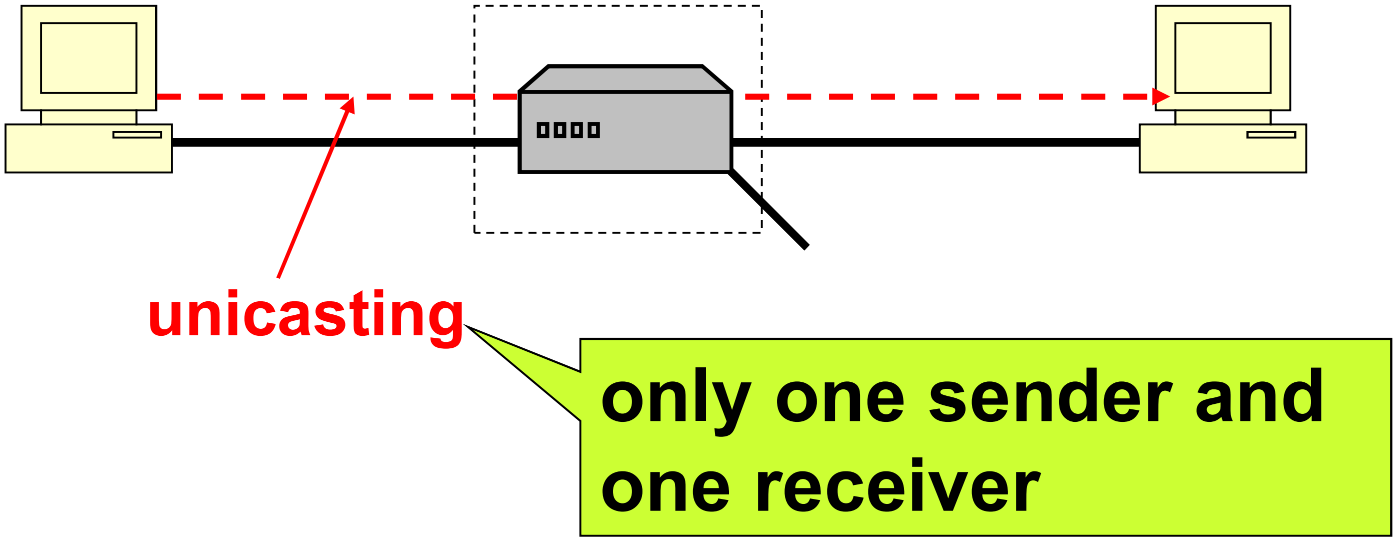
Broadcast

- A single communication channel is shared by all computers, that is, sending a message implies that all others receive it.



Unicast

- Computers are connected in pairs, that is, sending a packet goes strictly from the sender to the receiver (**unicasting**), possibly having to visit intermediate machines (*routing*).



Chapter 1: Roadmap

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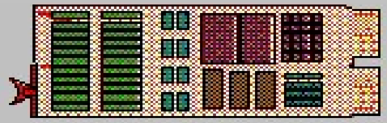
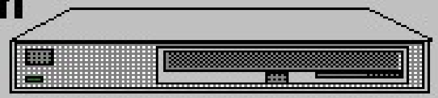
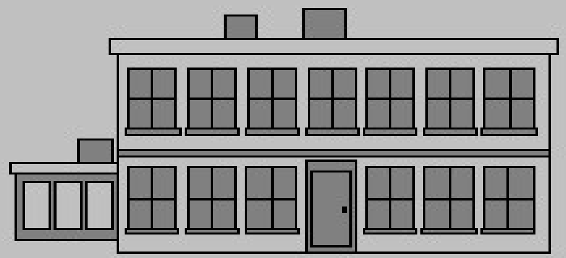
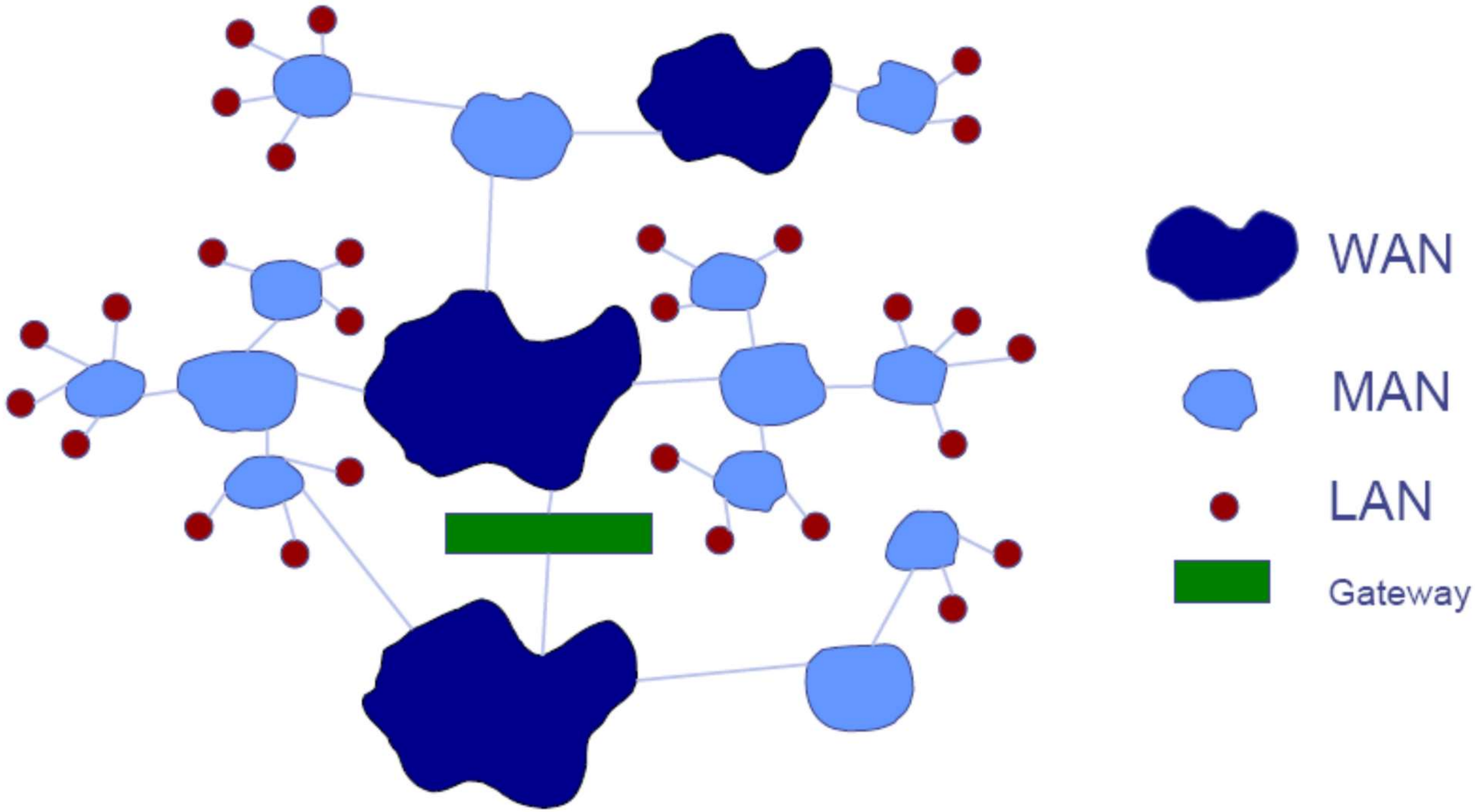
1.9 Internet History

Types of Computer 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
- **Caveat:** LAN, MAN, WAN may mean different things

Distance	Processors located in same	Network Type
0.1 m	board 	Data Flow Machine
1 m	system 	Multiprocessor
10 m	 room, building, campus	L A N Local Area Network
100 m		
1 km		
10 km	city 	W A N Wide Area Network
100 km	country	
1000 km	continent 	Interconnection of WANs
10000 km	planet	

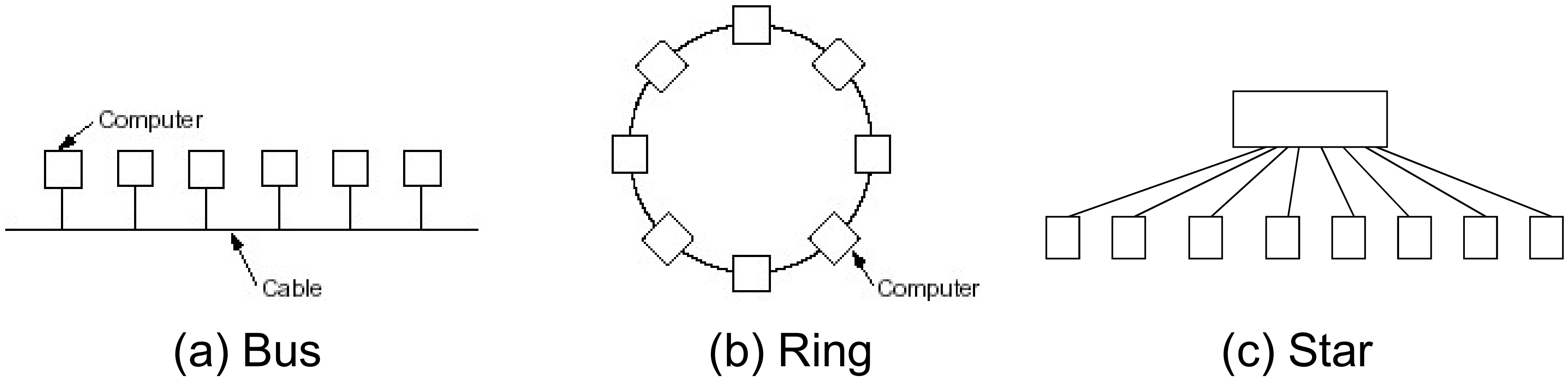


Internetwork of WAN, MAN and LAN

151

Local Area Networks (LAN)

- **Apart from scale, LANs distinguish themselves from other networks by (generally) using broadcast technology, and having simple topologies:**



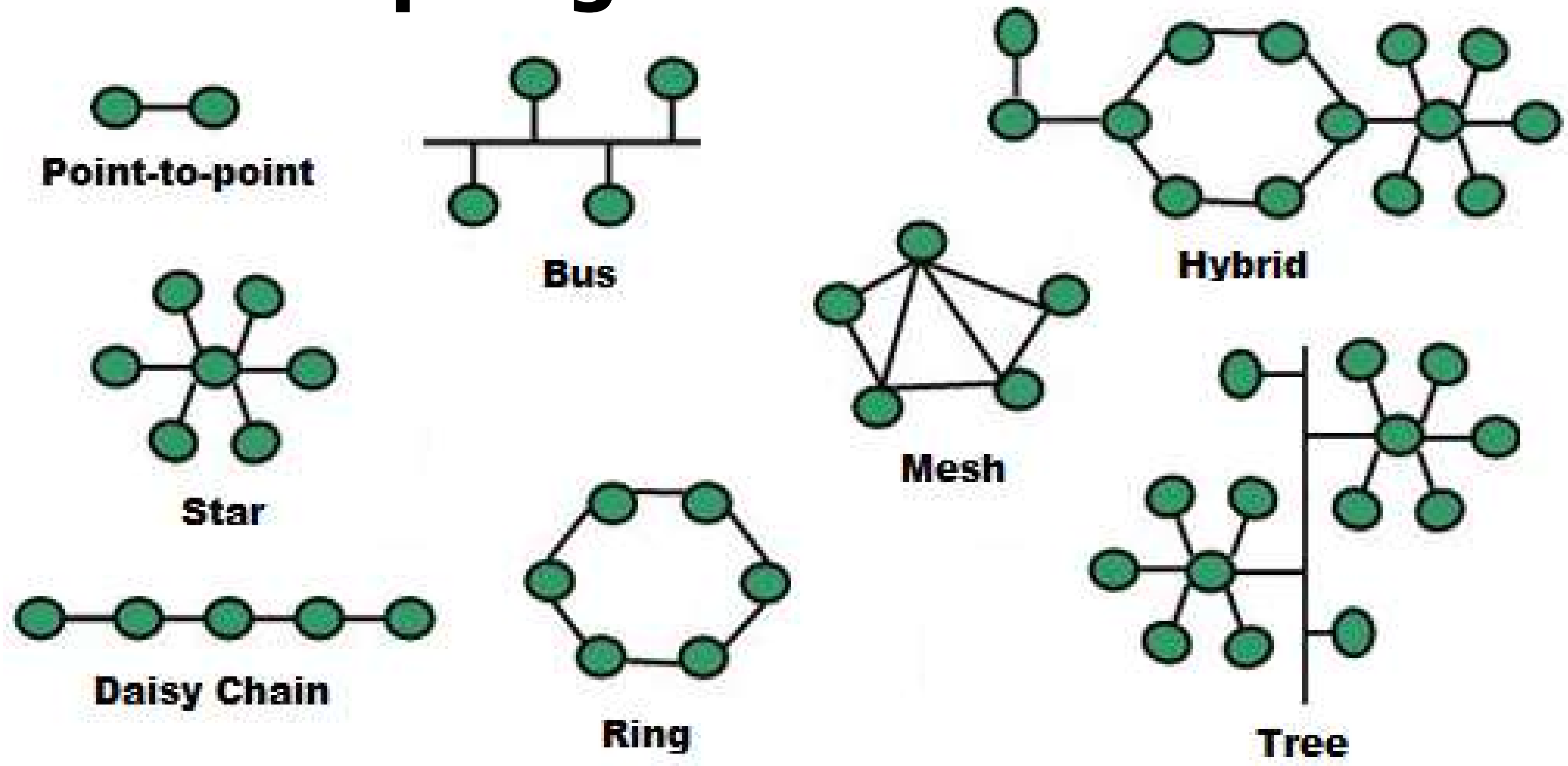
broadcast networks. (a) Bus. (b) Ring. (c) Star

Network Topology

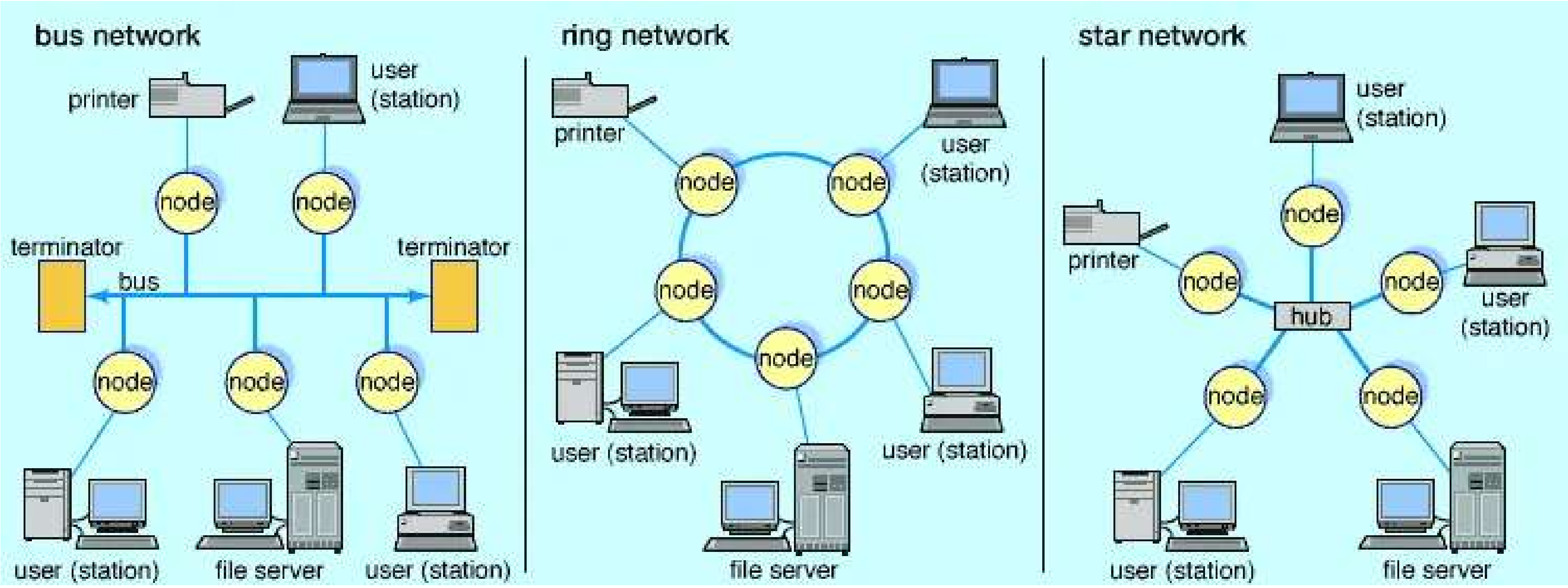
- **Computer network topology is the way various components of a network (like nodes, links, peripherals, etc.) are arranged.**
- **Network topologies define the layout, virtual shape or structure of network, not only physically but also logically.**

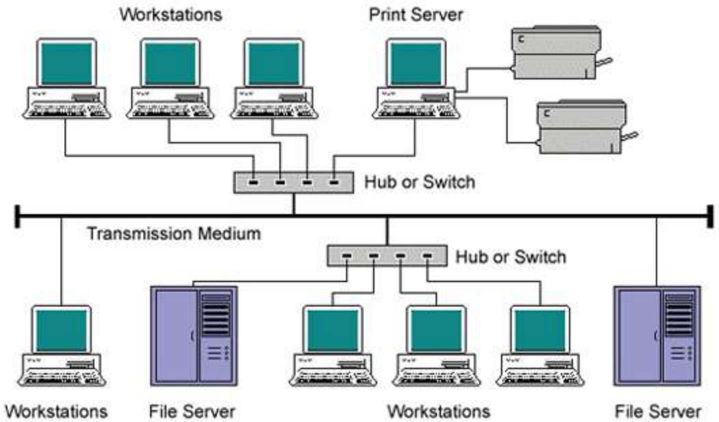
Network Topology

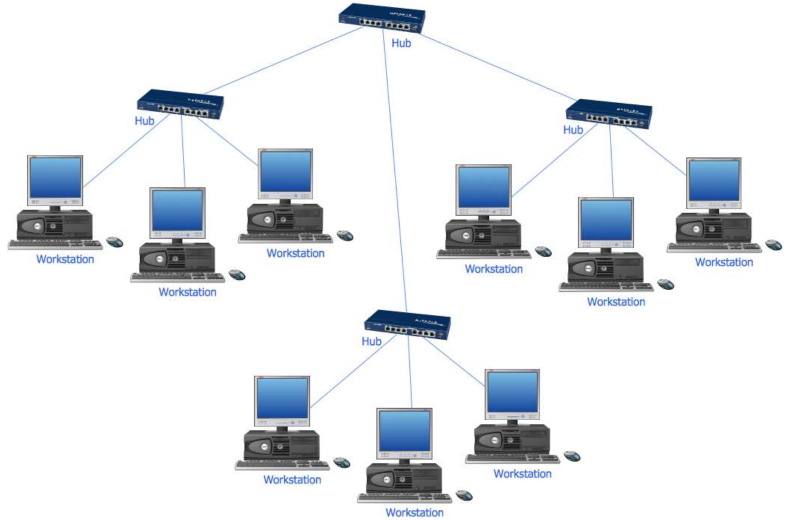
- **7 basic topologies:**



Local Area Networks (LAN)

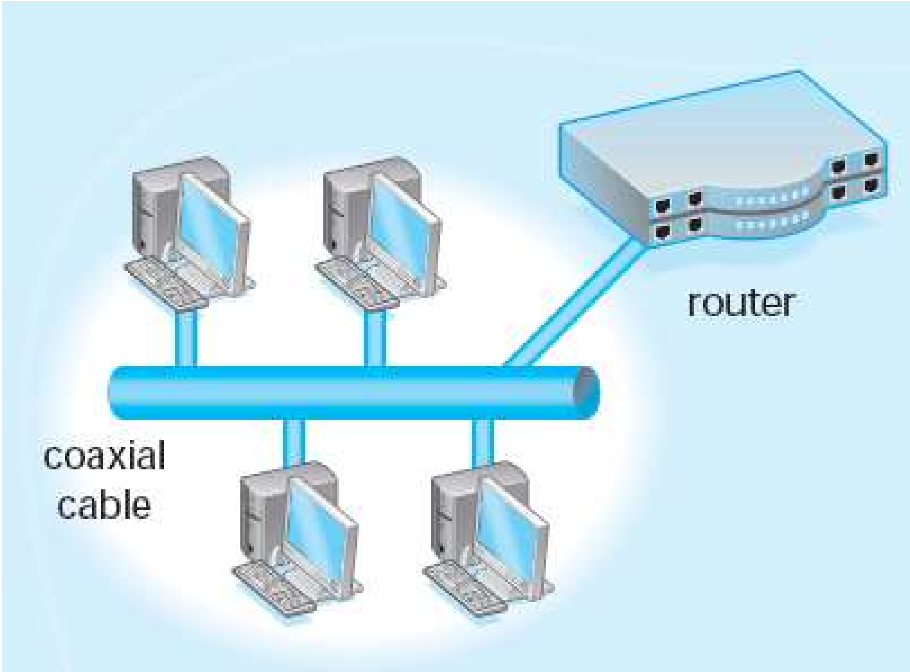






Bus Topology

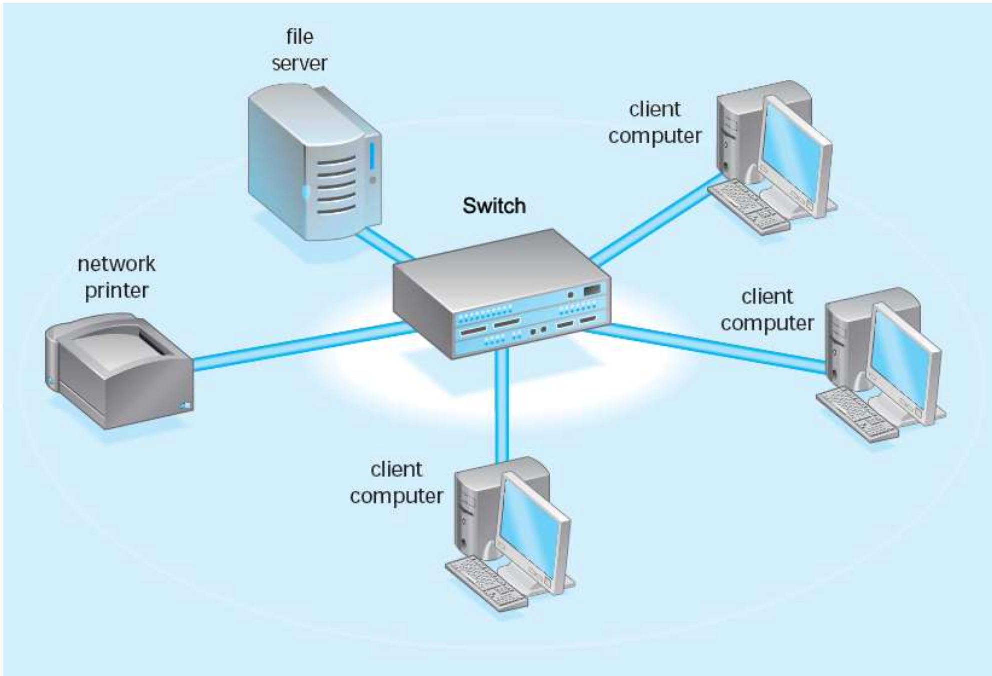
- All network devices connected to a common cable in logical linear fashion.
- Transmissions are sent along the length of the bus segment.



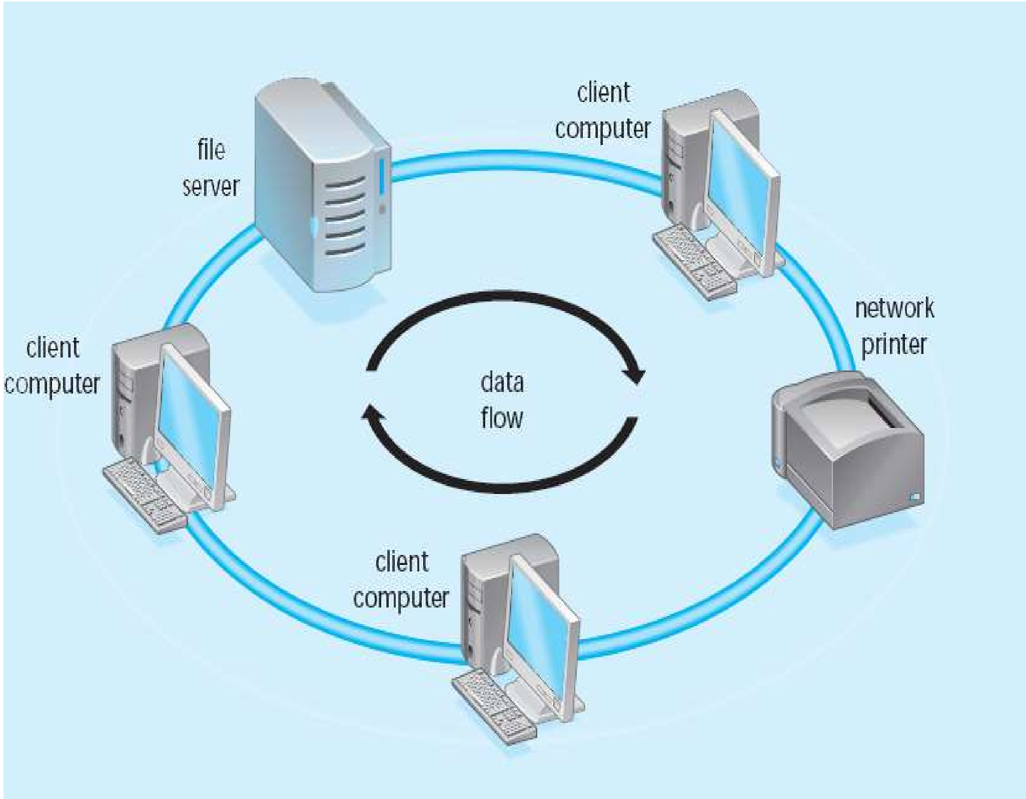
- Adding hosts to the network requires breaking the network.
- Failure of one host can cause failure of network.

Star Topology

- **Connection from each device to a central location, usually a switch.**
- **Most commonly used physical topology.**
- **Failure of one cable does not bring down network.**

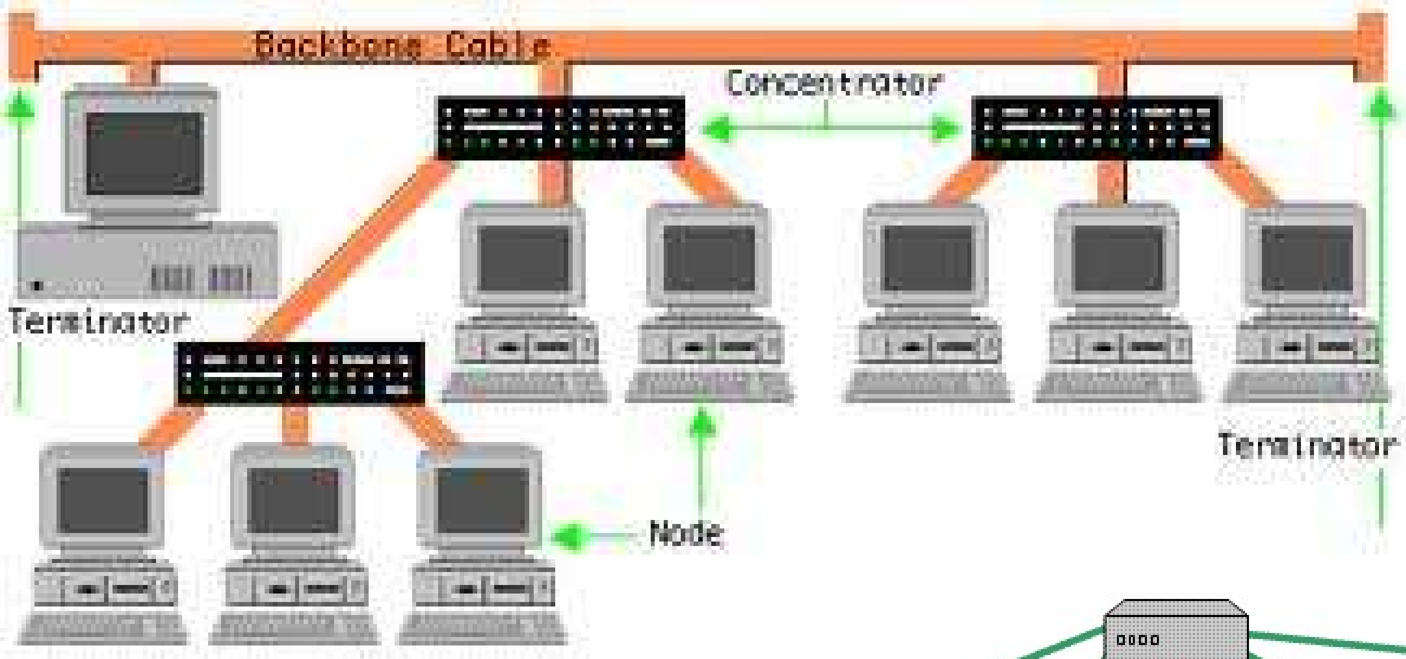


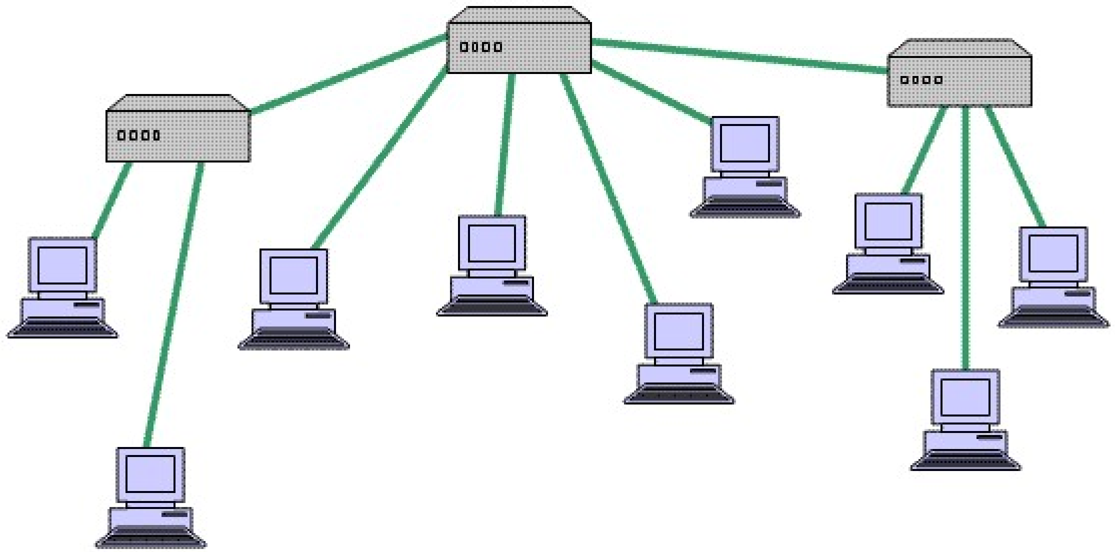
Ring Topology



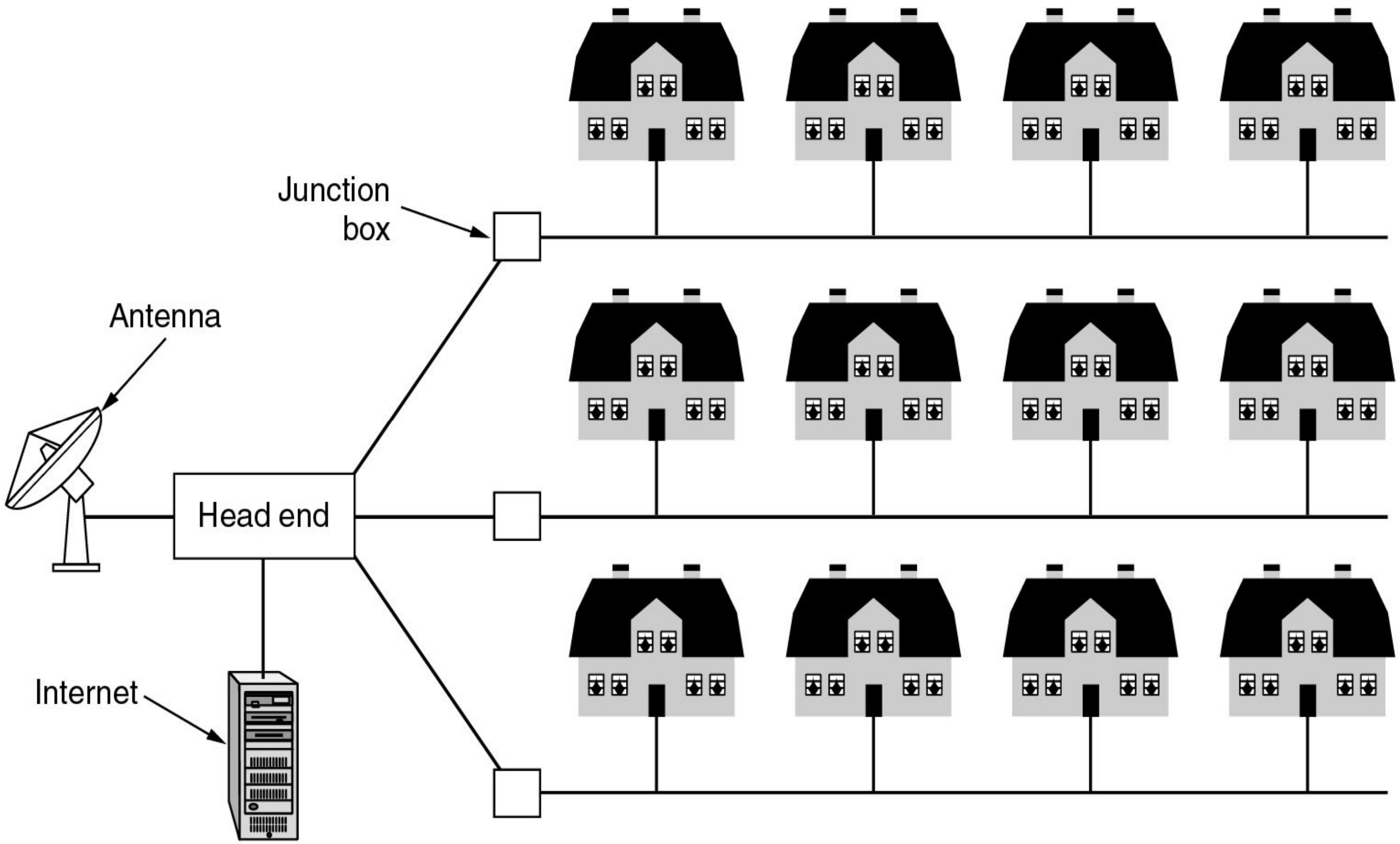
- Network is connected in an endless loop.
- No termination required.
- Uncommon topology today, more common in 1980s.

Tree Topology





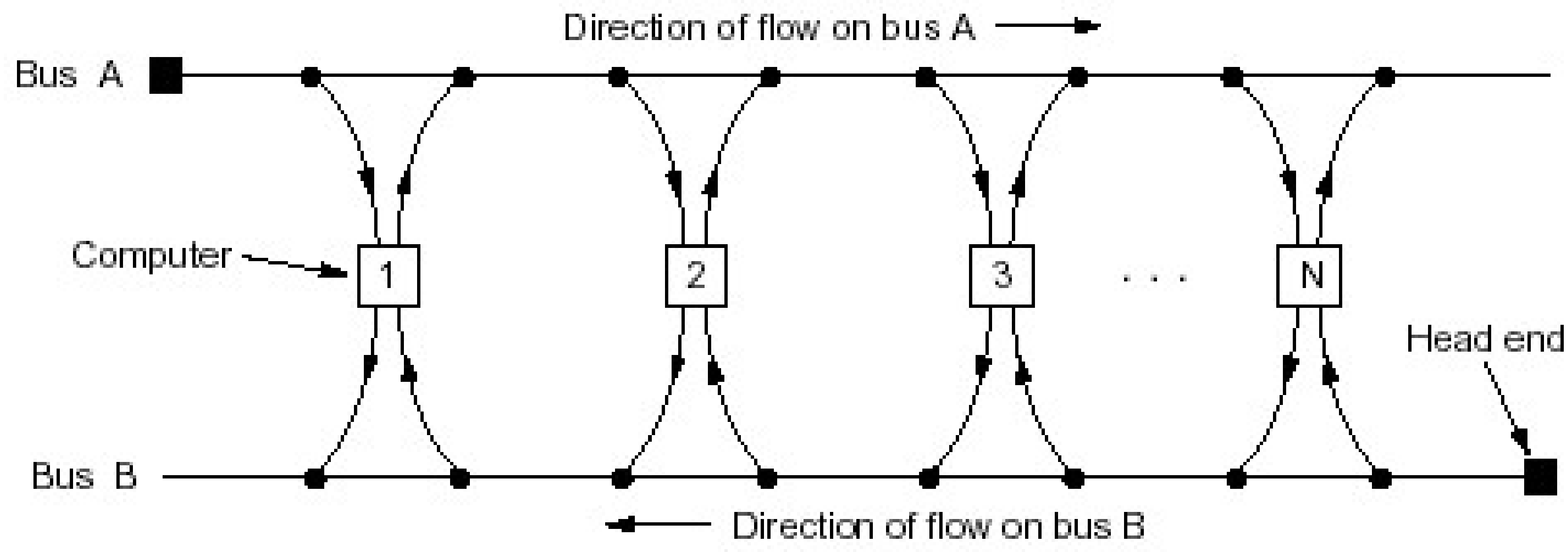
Metropolitan Area Networks (MAN)



A metropolitan area network based on cable TV.

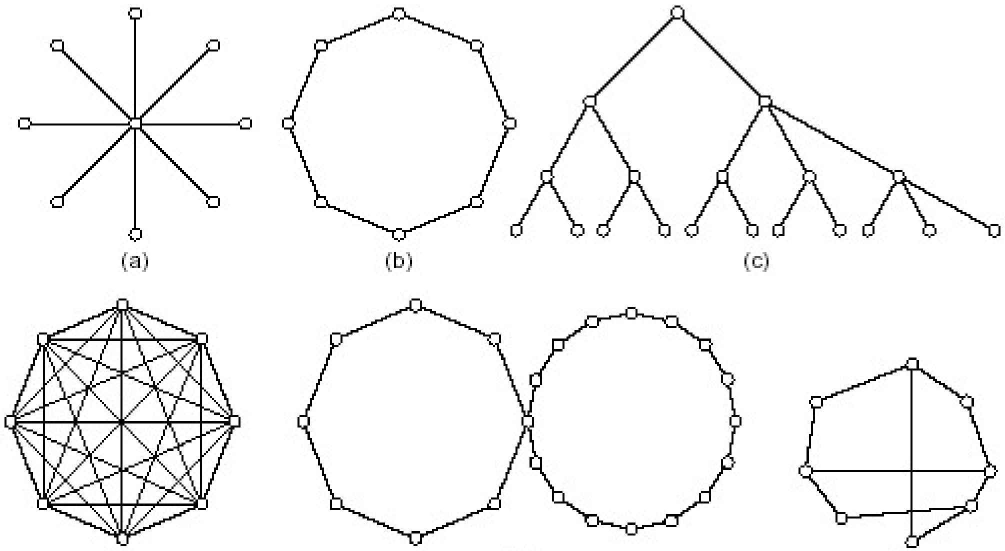
MAN: DQDB

- Basically, MANs are very similar to LANs in the sense that they also use broadcasting technology. **However,** to achieve scalability, a different mechanism is used: Distributed Queue, Dual Bus



WAN Topologies

- In contrast to LANs and MANs, the organization of a WAN in terms which hosts are interconnected is important

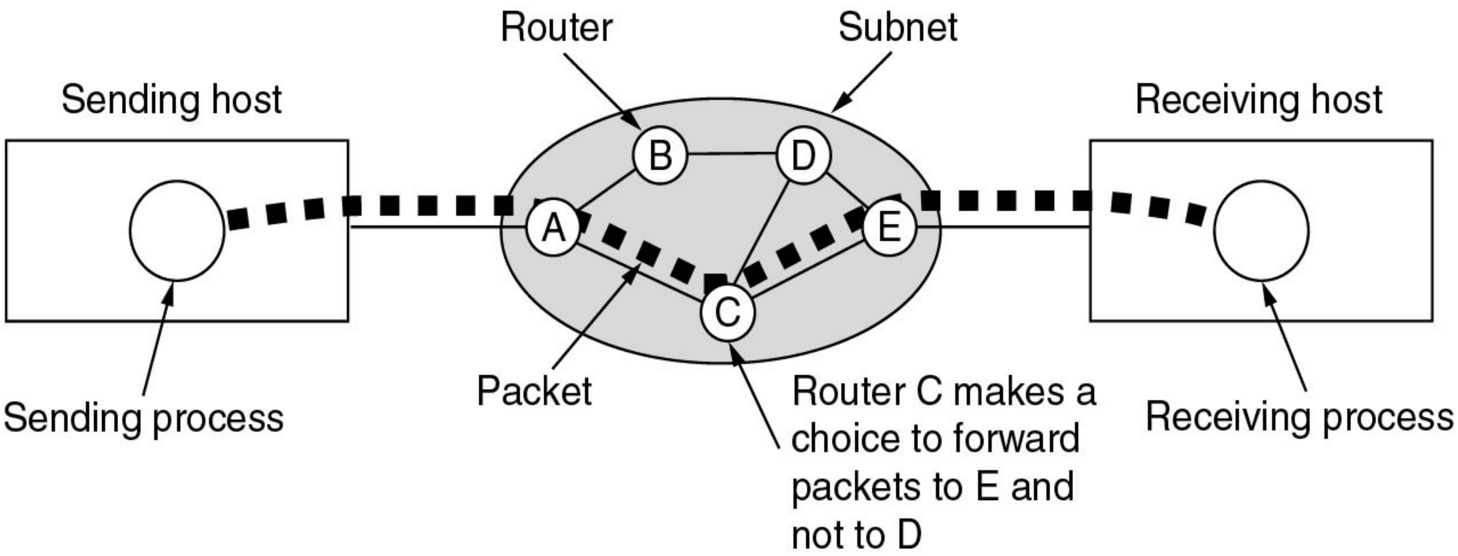


(a) (b) (c) (d) (e) (f)

- Most often you'll see **arbitrary topologies**; the others are used in application-specific ways (mostly star, ring, and tree)

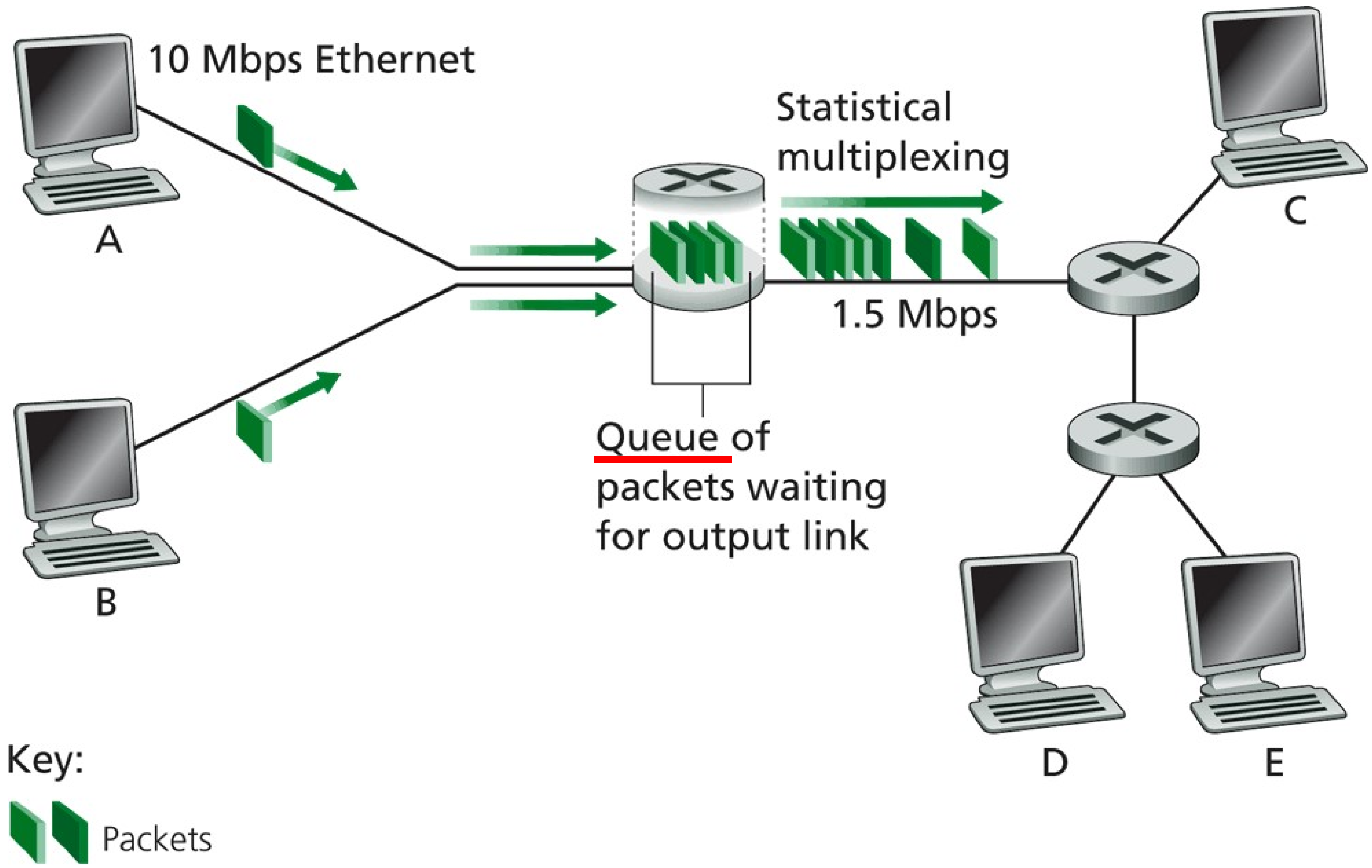
Wide Area Networks (WAN)

- In a WAN, hosts are connected to a subnet, which in turn consists of routers (switching elements) and trunks.
- Routers generally adhere to a **store-and-forward principle**



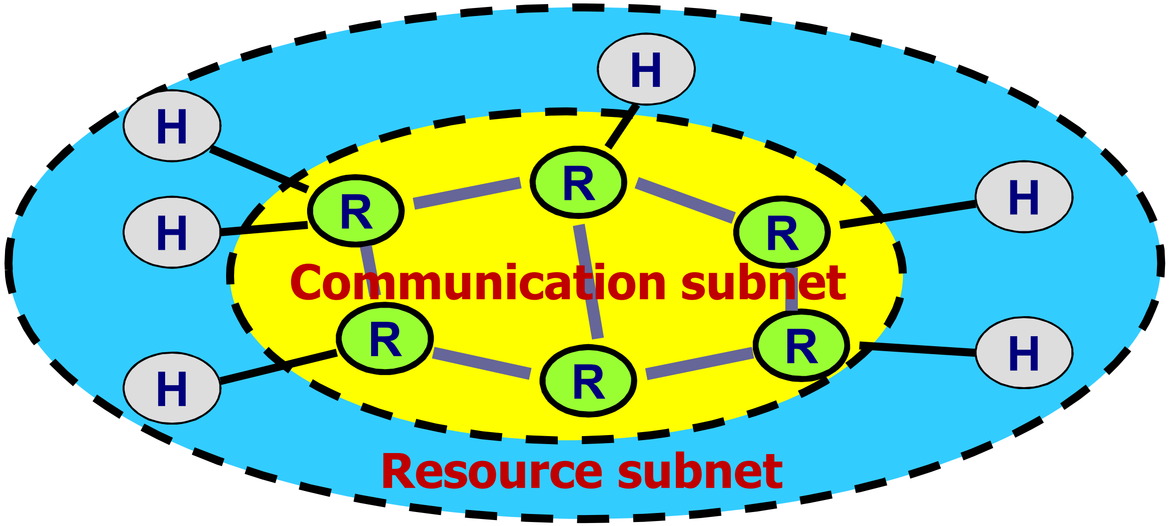
A stream of packets from sender to receiver.

Wide Area Networks (WAN)



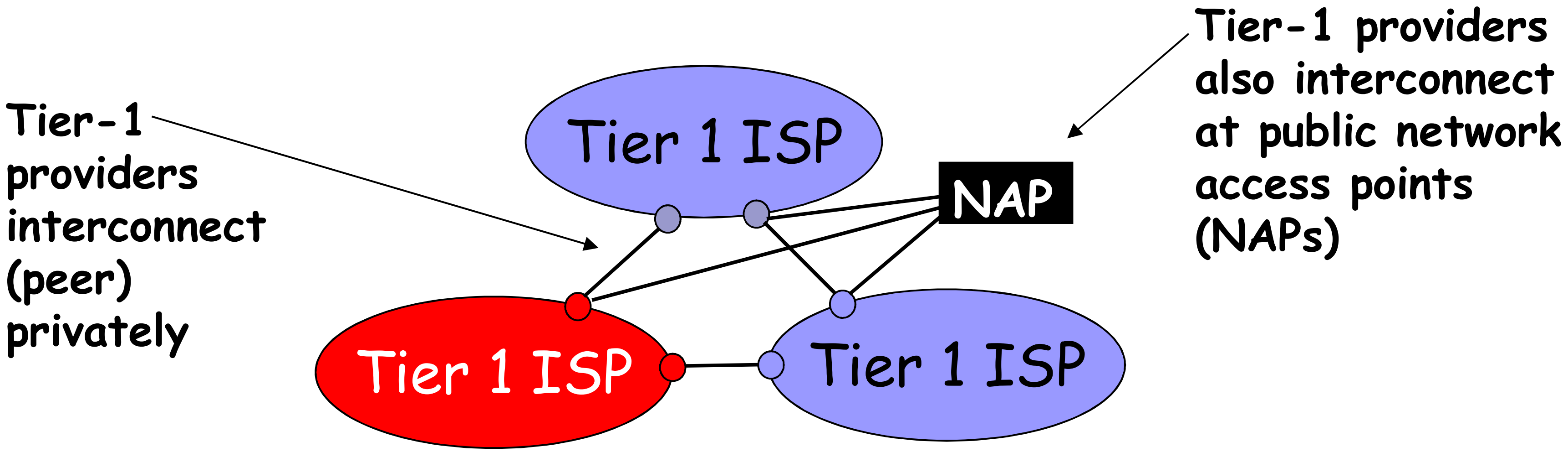
WAN consists of two subnets

- **Resource subnet**
  - Includes computers, terminals, programs, etc.
  - Responsible for information processing
- **Communication subnet**
  - Includes transportation lines, switching elements (routers and switches, etc.)
  - Responsible for information delivery and distribution



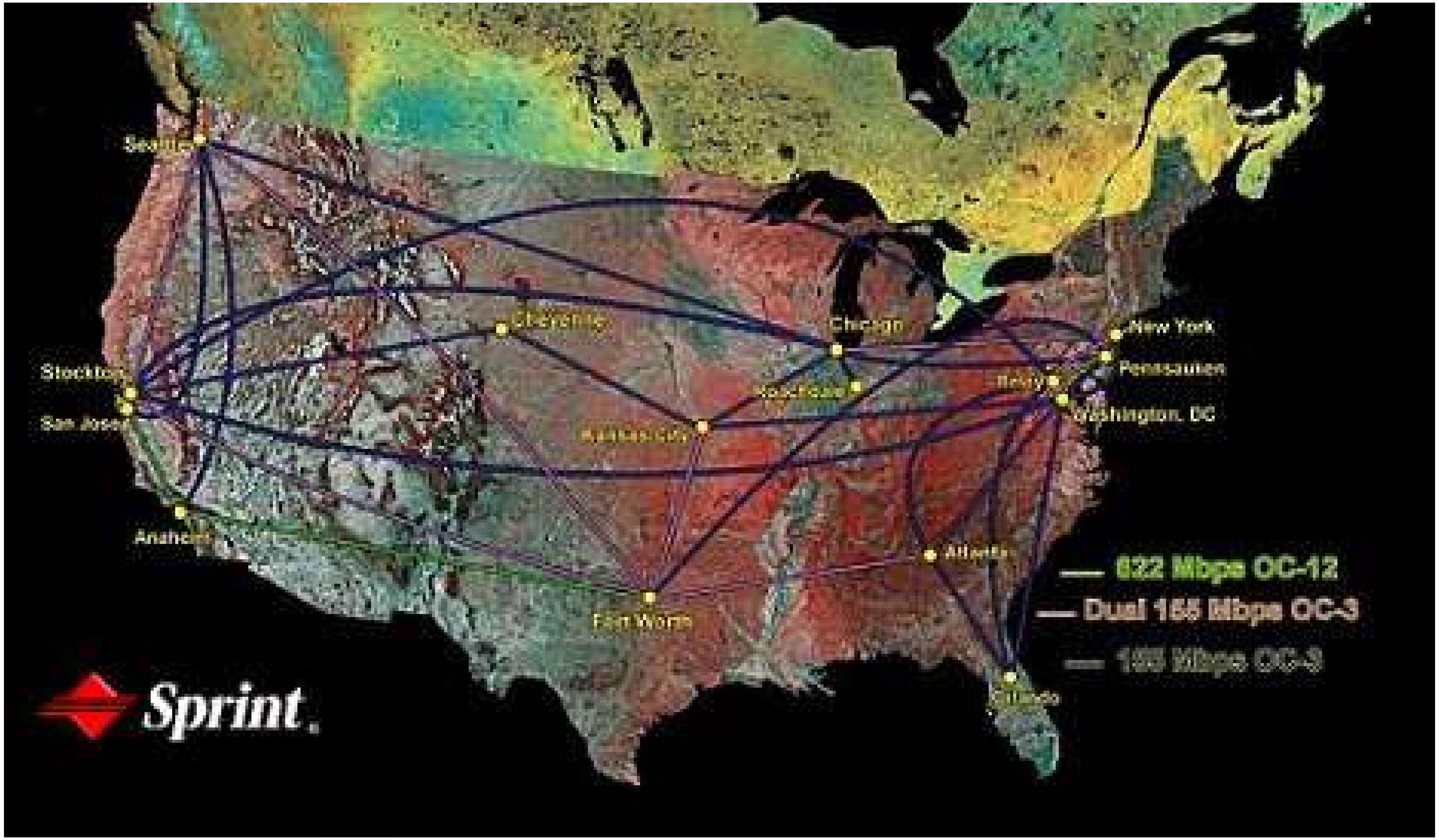
Internet topology: network of networks

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



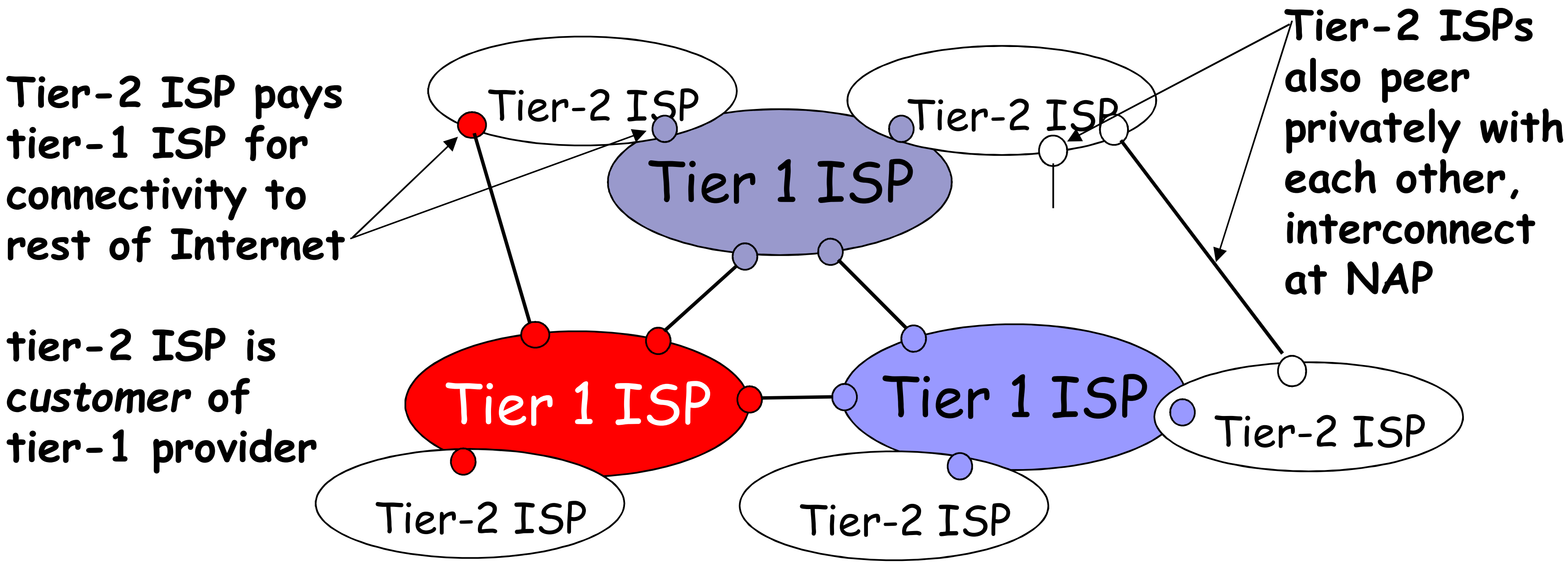
Tier-1 ISP: e.g., Sprint

Sprint US backbone network



Tier-2 ISP: smaller ISP

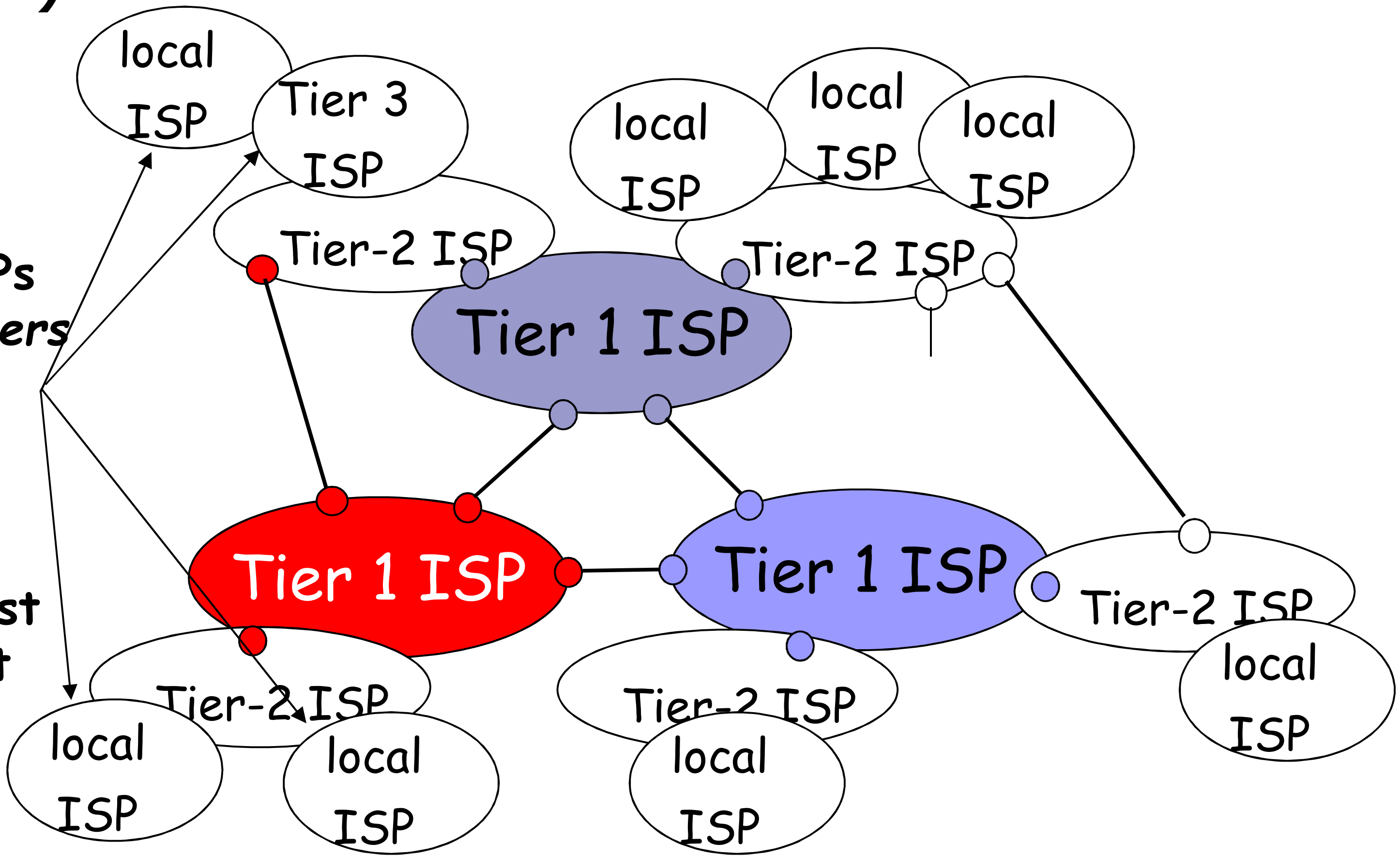
- Connect to one or more tier-1 ISPs, possibly other tier-2 ISPs



Tier-3 ISPs and local ISPs

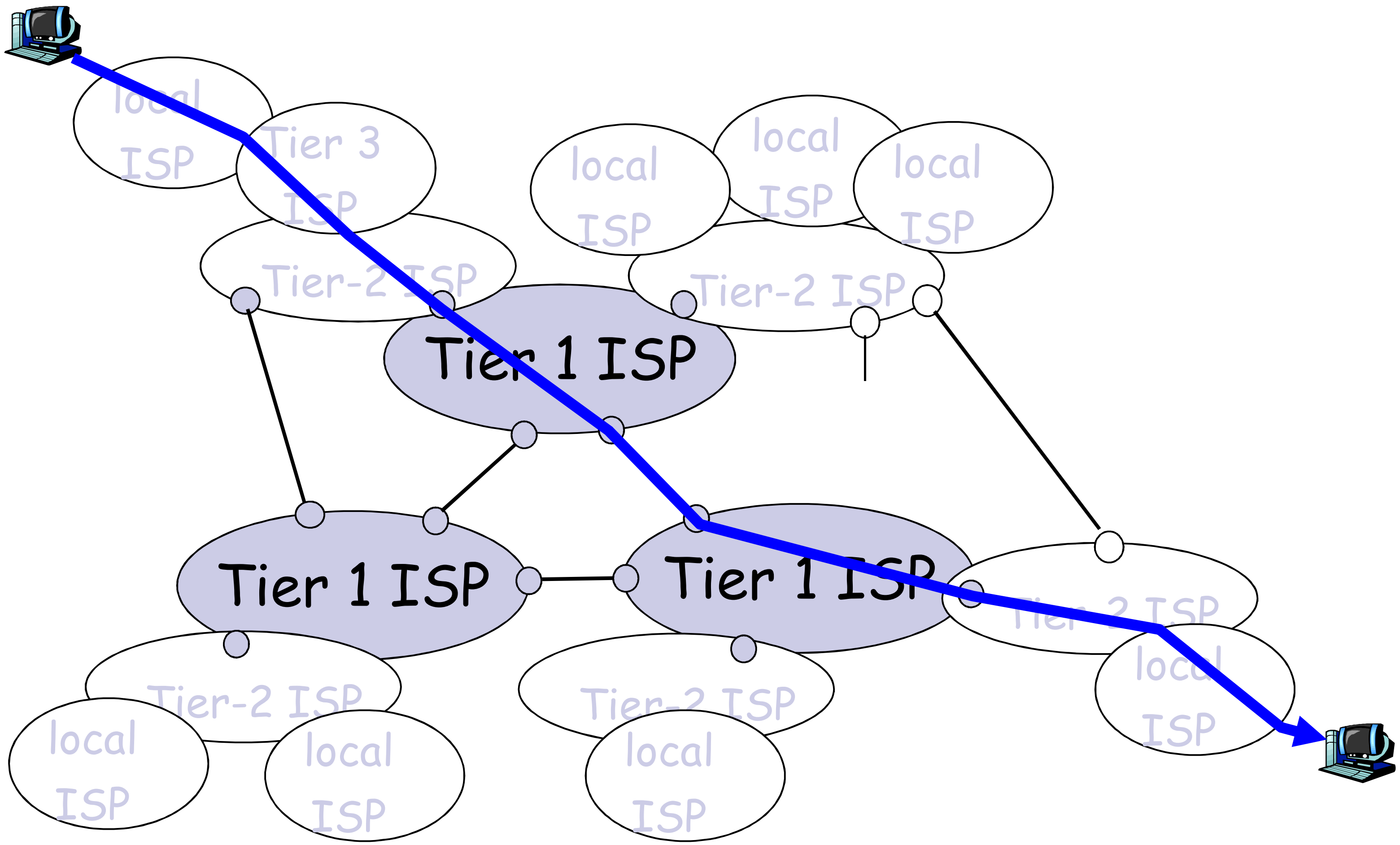
- last hop ("access") network (closest to end systems)

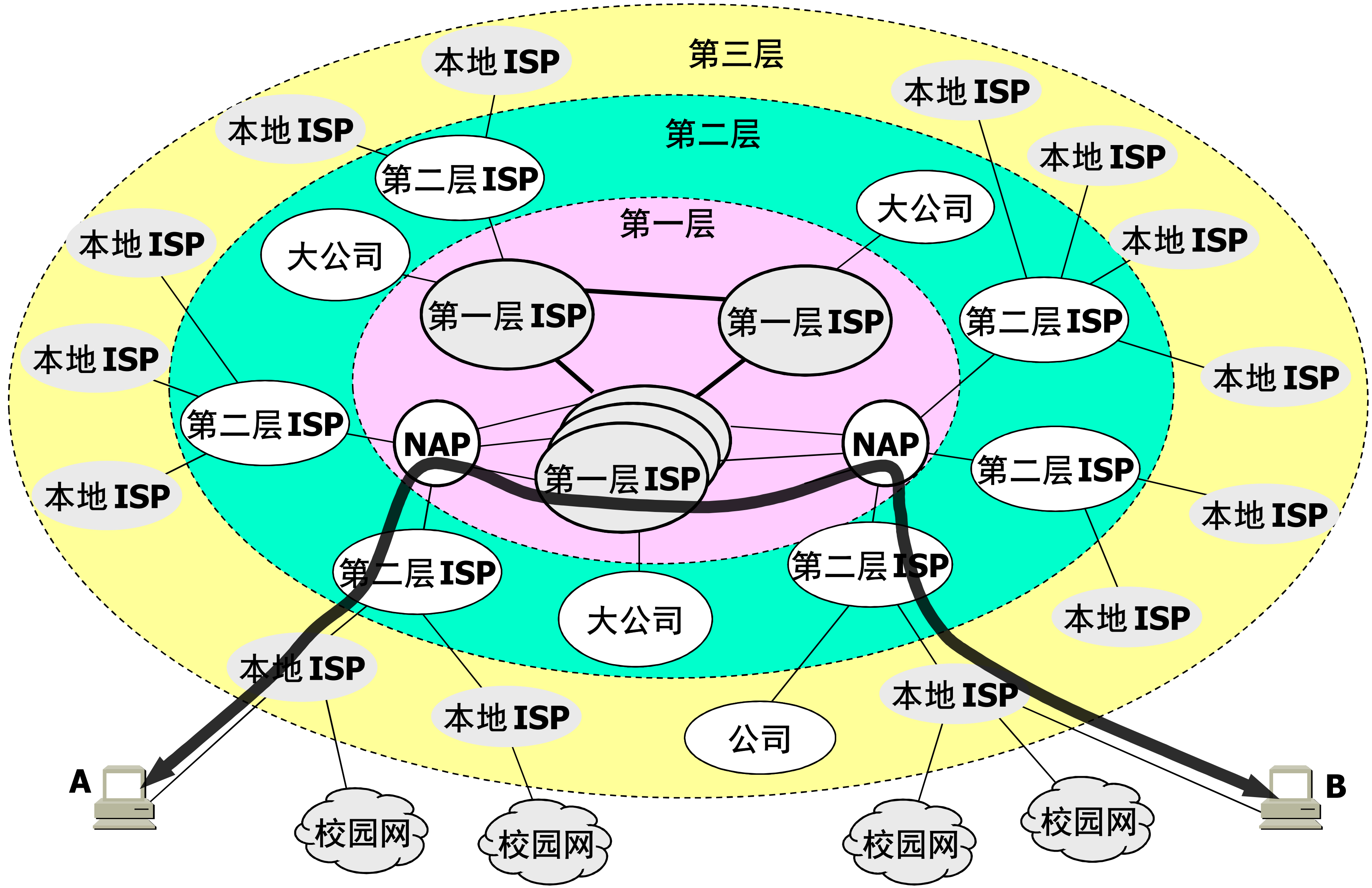
Local and tier- 3 ISPs are *customers* of higher tier ISPs connecting them to rest of Internet



Internet topology: network of networks

- **a packet passes through many networks!**





主机A → 本地 ISP → 第二层 ISP → NAP → 第一层 ISP → NAP → 第二层 ISP → 本地 ISP → 主机B

Chapter 1: Roadmap

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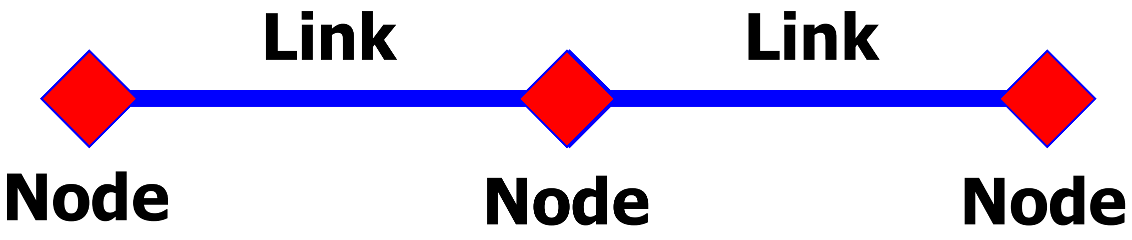
Nodes and Links

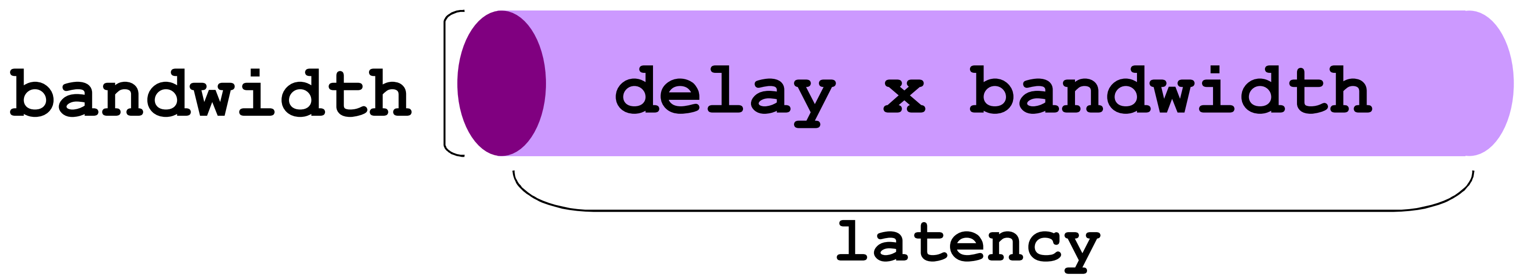
- **Link:** transmission technology
  - Twisted pair, optical, radio, whatever

- **Node:** computational devices on end of links
  - **Host:** general-purpose computer
  - **Network node:** switch or router



Properties of Links

- **Latency (delay)**
  - Time for data sent along the link
  - Corresponds to the "length" of the link
- **Bandwidth (capacity)**
  - Amount of data sent (or received) per unit time
  - Corresponds to the "width" of the link
- **Bandwidth-delay product: (BDP)**
  - Amount of data that can be "in flight" at any time
  - Propagation delay $\times$ bits/time = total bits in link



Examples of Bandwidth-Delay

- **Same city over slow link:**
  - Bandwidth: ~100mbps
  - Latency: ~ 0.1msec
  - BDP: ~ 10^4 bits ~ 1.25 MBytes
- **Cross-country over fast link:**
  - Bandwidth: ~10Gbps
  - Latency: ~ 10msec
  - BDP: ~ 10^8 bits ~ 12.5 GBytes
- **Another example where the Internet has to be prepared for a wide range of conditions!**

Utilization

- Fraction of time link is busy transmitting
  - Often denoted by ρ

- Ratio of arrival rate to bandwidth
  - Arrival: A bits/sec on average
  - Bandwidth: B bits/sec
  - Utilization $\rho = A/B$

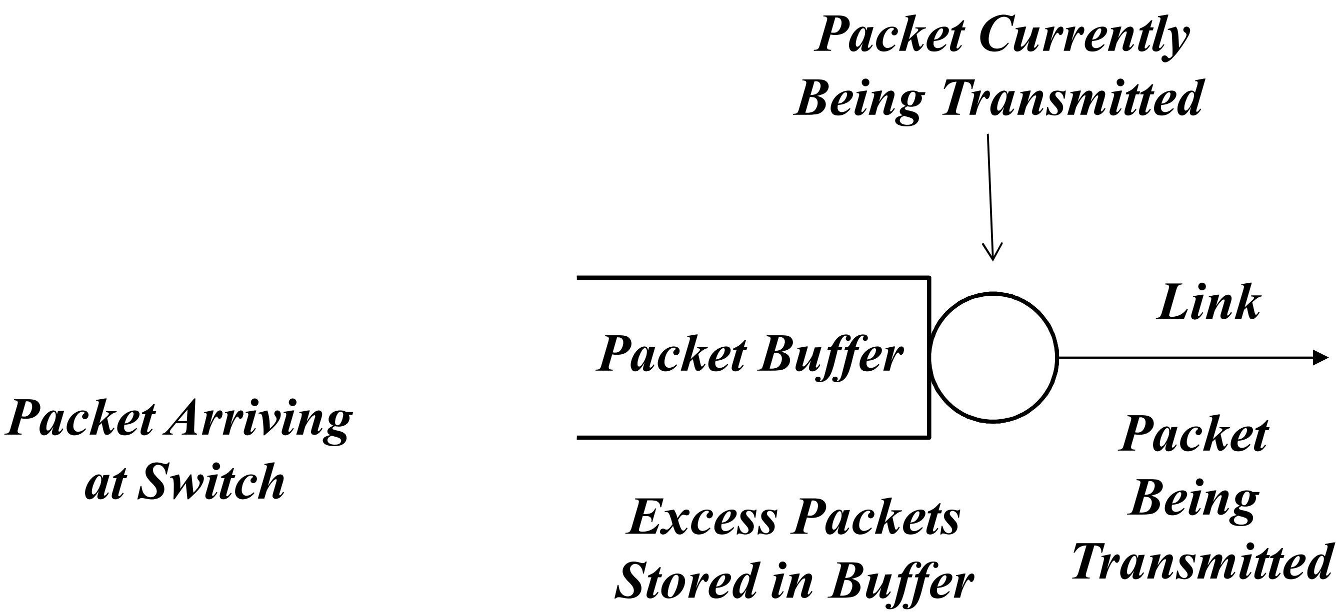
Packet Switching

Packet	Header	Payload

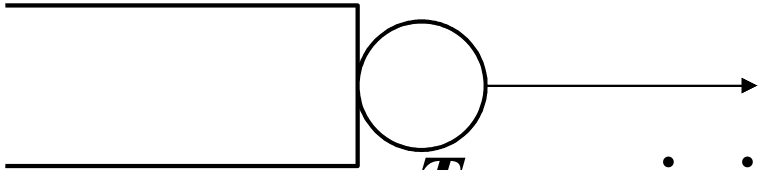
- **Header**
  - Instructions to the network for how to handle packet
  - Think of the header as an interface!

- **Payload (Body)**
  - Data being transferred

The Lifecycle of Packets



The Delays of Their Lives



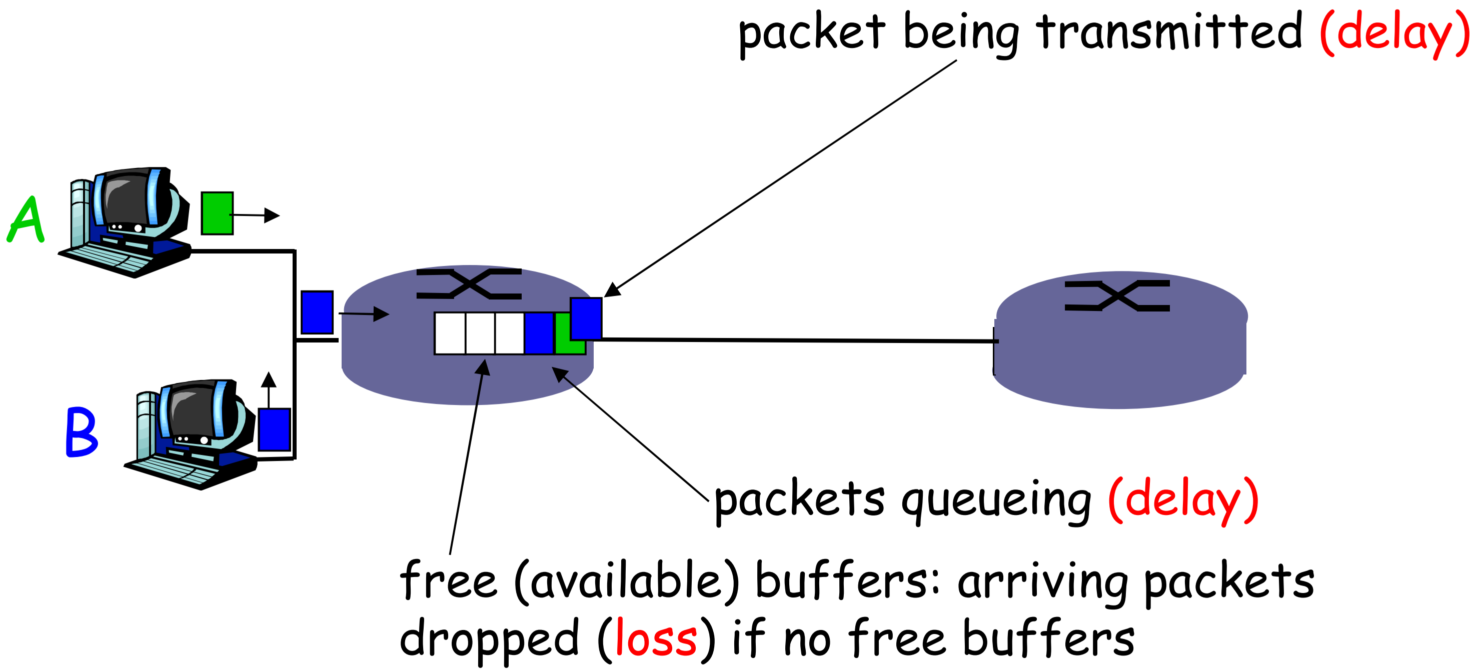
Round-Trip Time (RTT) is the time it takes a packet to reach the destination and the response to return to the sender

Propagation Delay is how long it takes to reach the next switch after transmission

How do loss and delay occur?

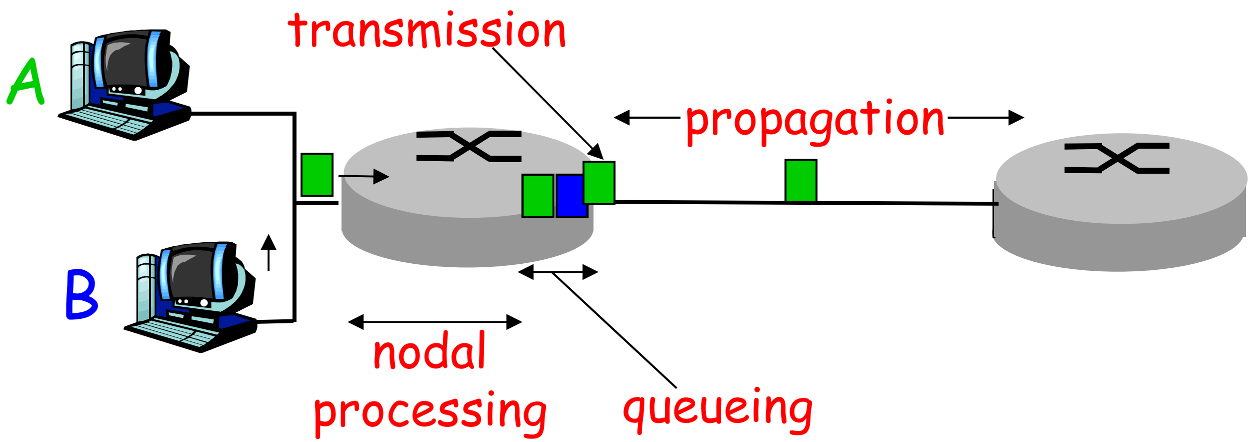
packets *queue* in router buffers

- **packet arrival rate to link exceeds output link capacity**
- **packets queue, wait for turn**



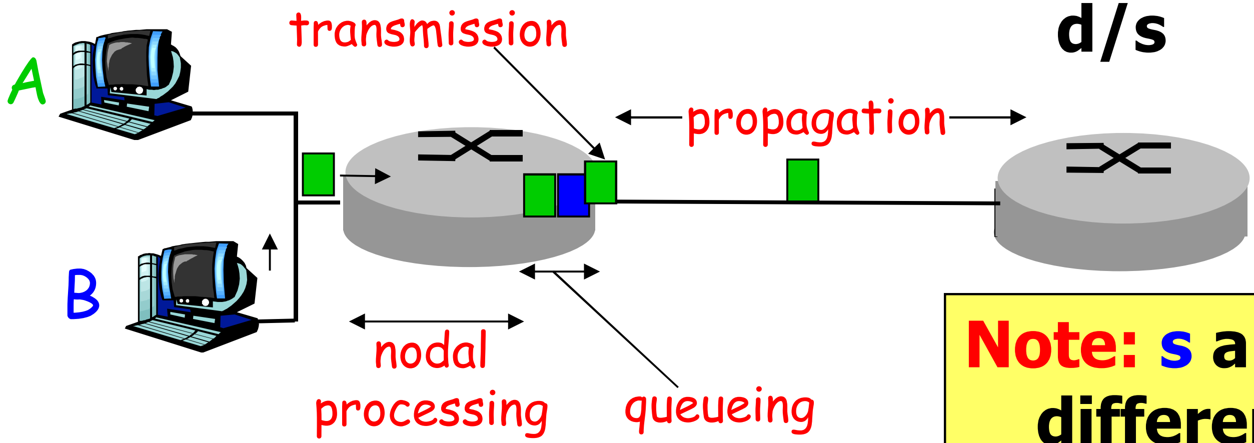
Four sources of packet delay

- **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:**
  - R=link bandwidth (bps)
  - L=packet length (bits)
  - time to send bits into link = L/R
- **4. Propagation:**
  - 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!

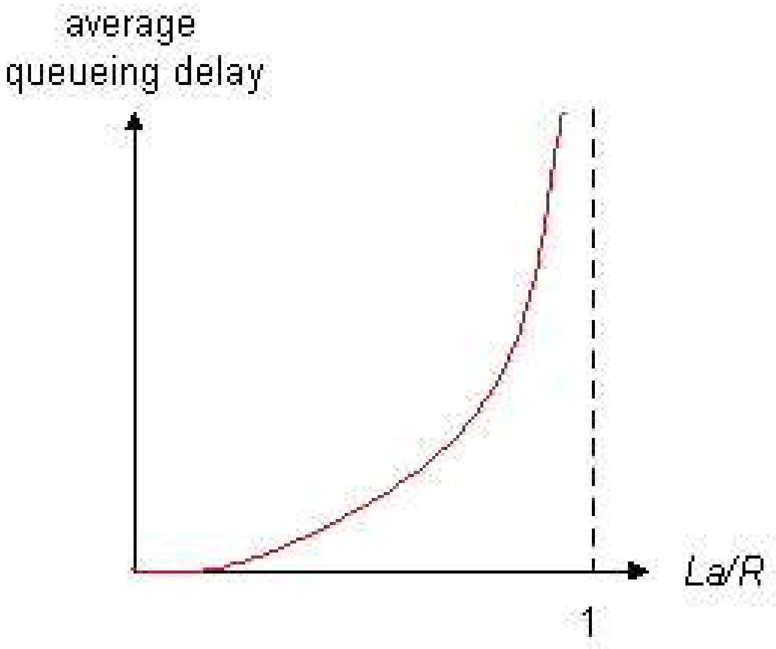
Nodal delay

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

- 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
  - a few microsecs to hundreds of msecs

Queueing delay (revisited)

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

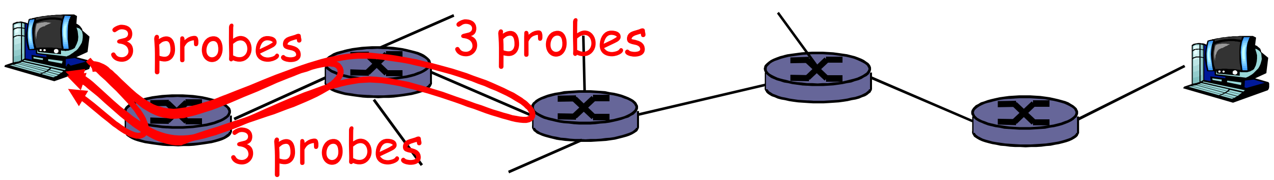


traffic intensity = La/R

- 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!

"Real" Internet delays and routes

- **What do "real" Internet delay & loss look like?**
- **Traceroute program: provides delay measurement from source to router along end-end Internet path towards destination. For all *i*:**
  - sends three packets that will reach router *i* on path towards destination
  - router *i* will return packets to sender
  - sender times interval between transmission and reply.



"Real" Internet delays and routes

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

Three delay measements 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 reponse (probe lost, router not replying)

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

分析举例

- 结点 A 要将一个数据块通过 1000 km 的光纤链路发送给结点 B。假设忽略处理时延和排队时延。请分别计算下列情况时的总时延，并验证“数据的发送速率越高，其传送的总时延就越小”的说法是否正确。
  - （1）数据块大小为 100 MB，信道带宽为 1 Mbit/s
  - （2）数据块大小为 100 MB，信道带宽为 100 Mbit/s
  - （3）数据块大小为 1 B，信道带宽为 1 Mbit/s
  - （4）数据块大小为 1 B，信道带宽为 1 Gbit/s

分析举例

- **解：**

传播时延 = 1000 km / 2.0 x 10^5 km/s = 5 ms。

(1）发送时延 = $100 \times 2^{20} \times 8 \div 10^6 = 838.9$ s，

总时延 = 838.9 + 0.005 ≈ **838.9 s**。

(2）发送时延 = $100 \times 2^{20} \times 8 \div 10^8 = 8.389$ s

总时延 = 8.389 + 0.005 = **8.394 s**。**缩小到（1）的近 1/100。**

(3）发送时延 = $1 \times 8 \div 10^6 = 8 \times 10^{-6}$ s = 8 μs，

总时延 = 0.008 + 5 = **5.008 ms**。

(4）发送时延 = $1 \times 8 \div 10^9 = 8 \times 10^{-9}$ s = 0.008 μs

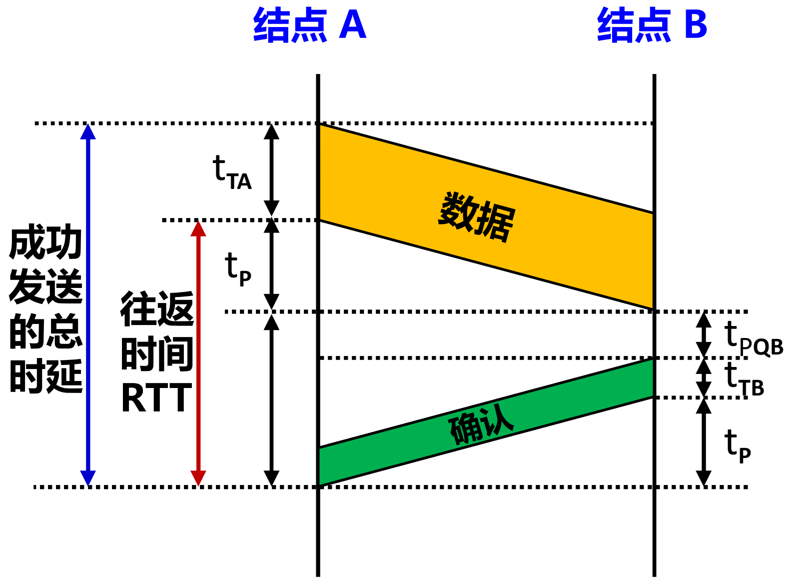
总时延 = 0.000008 + 5 = **5.000008 ms**。**与（3）相比没有明显减小。**

不能笼统地认为：“数据的发送速率越高，其传送的总时延就越小”。

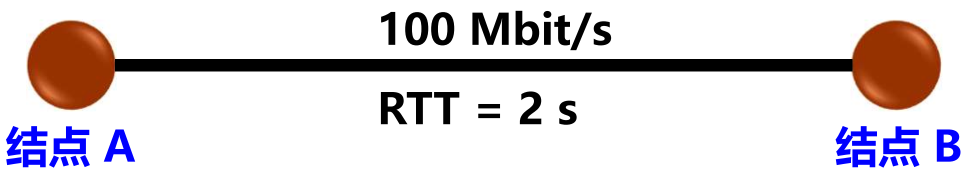
往返时间 RTT (Round-Trip Time)

- 表示从发送方**发送完数据**，到发送方**收到来自接收方的确认**总共经历的时间。

往返时间 RTT = 结点 A 到 B 的传播时延 t_P
+ 结点 B 处理和排队时延 t_{PQB}
+ 结点 B 发送时延 t_{TB}
+ 结点 B 到 A 的传播时延 t_P
= 2 x 传播时延 t_P
+ 结点 B 处理和排队时延 t_{PQB}
+ 结点 B 发送时延 t_{TB}

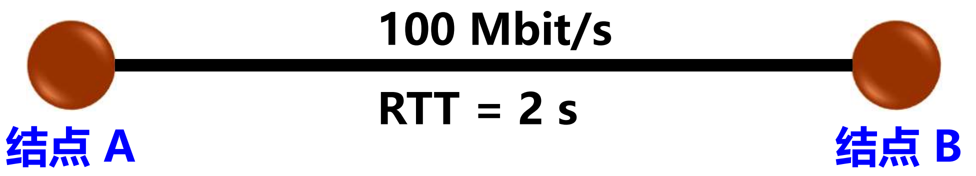


分析举例



- 结点 A 要将一个 100 MB 数据以 100 Mbit/s 的速率发送给结点 B，B 正确收完该数据后，就立即向 A 发送确认。假定 A 只有在收到 B 的确认信息后，才能继续向 B 发送数据，且确认信息很短。计算 A 向 B 发送数据的有效数据率。

分析举例



- **解:**

$$\text{发送时延} = \frac{\text{数据长度}}{\text{发送速率}} = \frac{100 \times 2^{20} \times 8}{100 \times 10^{6}} \approx 8.39\ \text{s}$$

$$\text{有效数据率} = \frac{\text{数据长度}}{\text{发送时间} + \text{RTT}} = \frac{100 \times 2^{20} \times 8}{8.39 + 2} \approx 80.7\ \text{Mbit/s}$$

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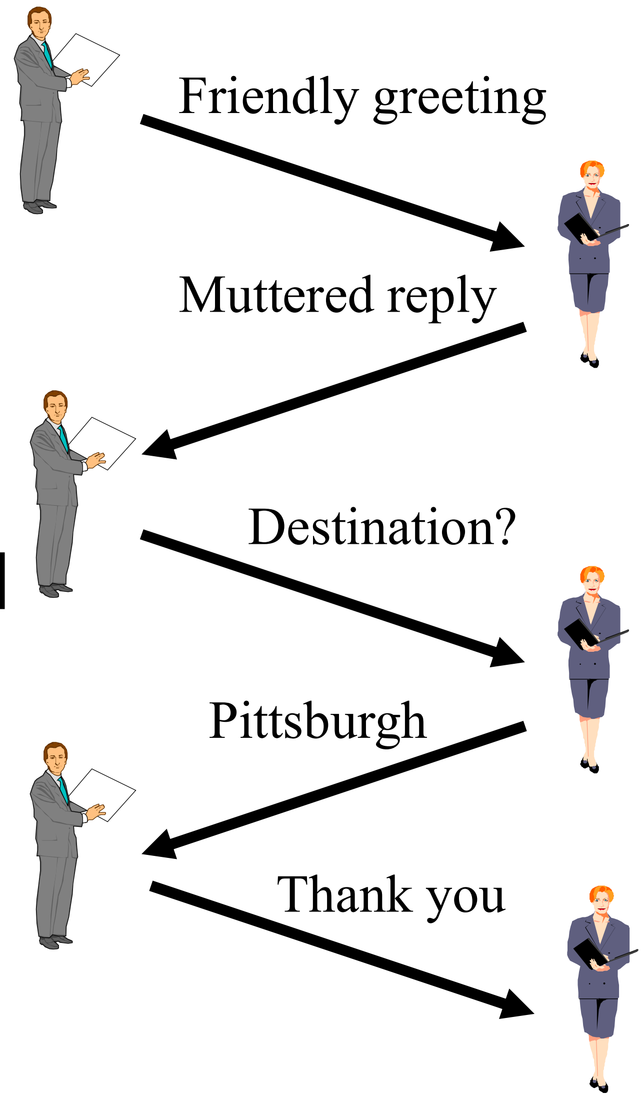
Protocols

- **Protocol:** an agreement on how to communicate
  - To exchange data
  - To coordinate sharing of resources
- Protocols specifies ***syntax*** and ***semantics.***
- **Syntax:** how protocol is structured
  - Format, order messages are sent and received
- **Semantics:** what these bits mean
  - How to respond to various messages, events, etc.

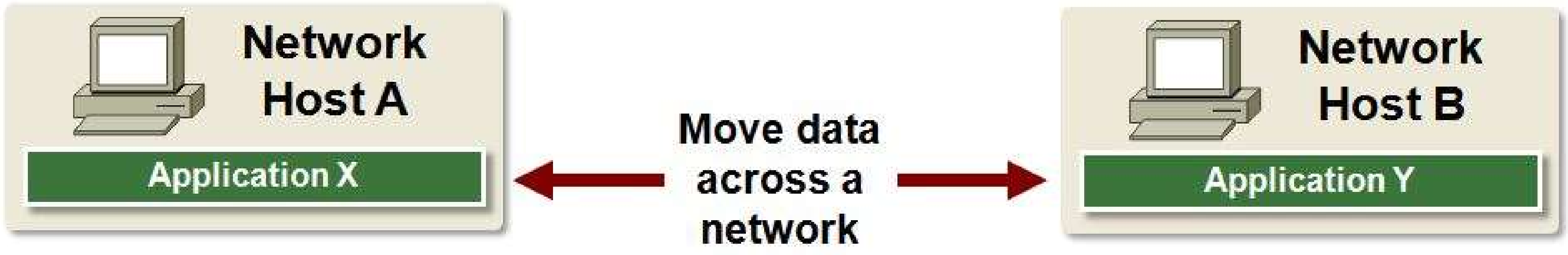


Protocol "Layers"

Networks are complex!

- many "pieces":
  - hosts
  - routers
  - links of various media
  - applications

Protocol "Layers"



Some of the applications we use require us to move data from point a to point b across a network.

Modularity in Computer Science

"Modularity based on abstraction is the way things get done"

--Barbara Liskov

Benefits of Modularity

- Implementations hidden behind clean interfaces
  - Interfaces are incarnations of abstractions
- Changes are limited in scope
- Allows for continuing evolution and innovation
- Easier to reason about

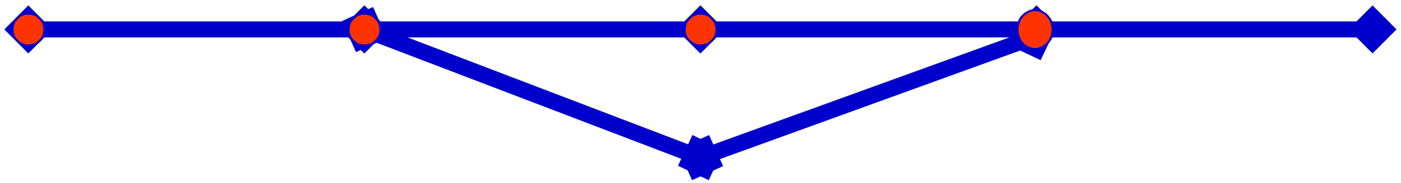
Methodology

- Break job down into smaller tasks
  - And understand how they interact
- Define abstractions for these tasks
- Then implement them…..

Tasks in Networking

- What does it take to send packets across country?
- Simplistic decomposition:
  - Task 1: send along a single wire

  - Task 2: string these together to go across country



- What makes Task 2 nontrivial?
  - Routing!

Tasks in Networking (bottom up)

- **Electrons on wire**
- **Bits on wire**
- **Packets on wire**
- **Deliver packets across local network**
  - Local addresses
- **Deliver packets across country**
  - Global addresses
- **Ensure that packets get there**
- **Do something with the data**

How do we organize these tasks?

- **Put them into "layers"**

- **Layering is a particularly strict form of modularity**
  - **Interactions limited to interfaces above and below**

- **To motivate layers, we go back to the beginning…**

You now have 1 minutes to answer…

Who invented layering?

A. ISO
B. ARPANET
C. ITU
D. Walt Disney
E. Henry Ford
F. IBM

Answer: Henry Ford

- **Before:**
  - Each person worked on the whole car
- **After:**
  - Each person only handled one particular task
  - Handed off car to next person in line
- **Only needed to understand the state of the car as it arrived, and only needed to produce the appropriate output**
  - Could remain ignorant of everything else!

Advantages of Assembly Line

- **Specialization allows people to get faster**
  - i.e., local improvements in implementation

- **If you want to change something in the car, only one person needed to know.**
  - i.e., changes of limited scope

More Layering in the Real World

- CEO A writes letter to CEO B
  - Folds letter and hands it to administrative aide
- Aide:
  - Puts letter in envelope with CEO B's name
  - Takes to FedEx
- FedEx Office
  - Puts letter in larger envelope
  - Puts name and street address on FedEx envelope
  - Puts package on FedEx delivery truck
- FedEx delivers to other company

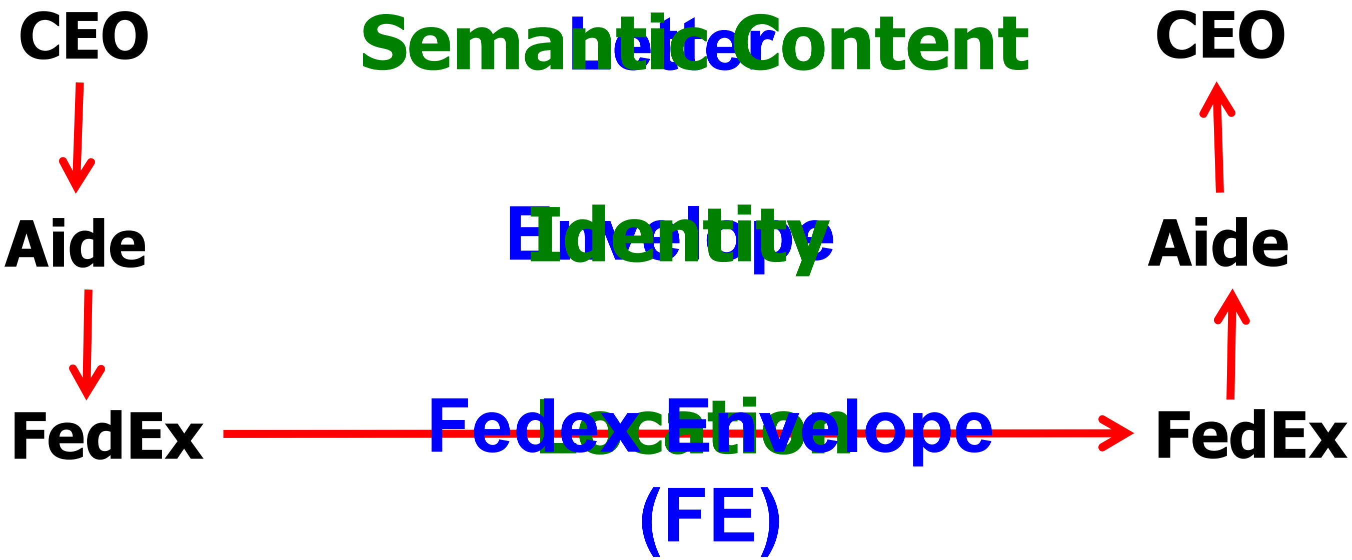
Dear Steve,

We give up. Let's merge.

--Bill

The Path of the Letter

"Peers" on each side understand the same things
No one else does
Lowest level has most packaging



The Path Through FedEx

Higher "Stack" at Ends

Highest Level of "Transit Stack" is Routing

Partial "Stack" During Transit

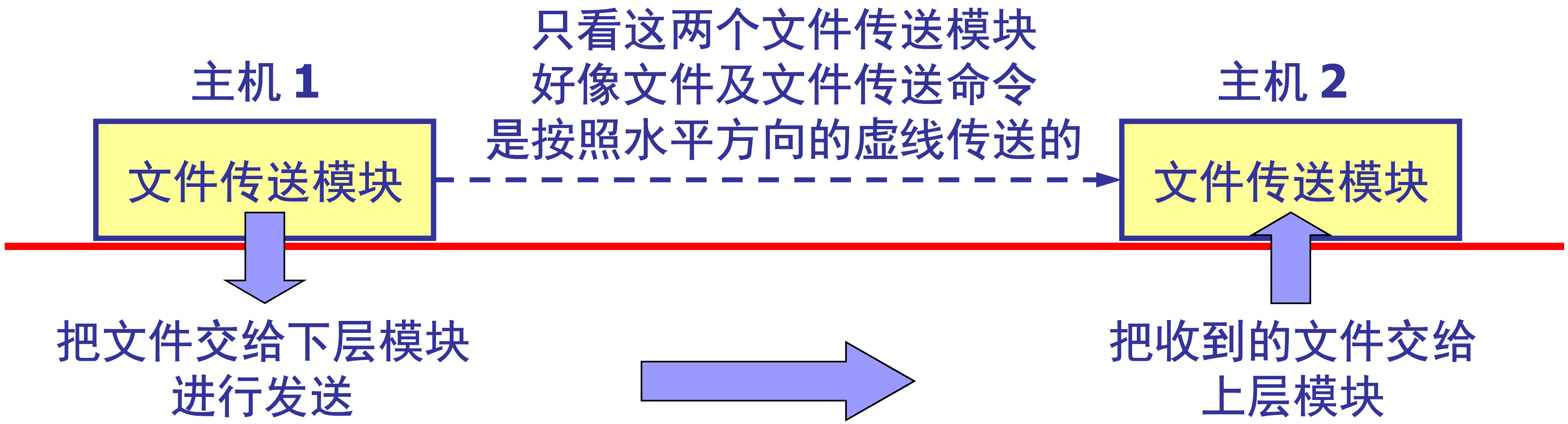
Truck				Truck
↓ FE		FE		FE ↑
Sorting Office		Sorting Office		Sorting Office
↓ Crate		Crate ↑ ↓ New Crate		Crate ↑
Airport	→	Airport	→	Airport

Deepest Packaging at the Lowest Level of Transport

How Does This Apply to Networking?

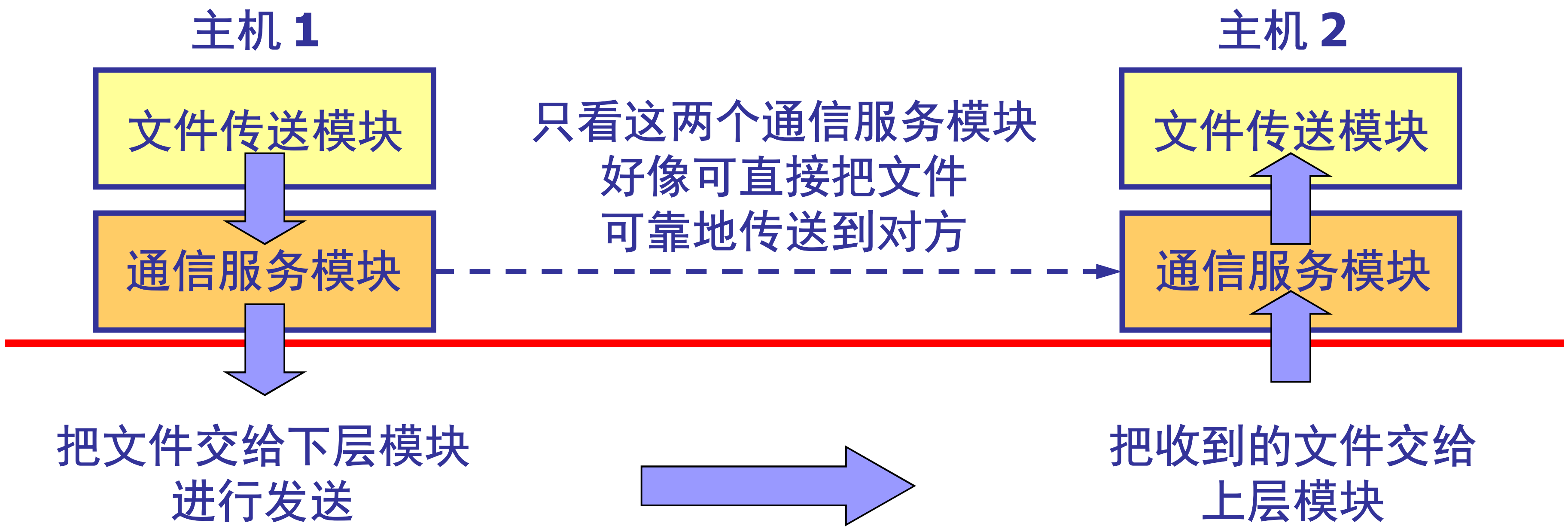
- **Let's return to task decomposition….**

两个主机交换文件

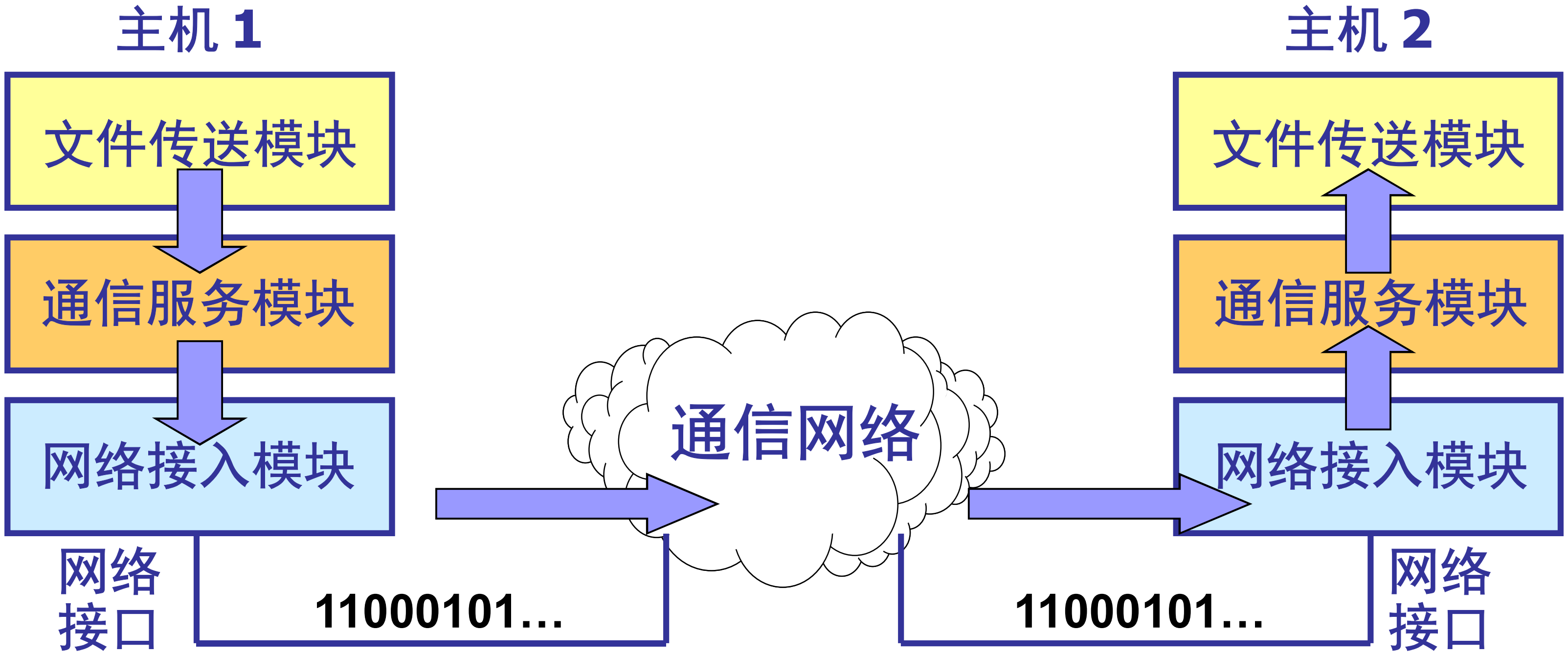


只看这两个文件传送模块
好像文件及文件传送命令
是按照水平方向的虚线传送的
主机 1
文件传送模块
把文件交给下层模块
进行发送
主机 2
文件传送模块
把收到的文件交给
上层模块

再设计一个通信服务模块



再设计一个网络接入模块



网络接入模块负责做与网络接口细节有关的工作，例如，规定传输的帧格式，帧的最大长度等。

Tasks in Networking

- Electrons on wire
- Bits on wire
- Packets on wire
- Deliver packets across local network
  - Local addresses
- Deliver packets across country
  - Global addresses
- Ensure that packets get there
- Do something with the data

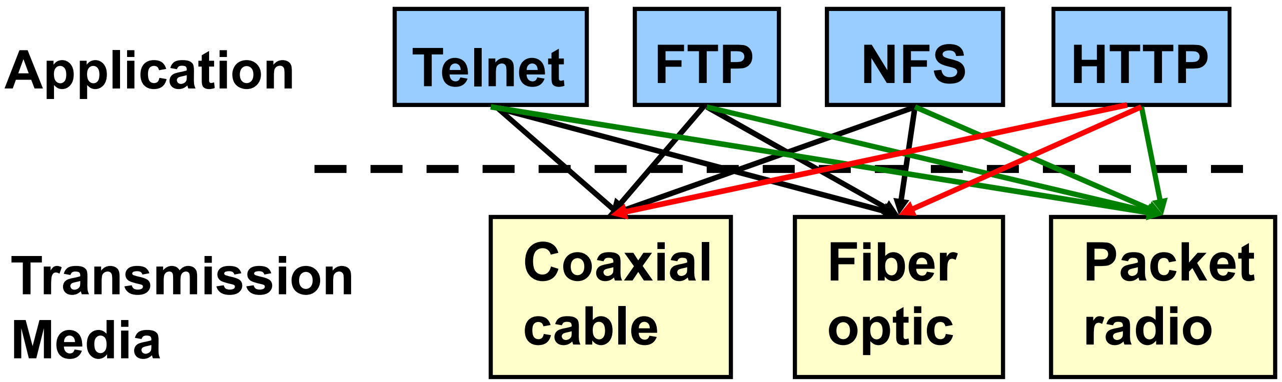
Resulting Layers

- Electrons on wire
- Bits on wire **(Physical)**
- Packets on wire (contained in next layer)
- Deliver packets across local network **(Data Link)**
  - Local addresses
- Deliver packets across country **(Network)**
  - Global addresses
- Ensure that packets get there **(Transport)**
- Do something with the data **(Application)**

What is Layering?

- **A technique to organize a network system into a succession of logically distinct entities, such that the service provided by one entity is solely based on the service provided by the previous (lower level) entity**

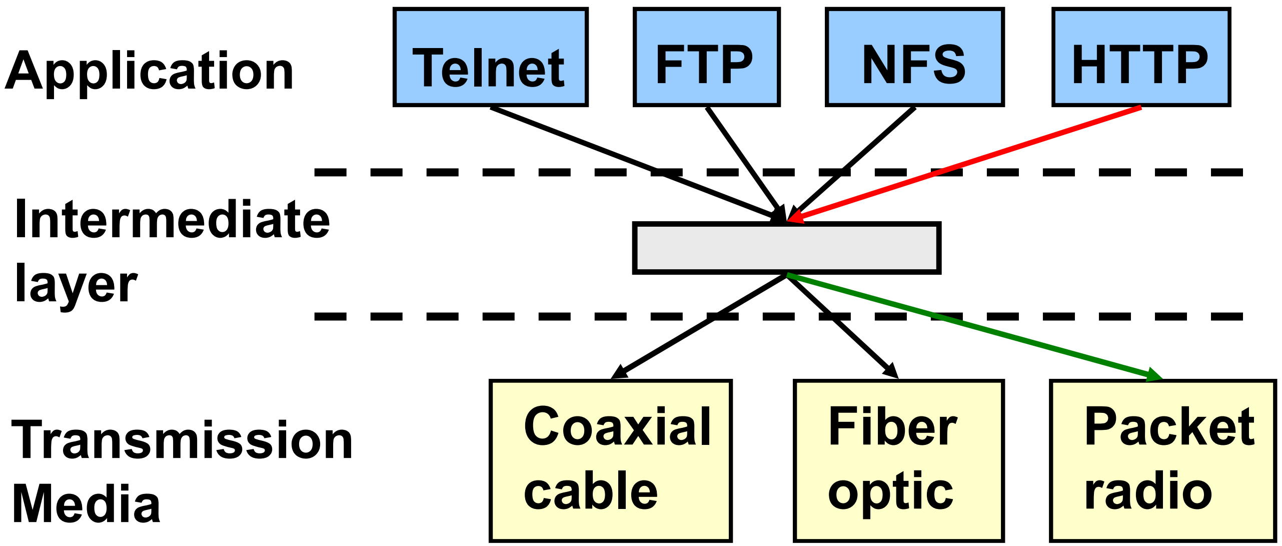
Why Layering?



- **No layering:** each new application has to be **re-implemented** for every network technology!

Why Layering?

- **Solution: introduce an intermediate layer that provides a unique abstraction for various network technologies**



Avoids NxM Implementation Problem

Why layering?

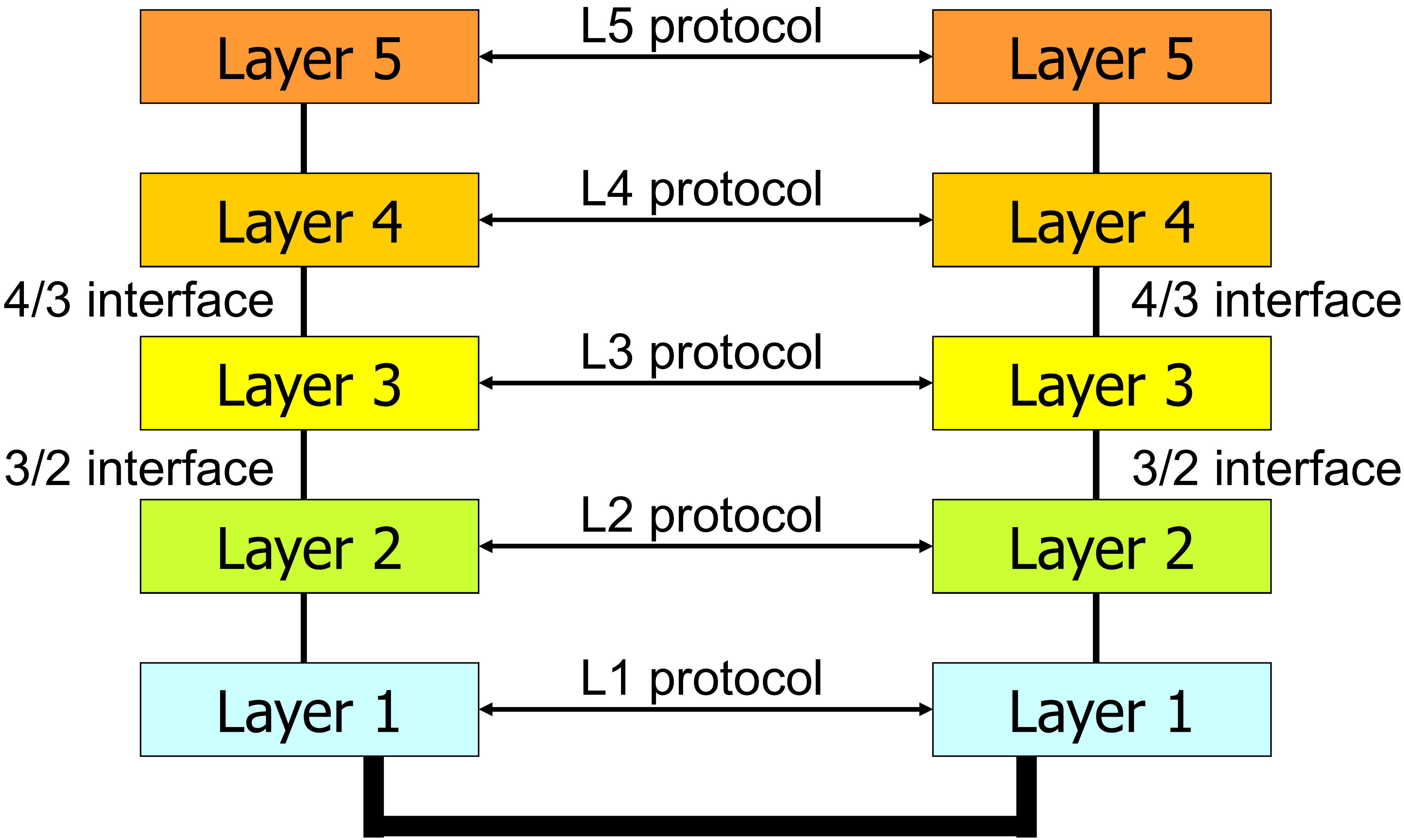
Dealing with complex systems:

- explicit structure allows identification, relationship of complex system's pieces
  - layered **reference model** for discussion
- modularization eases maintenance, updating of system
  - change of implementation of layer's service transparent to rest of system
  - e.g., change in gate procedure doesn't affect rest of system
  - also found in operating systems and languages
- **Q: layering considered harmful?**

Why layering?

- **Advantages**
  - ☑ Modularity – protocols easier to manage and maintain
  - ☑ Abstract functionality –lower layers can be changed **without** affecting the upper layers
  - ☑ Reuse – upper layers can reuse the functionality provided by lower layers
- **Disadvantages**
  - ☑ Information hiding – inefficient implementations

Layered Protocol Architecture



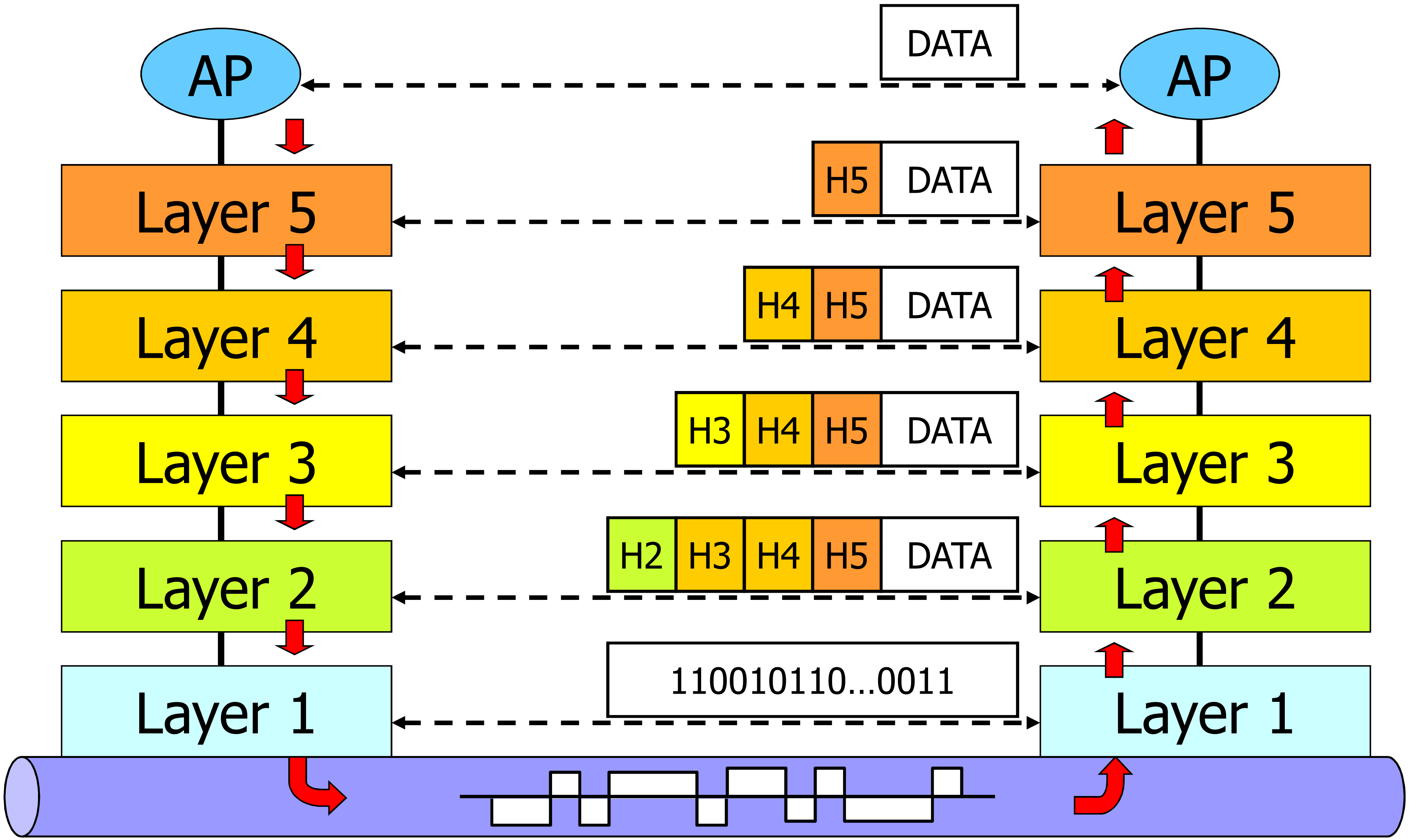
Layered Protocol Architecture

- To reduce design complexity, most networks are organized as a **series of layers**, each layer offers certain services to its upper layer.
- **Layer *n*** on one machine carries on a conversation with **layer *n*** on another machine.
- The rules and conventions used in this conversation are collectively known as the **layer *n* protocol**.

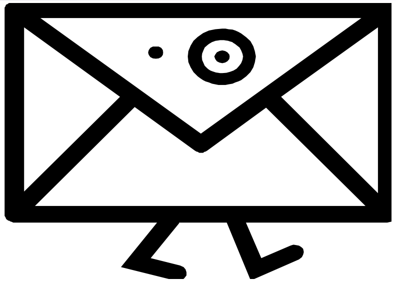
Characterizing the Layers

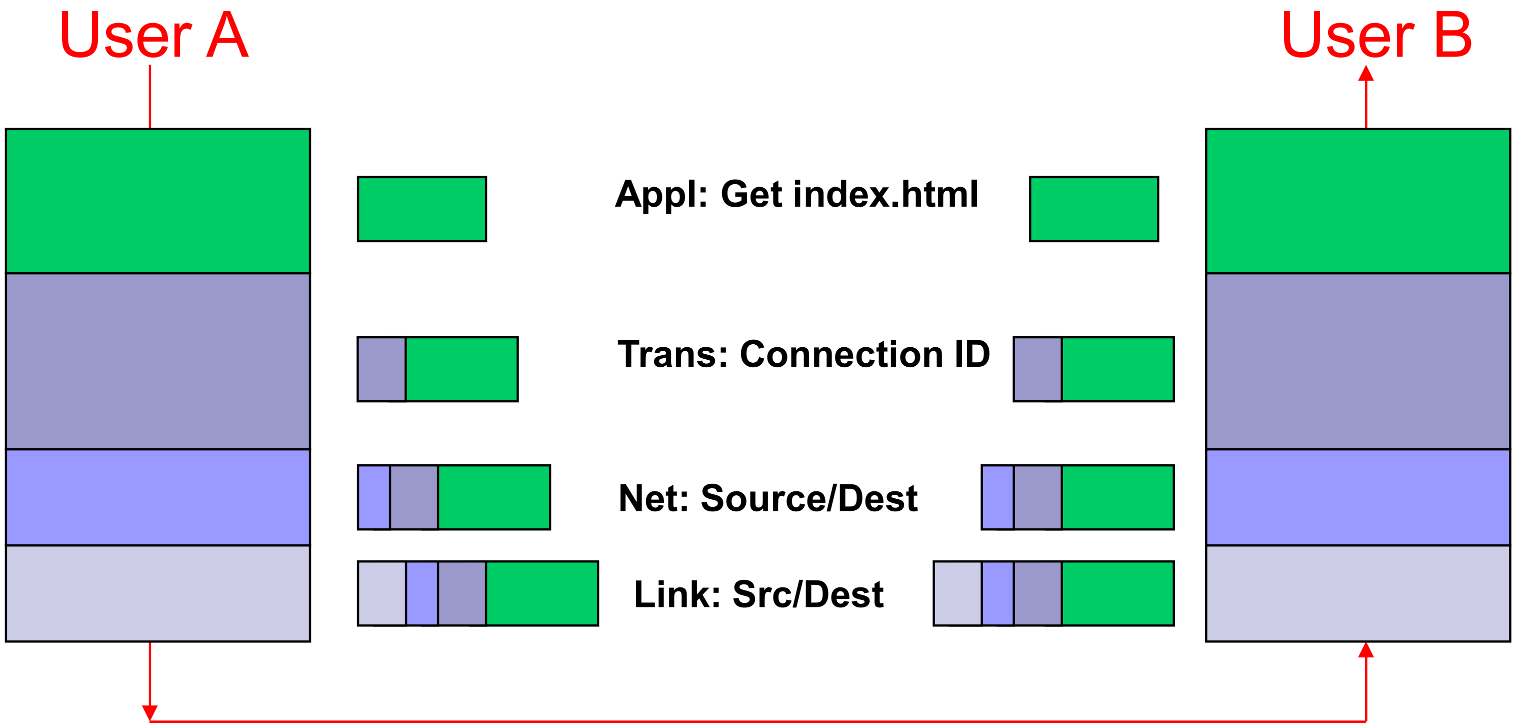
- **Service: what a layer *does***
- **Service interface: how to access the service**
  - Interface for layer above
- **Protocol: how peers communicate**
  - Protocol interface: set of rules and formats that govern the communication between network elements
  - Determines how the peers achieve the service
  - Does not govern implementation on a single machine, but how the layer is implemented between machines
- **Peer: the entities comprising the corresponding layers on different machines are called peers**

Layer Encapsulation



Layer Encapsulation

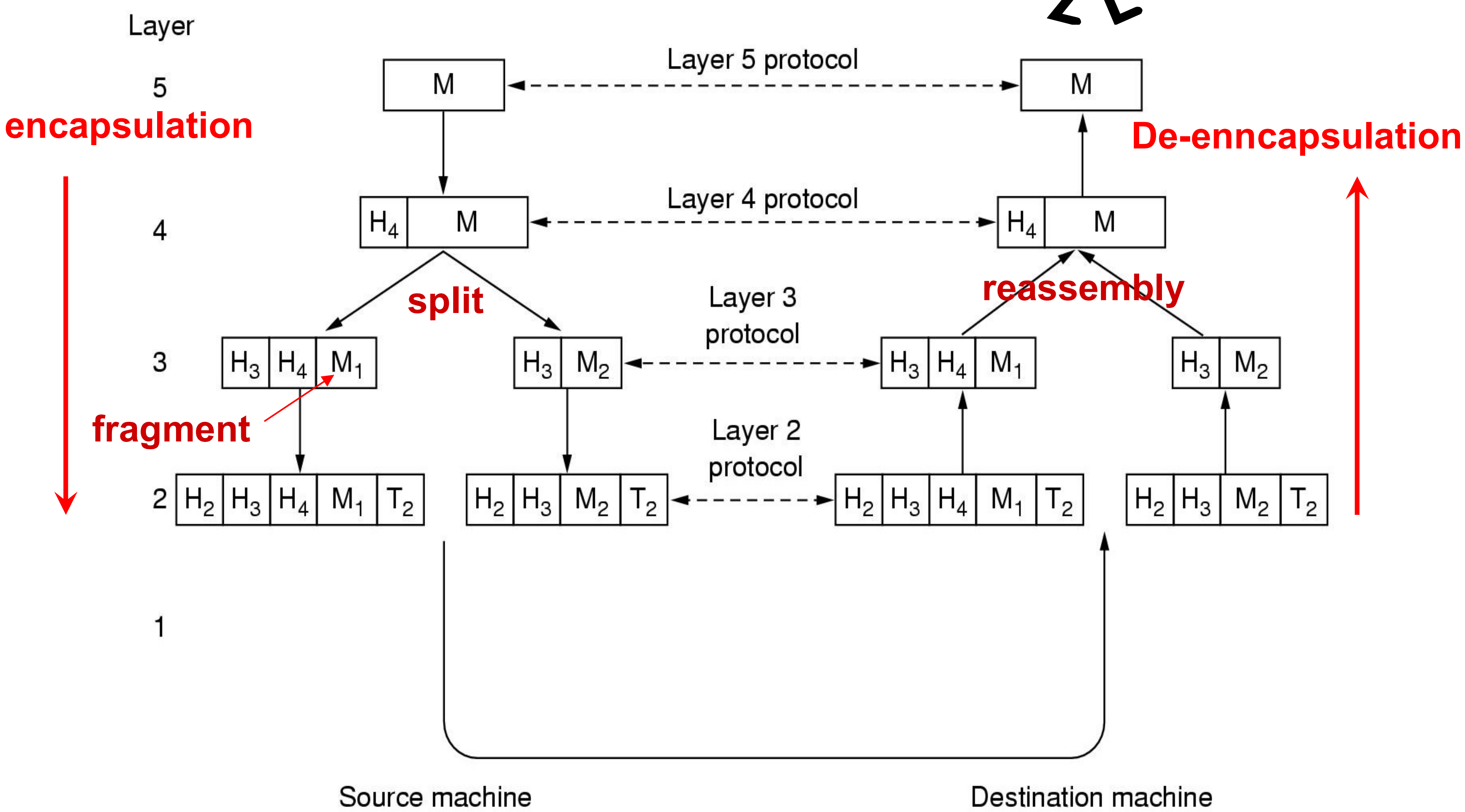




Common case: 20 bytes TCP header + 20 bytes IP header + 14 bytes Ethernet header = *54 bytes overhead*

224

Layer Encapsulation

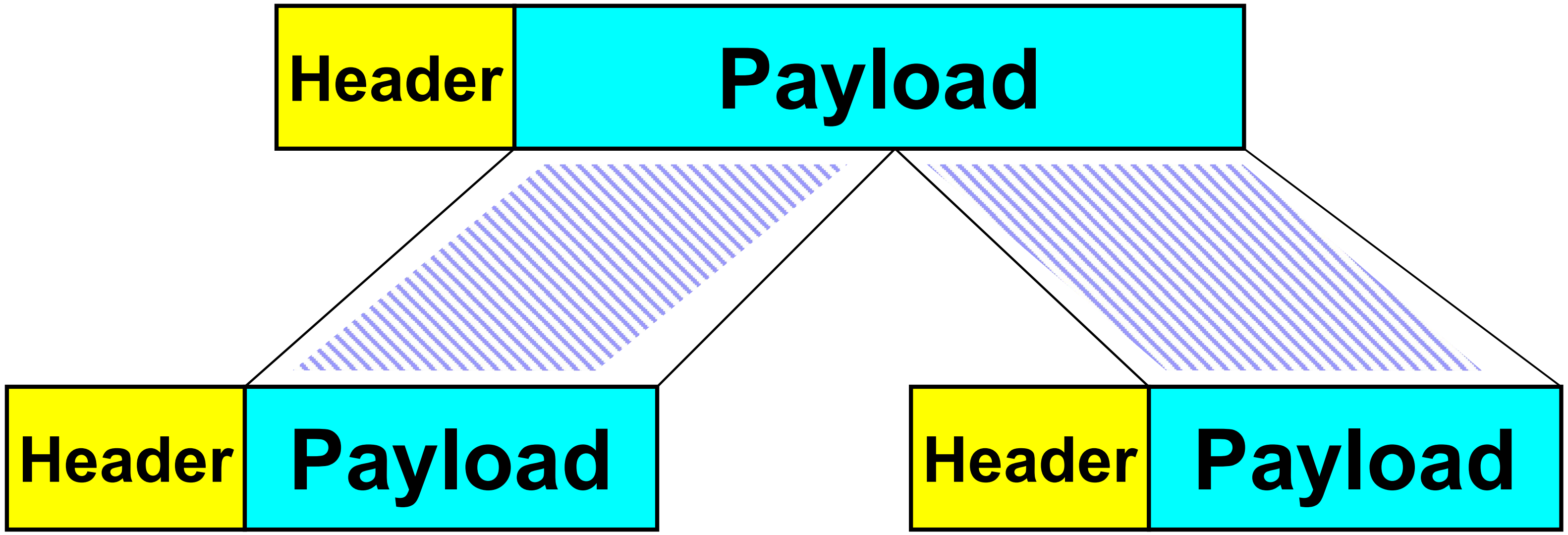


Information flow supporting virtual communication in layer 5

Fragmentation / Reassembly

- **Observation:** **In a protocol stack, *Layer k* puts its entire packet as data into a *Layer k-1* packet, that is, the *k-1* packet payload; the latter may add a header and/or a trailer.**
- **Note:** **It may even occur that *Layer k* data has to be split across several *Layer k-1* packets, i.e., fragmentation. At the destination, reassembly is needed to recover *Layer k* data.**

Fragmentation / Reassembly



Services

- **What is service?**
  - **A set of communication abilities and operations provided by lower layer to its higher layer.**
- **Types**
  - **Connection-oriented Service**
  - **Connectionless Service**

Services

- **Connection-oriented Service**
  - **Like the telephone model:** you first **establish** a connection, then do a lot **communication**, and finally **release** the connection. Three phases.
  - **Circuit switching**
  - **Virtual Circuit packet switching**
- **Connectionless Service**
  - **Like the postal model:** your data is put into some kind of envelope called packet, on which the destination address has been written. The packet is independently routed in communication subnet, until gets to the destination, and that's it.
  - **Datagram packet switching**

Services

- **Each service can provide some quality:**
  - ***Is data delivered in the order it was sent?*** **With connections, this is generally the case.**
  - ***Is data transmission reliable?*** **Generally offered with connections, but not always with connectionless services. Reliability requires sending acknowledgements, so that performance may degrade.**

Six different types of service

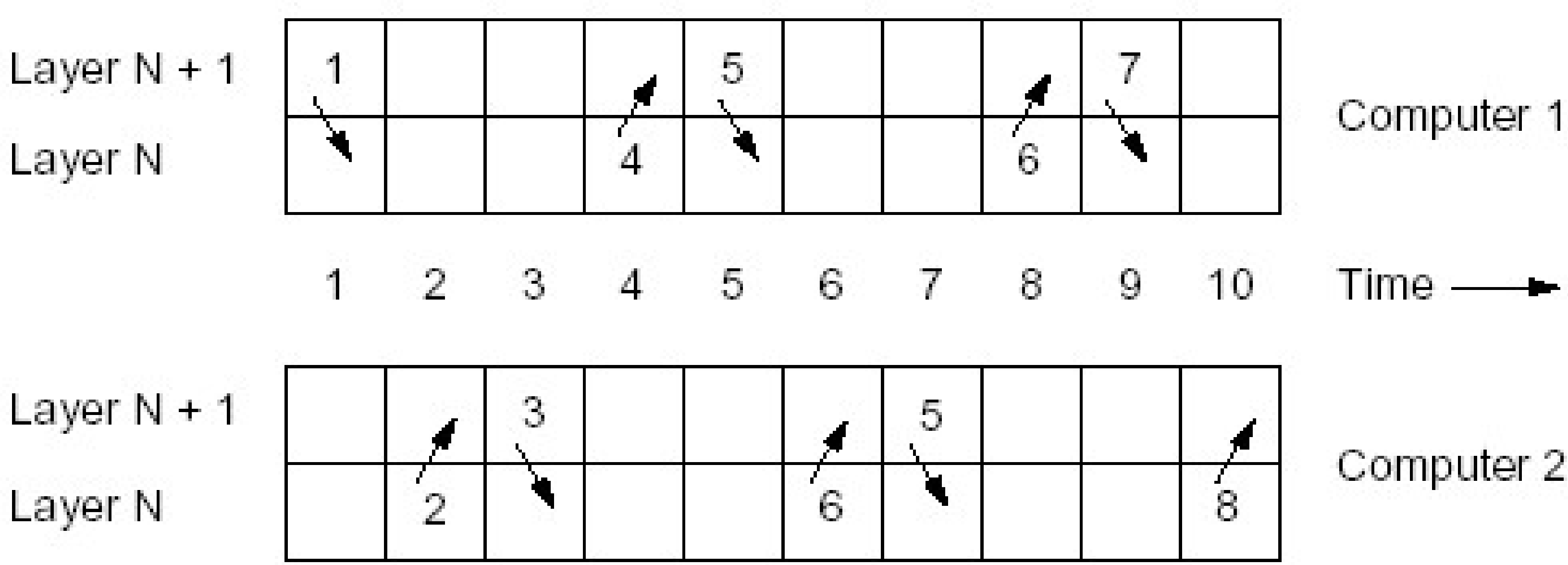
	Service	Example
Connection-oriented	Reliable message stream	Sequence of pages
	Reliable byte stream	Remote login
	Unreliable connection	Digitized voice
Connection-less	Unreliable datagram	Electronic junk mail
	Acknowledged datagram	Registered mail
	Request-reply	Database query

Service Primitives

- Services are generally specified by a set of **primitives** (operations), which tell the service to perform some action or report on an action taken by a peer entity. Primitives are normally system calls.

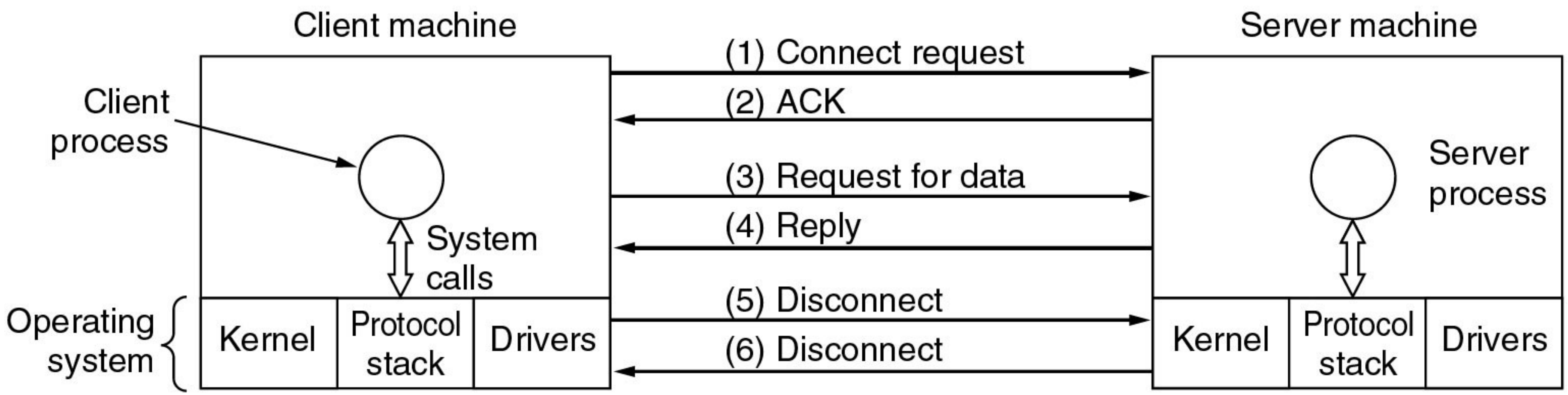
Primitive	Meaning
LISTEN	Block waiting for an incoming connection
CONNECT	Establish a connection with a waiting peer
RECEIVE	Block waiting for an incoming message
SEND	Send a message to the peer
DISCONNECT	Terminate a connection

1. **CONNECT.request: request for establishing a connection (*dial a phone number*).**
2. **CONNECT.indication: signal the callee (*phone rings*).**
3. **CONNECT.response: reaction by callee to indication (*pick up the phone*).**
4. **CONNECT.confirm: tell caller whether call was accepted (*caller hears ringing stop*).**
5. **DATA.request: request data to be sent (*say something*)**
6. **DATA.indication: signal arrival of data (*callee hears you*)**
7. **DISCONNECT.request: request release of connection (*caller hangs up*)**
8. **DISCONNECT.indication: signal release of connection (*callee hears busy tone*)**



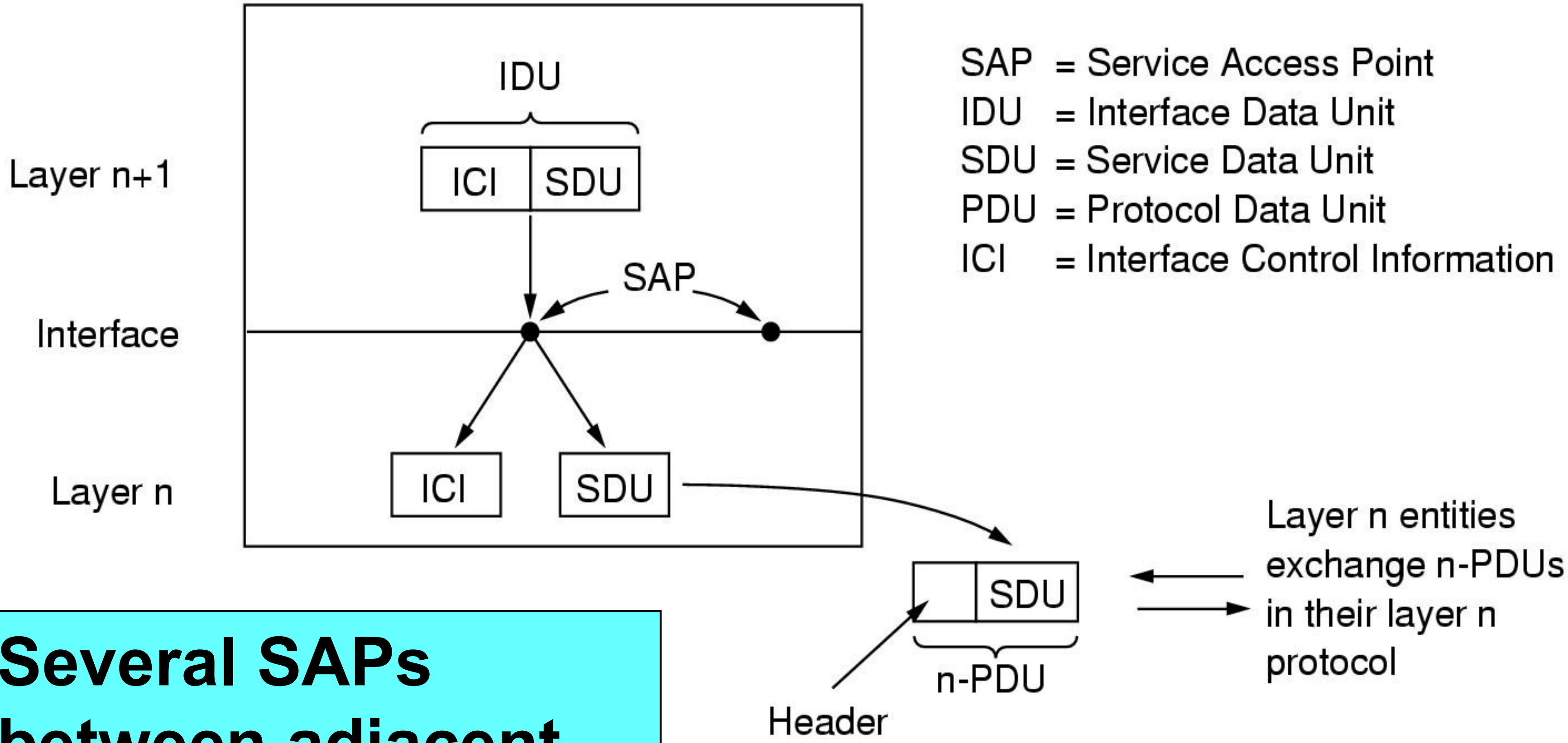
Service Primitives

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



Interfaces and Services

Relation between layers at an interface



SAP = Service Access Point
IDU = Interface Data Unit
SDU = Service Data Unit
PDU = Protocol Data Unit
ICI = Interface Control Information

Several SAPs between adjacent layers.

Interfaces and Services

- **A Service Access Point (SAP) is identified by an address, and forms the interface to a set of services.**
- **The Service Data Unit contains the data you want to send.**
- **The Interface Control Information contains info needed to send the SDU, e.g. number of bytes.**
- **The Protocol Data Unit is the data that is sent across the network, containing your SDU as well as protocol-specific data.**

Interfaces and Services

(N)PCI	(N) User Data (optional)

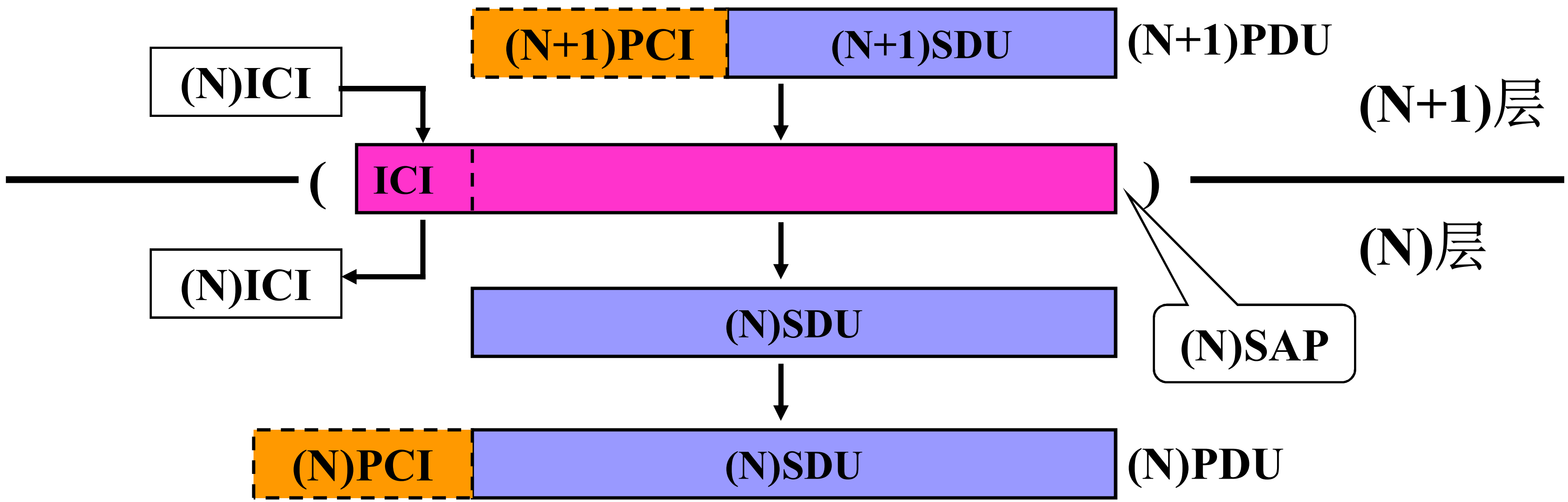
(N)PCI: Protocol Control Information.
Header

a. (N)PDU Format

(N)ICI	(N+1) PDU

(N)ICI: Interface Control Information.
Only useful for PDUs over the interface.

b. (N)IDU Format

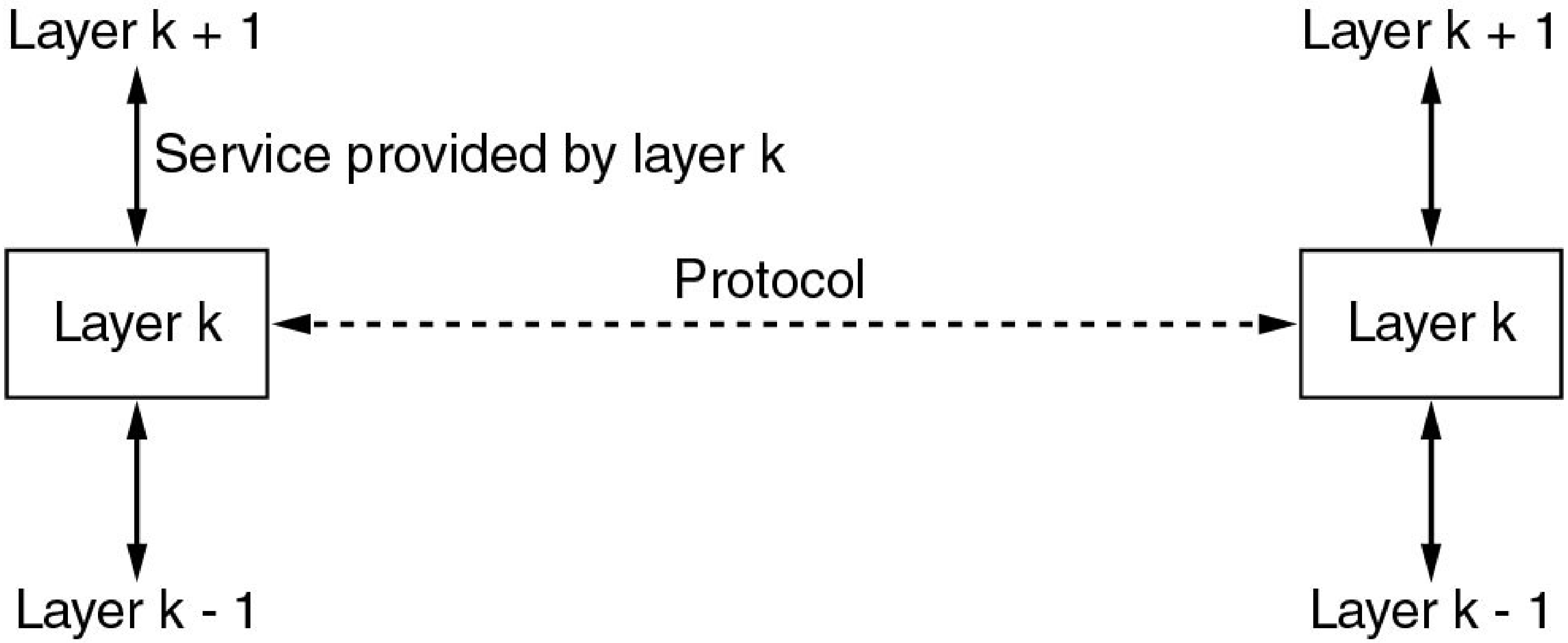


SAP and Data Units

The Relationship of Services to Protocols

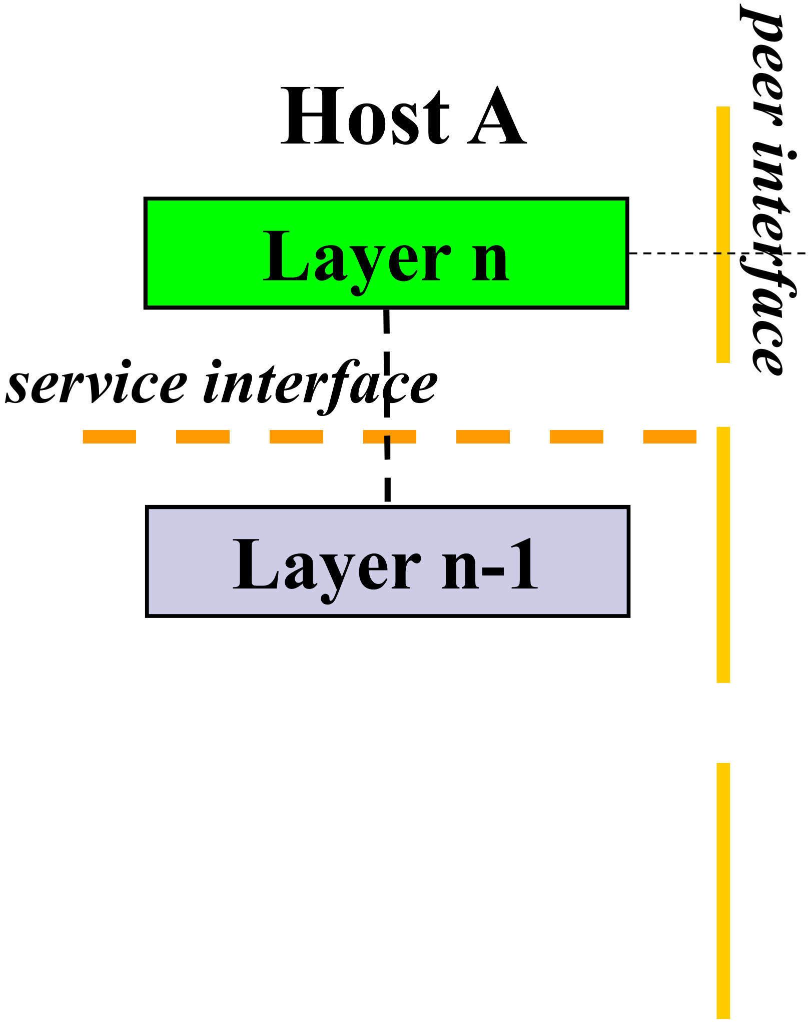
- **Service**
  - is a set of primitives (operations) that a layer provides to the layer above it, defining what operations the layer is prepared to perform on behalf of its users, but nothing about how these operations are implemented.
- **Protocol**
  - is a set of rules governing the format and meaning of the packets, or messages that are exchanged by the peer entities within a layer. Entities use protocols to implement their service definitions.

The Relationship of Services to Protocols



The relationship between a service and a protocol

Protocols, Layers, and Interfaces



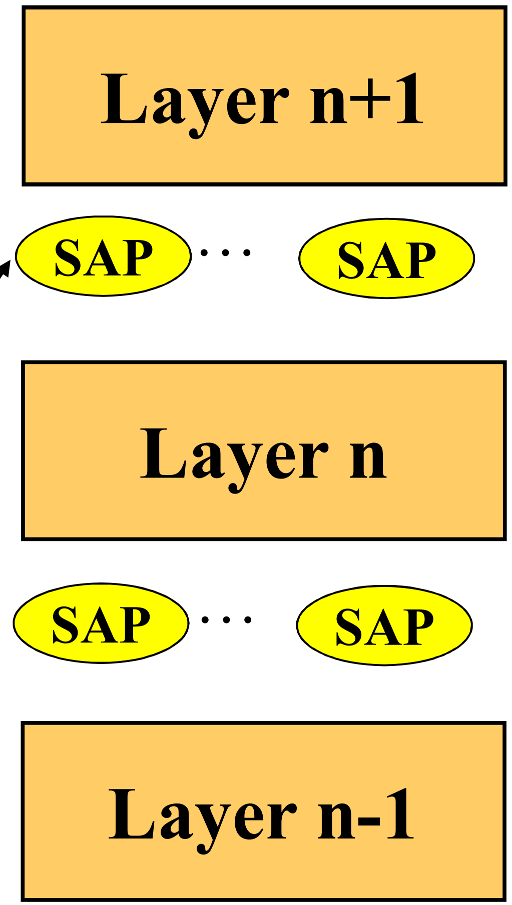
Protocol: a communication service that higher-level objects use to exchange messages.

Communication Between Layers within a Host

It's important to specify the services offered to higher layers in the hierarchy.
What they are + how to use them = *interface*.

SAPs (service access points)

<u>Note:</u> This is ISO terminology.



Chapter 1: Roadmap

1.1 Computer network and the Internet
1.2 Network edge and core
1.3 Network access and physical media
1.4 Transmission Technology
1.5 Type and Topology
1.6 Network Performance
1.7 Protocol layers, service models
1.8 Architecture, OSI and TCP/IP Models
1.9 Internet History

Some terminologies

- **Network Architecture**
  - A set of layers and protocols, together with interfaces between layers, is called Network Architecture.
- **protocol hierarchies**
  - Fundamental to *all* software that makes a computer network run, is the notion of **protocol hierarchies:** structuring the services that a network must offer in terms of layers.
- **Protocol stack**
  - A list of protocols **used by a certain system**, one protocol per layer, is called a protocol stack.

Back to Modularity

- **Modularity in programming:**
  - **Set of abstractions**

- **Modularity in networking:**
  - **Distributed nature of system requires deciding where abstractions are implemented**

Three Basic Architectural Decisions

- **How to break system into modules?**
- **Where modules are implemented?**
- **Where state is stored?**

Network Architectures

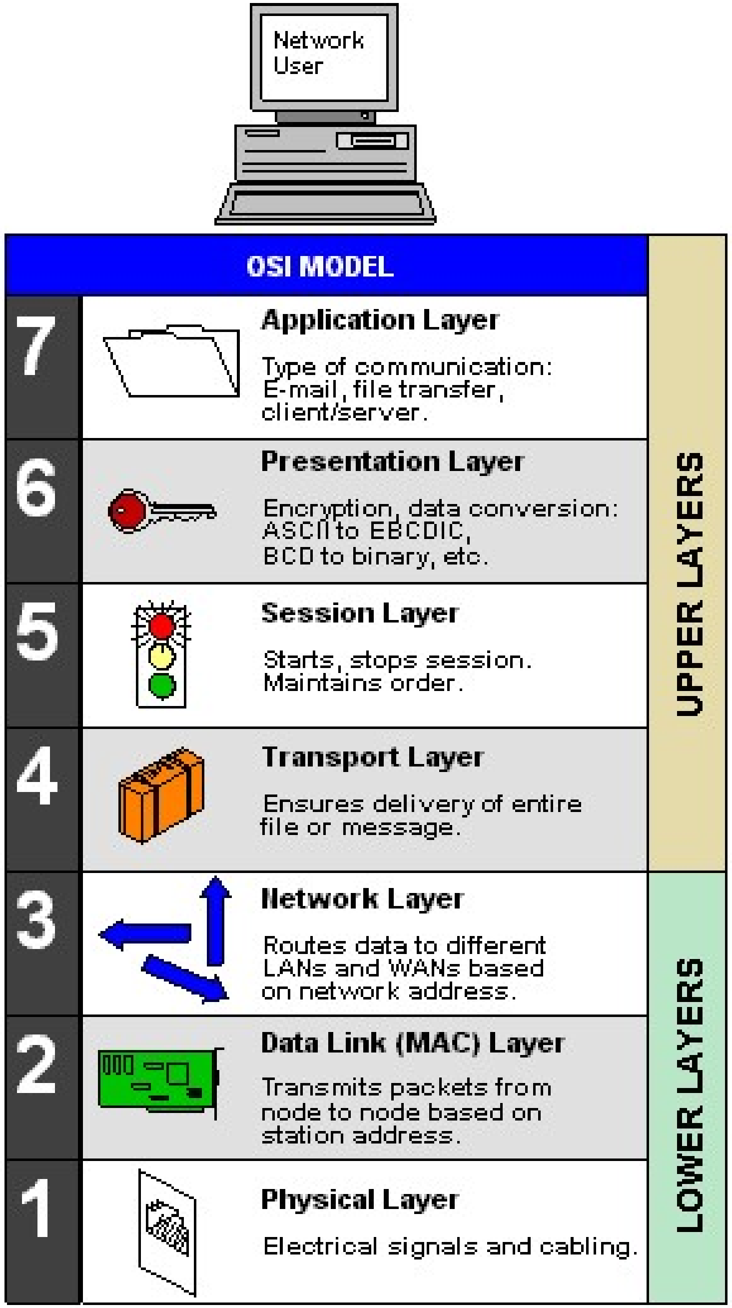
- **Network Architecture**
  - A set of layers and protocols, together with interfaces between layers, is called Network Architecture
  - Describe how networks are organized
- **Reference Model** = Architecture
- **2 typical Reference Models**
  - ISO/OSI
  - TCP/IP

ISO OSI Reference Model

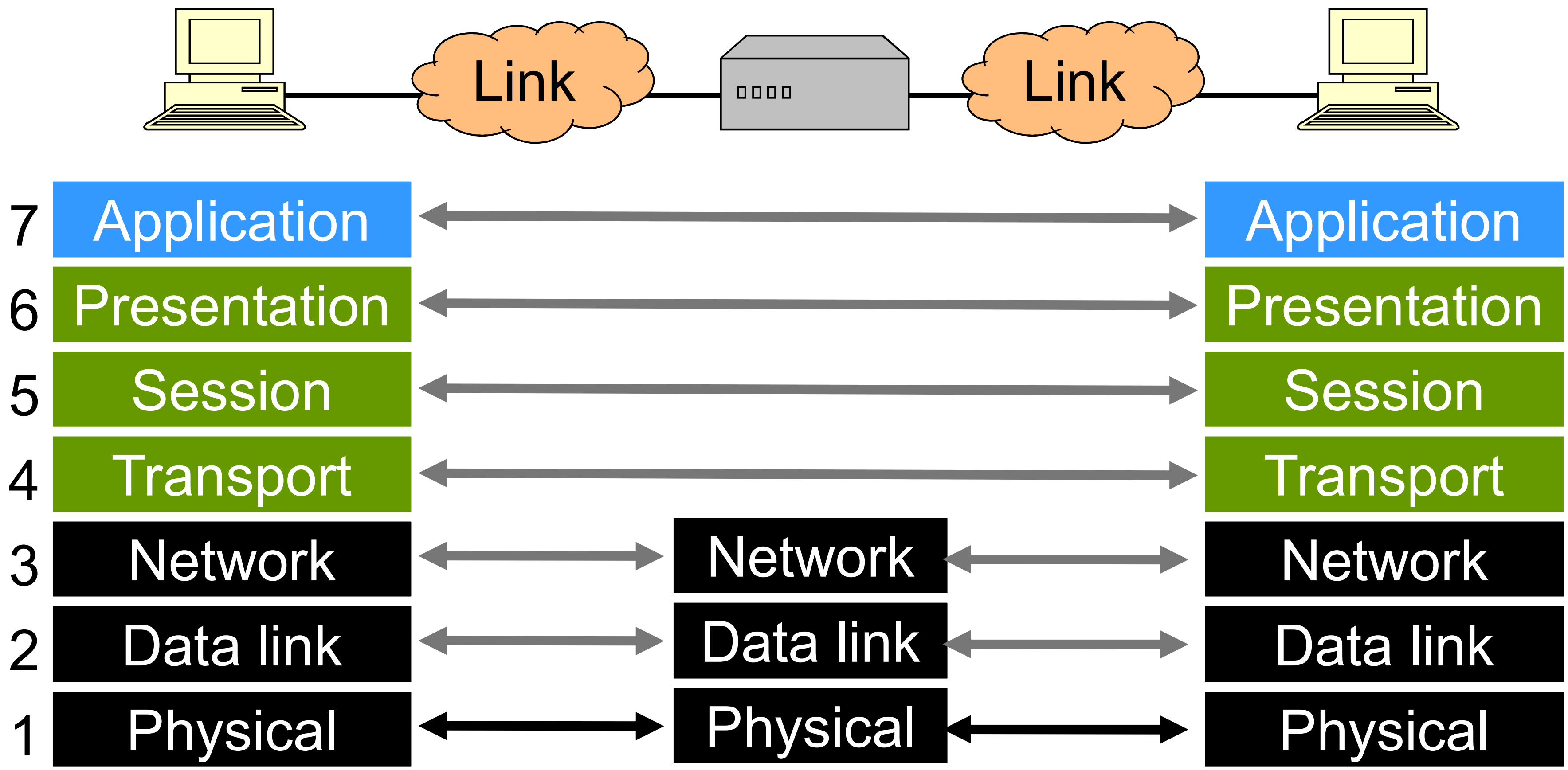
- ISO – International Standard Organization
- **OSI – Open System Interconnection**
- Started to 1978; first standard 1979
  - ARPANET started in 1969; TCP/IP protocols ready by 1974
- ***Goal***: a general open standard
  - Allow vendors to enter the market by using their own implementation and protocols

ISO OSI Referen

- **Model consists of a 7-layer stack:**



ISO OSI Reference Model



OSI Functions

- **(1) Physical**: transmission of a bit stream.
- **(2) Data link**: flow control, framing, error detection.
- **(3) Network**: switching and routing.
- **(4) Transport**: reliable end to end delivery.
- **(5) Session**: managing logical connections.
- **(6) Presentation**: data transformations.
- **(7) Application**: specific uses, e.g. mail, file transfer, telnet, network management.

Multiplexing takes place in multiple layers

Physical Layer (1)

- **Service:** **move *bits* between two systems connected by a *single physical link***
- **Interface:** **specifies how to send and receive *bits***
  - **E.g., require quantities and timing**
- **Protocols:** **coding scheme used to represent *bits*, voltage levels, duration of a bit**
- **Examples:** **Optical, wireless, etc.**

(Data) Link Layer (2)

- **Service:** Enable hosts to exchange **messages**
  - Using abstract (but local) addresses
  - Not just direct physical connections
- **Interface:** send messages (frames) to other end hosts; receive messages addressed to end host
- **Protocols:**
  - Routing
  - Media Access Control (MAC)
- **Examples:**
  - **Ethernet, 802.11**, Frame Relay, ATM

(Inter) Network Layer (3)

- **Service:** Deliver **packets** to specified destination
  - Using abstract global addresses
  - Inter-network = across multiple layer-2 networks
  - E.g., from Ethernet to 802.11 to Frame Relay to ATM
- **Interface:** send packets to specified internetwork destinations; receive packets destined for end host
- **Protocols:** construct routing tables
- **Examples:** **IP**
  - Why no other examples?

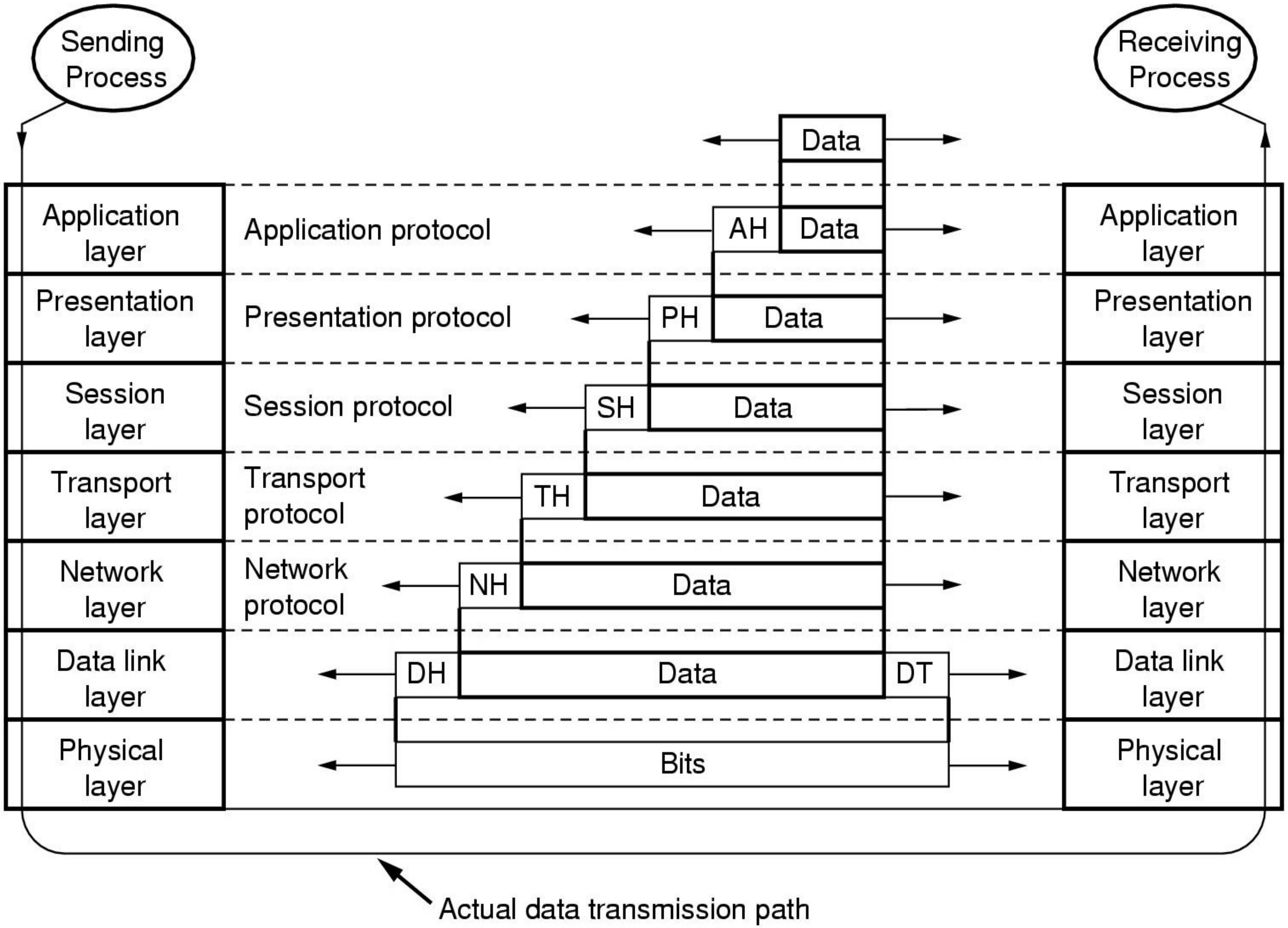
Transport Layer (4)

- **Service:** Communication between processes
  - Demultiplexing of communication between hosts
  - Perhaps: reliable transport, rate adaptation
- **Interface:**
  - send message to specific process at given destination
  - local process receives messages sent to it
- **Protocols:** reliability, flow control, packetization of large messages, framing
- **Examples:** TCP and UDP
  - SCTP, T/TCP, DCCP,

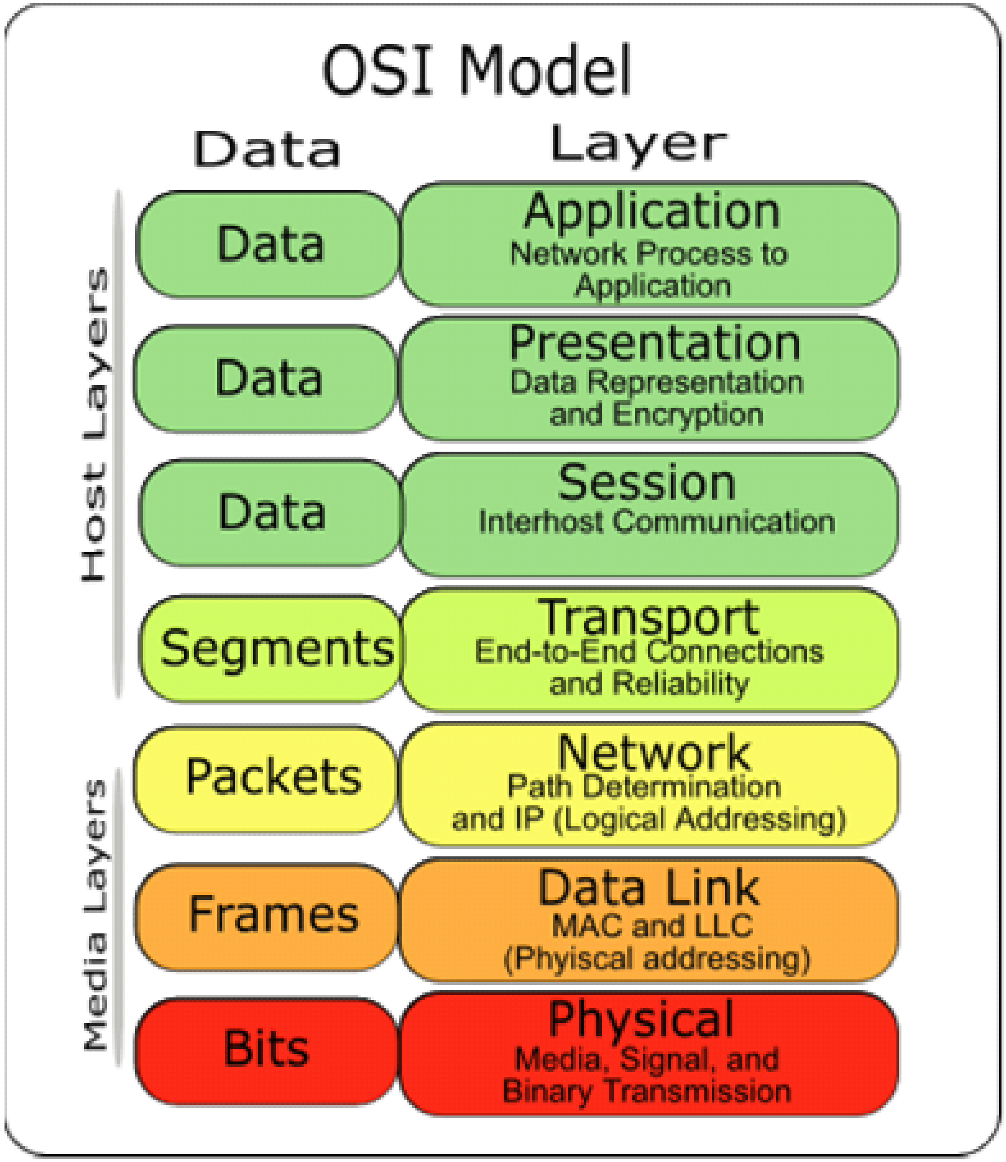
Application Layer (7)

- **Service:** any service provided to the end user
- **Interface:** depends on the application
- **Protocols:** depends on the application
- **Examples:** Skype, SMTP (email), HTTP (Web), Halo, BitTorrent …

Data Transmission in the OSI Model



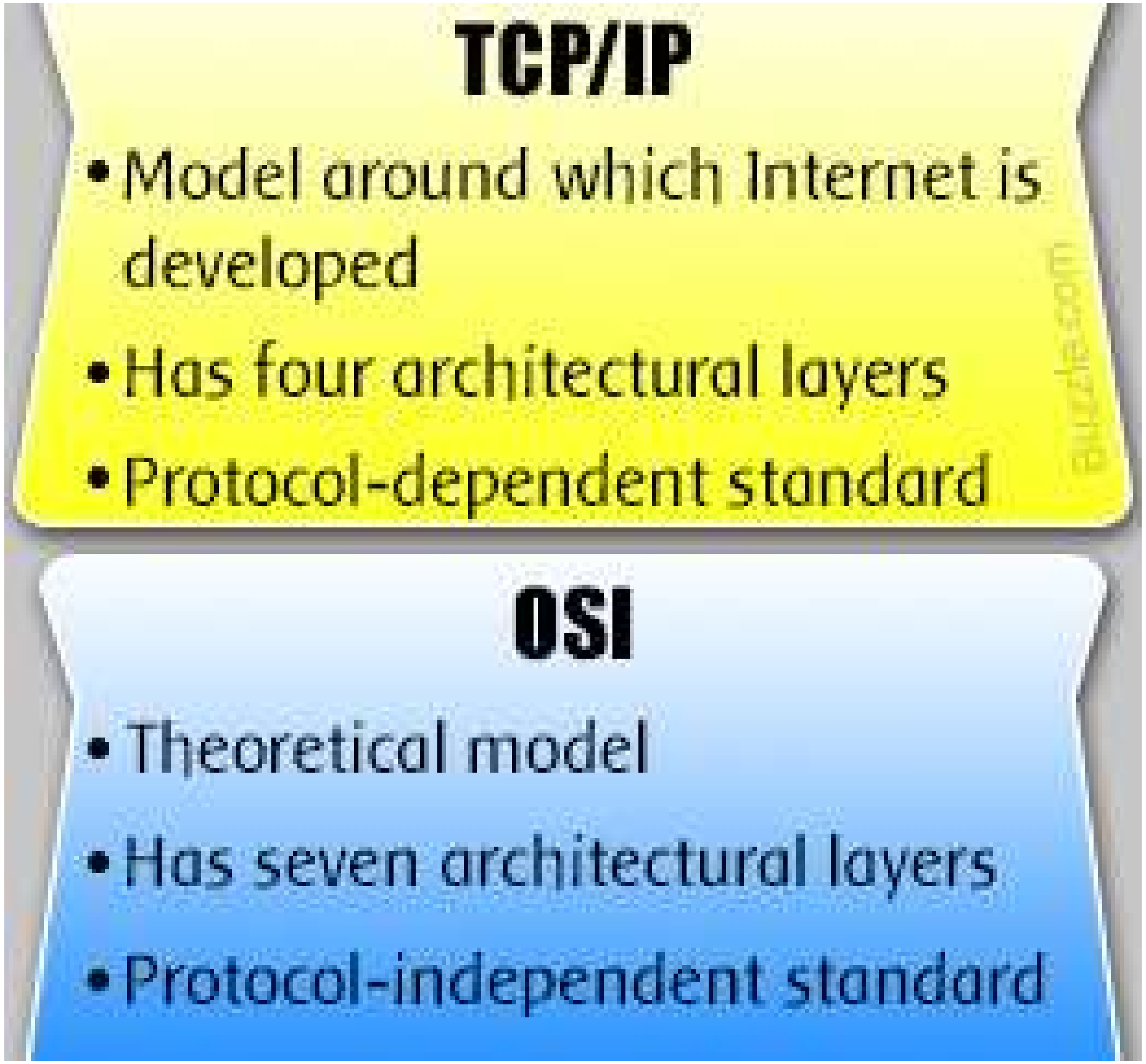
ISO OSI Reference Model



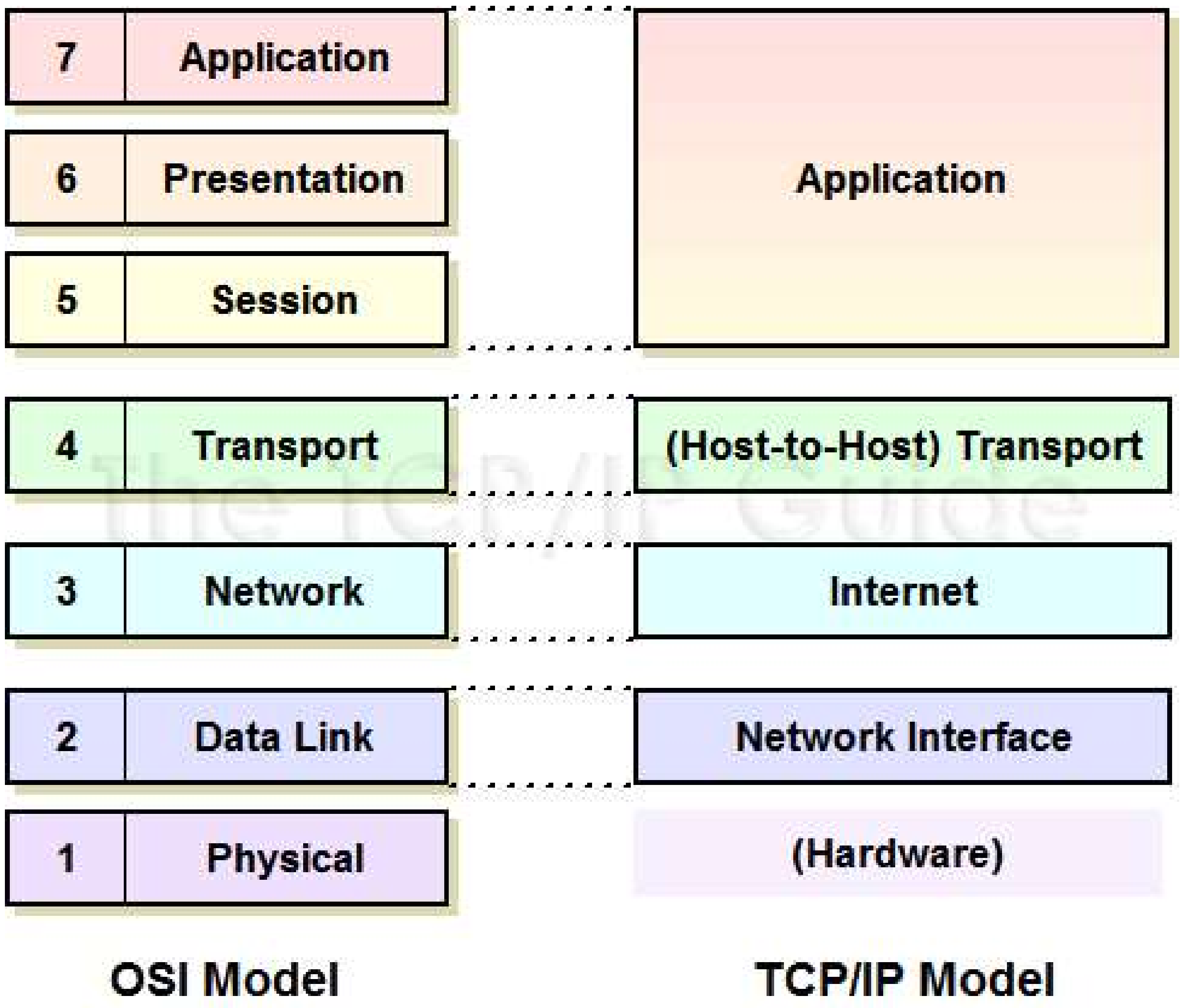
The TCP/IP Reference Model

- TCP/IP is a result of protocol research and development conducted on the experimental packet switched network, ARPANET, funded by the Defense Advanced Research Projects Agency (DARPA), and is generally referred to as the TCP/IP protocol suite.
- This protocol suite consists of a large collection of protocols that have been issued as Internet standards by the Internet Activities Board (IAB).

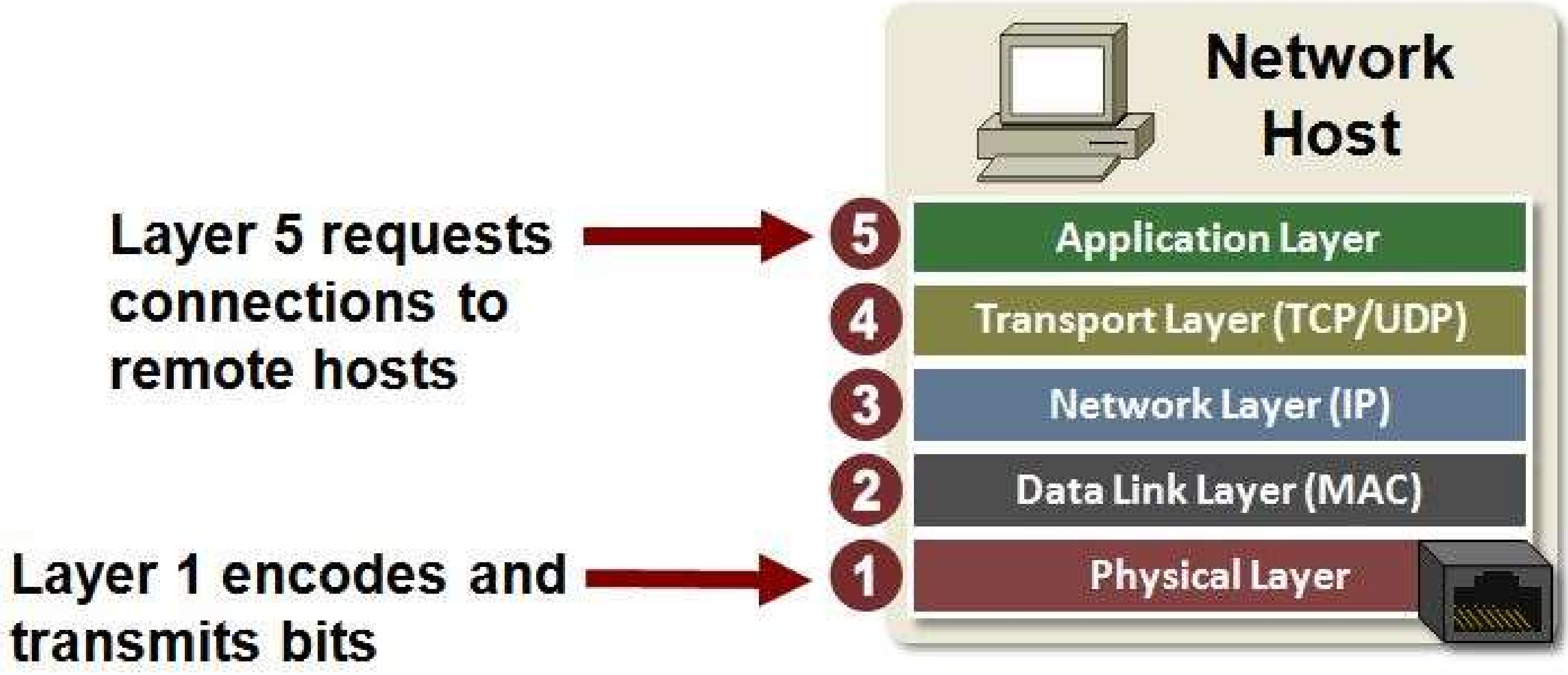
The TCP/IP Reference Model



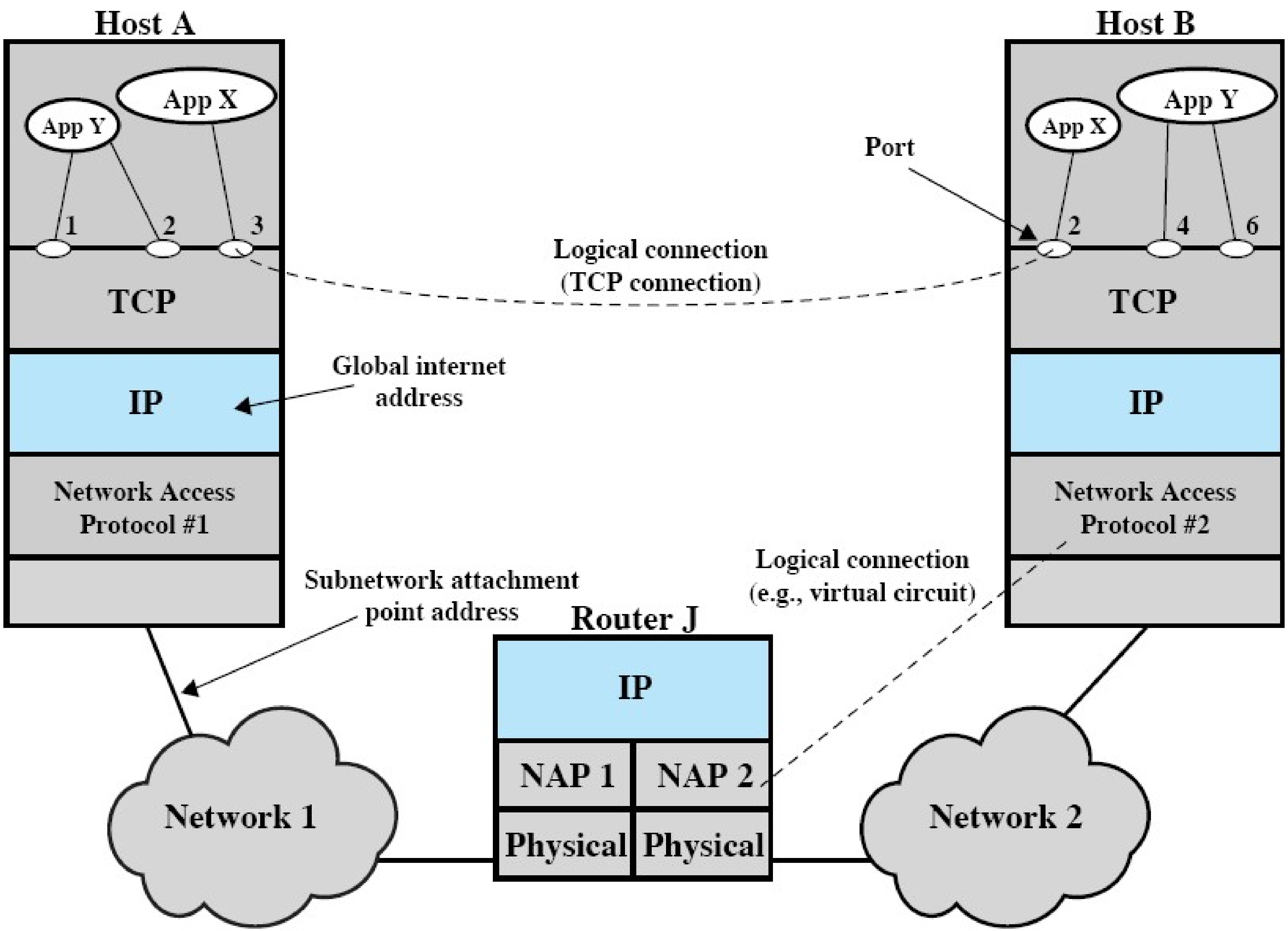
The TCP/IP Reference Model



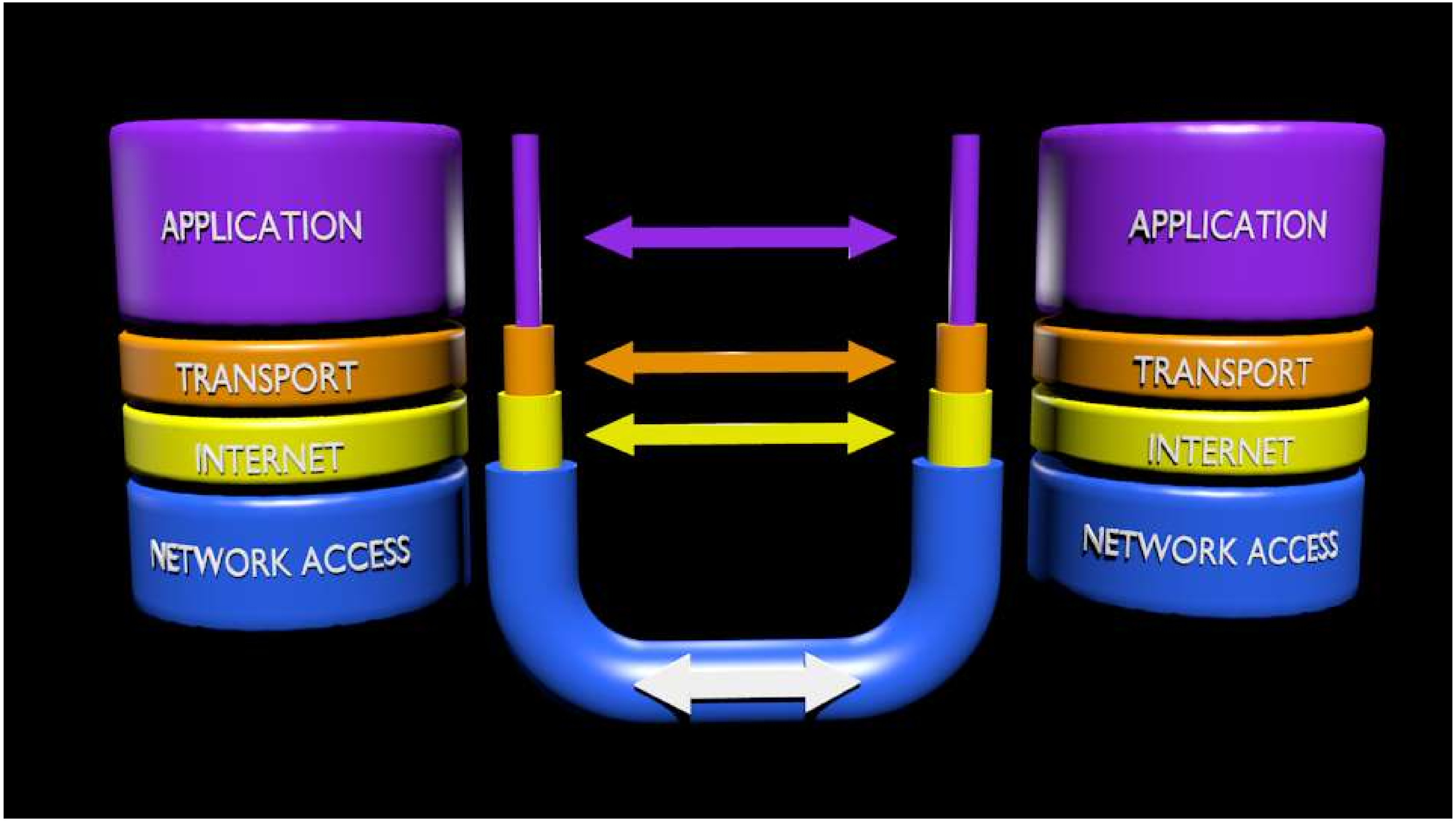
The TCP/IP Reference Model



Modern TCP/IP model

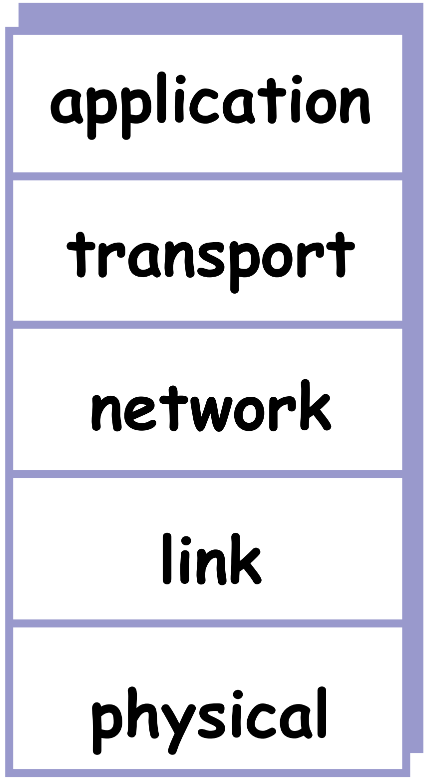

Host A
App X
App Y
1
2
3
TCP
IP
Network Access
Protocol #1
Host B
App Y
App X
2
4
6
TCP
IP
Network Access
Protocol #2
Port
Logical connection
(TCP connection)
Global internet
address
Subnetwork attachment
point address
Logical connection
(e.g., virtual circuit)
Router J
IP
NAP 1
NAP 2
Physical
Physical
Network 1
Network 2

The TCP/IP Reference Model

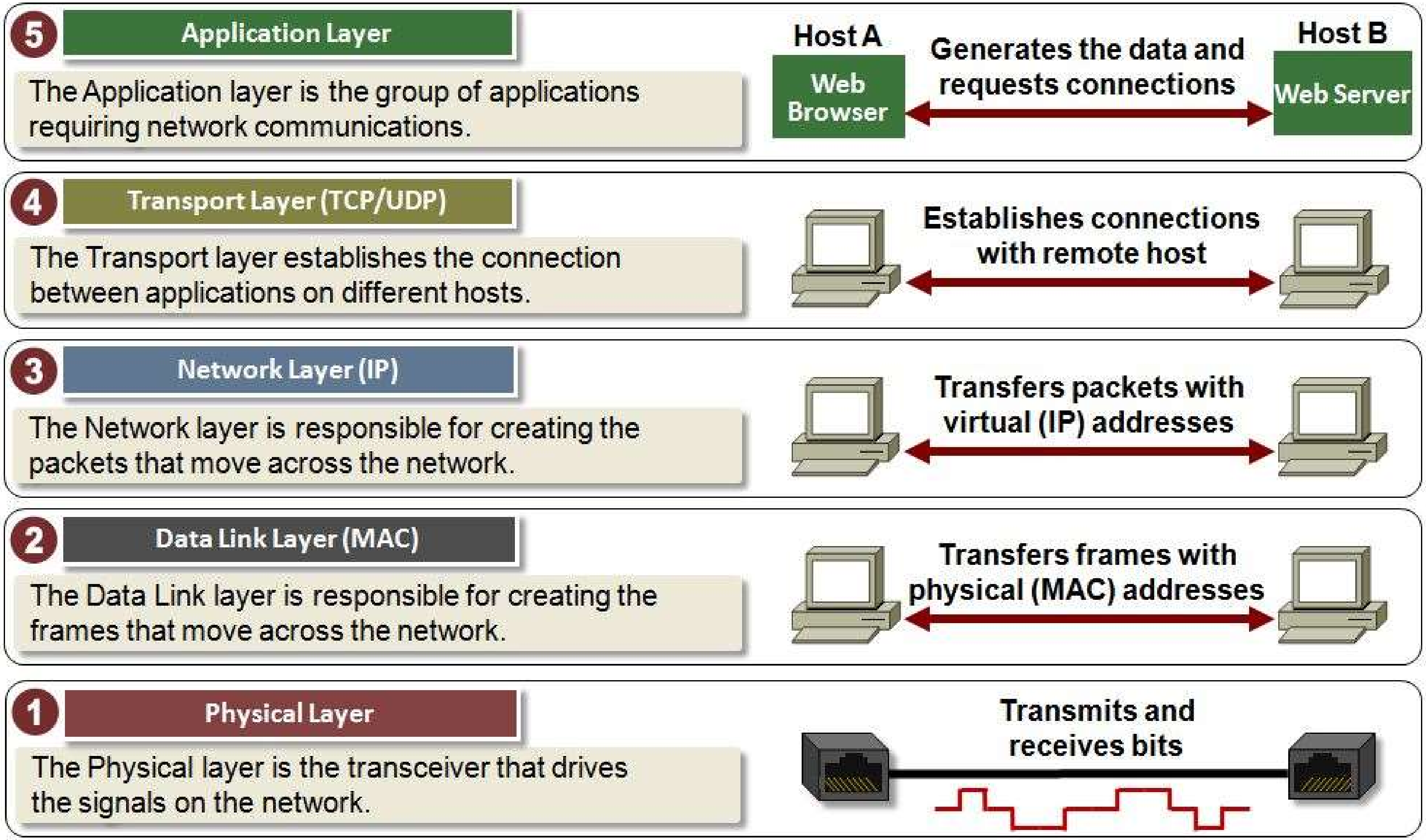


The TCP/IP Reference Model

- **application: supporting network applications**
  - FTP, SMTP, STTP
- **transport: host-host data transfer**
  - TCP, UDP
- **network: routing of datagrams from source to destination**
  - IP, routing protocols
- **link: data transfer between neighboring network elements**
  - PPP, Ethernet
- **physical: bits “on the wire”**

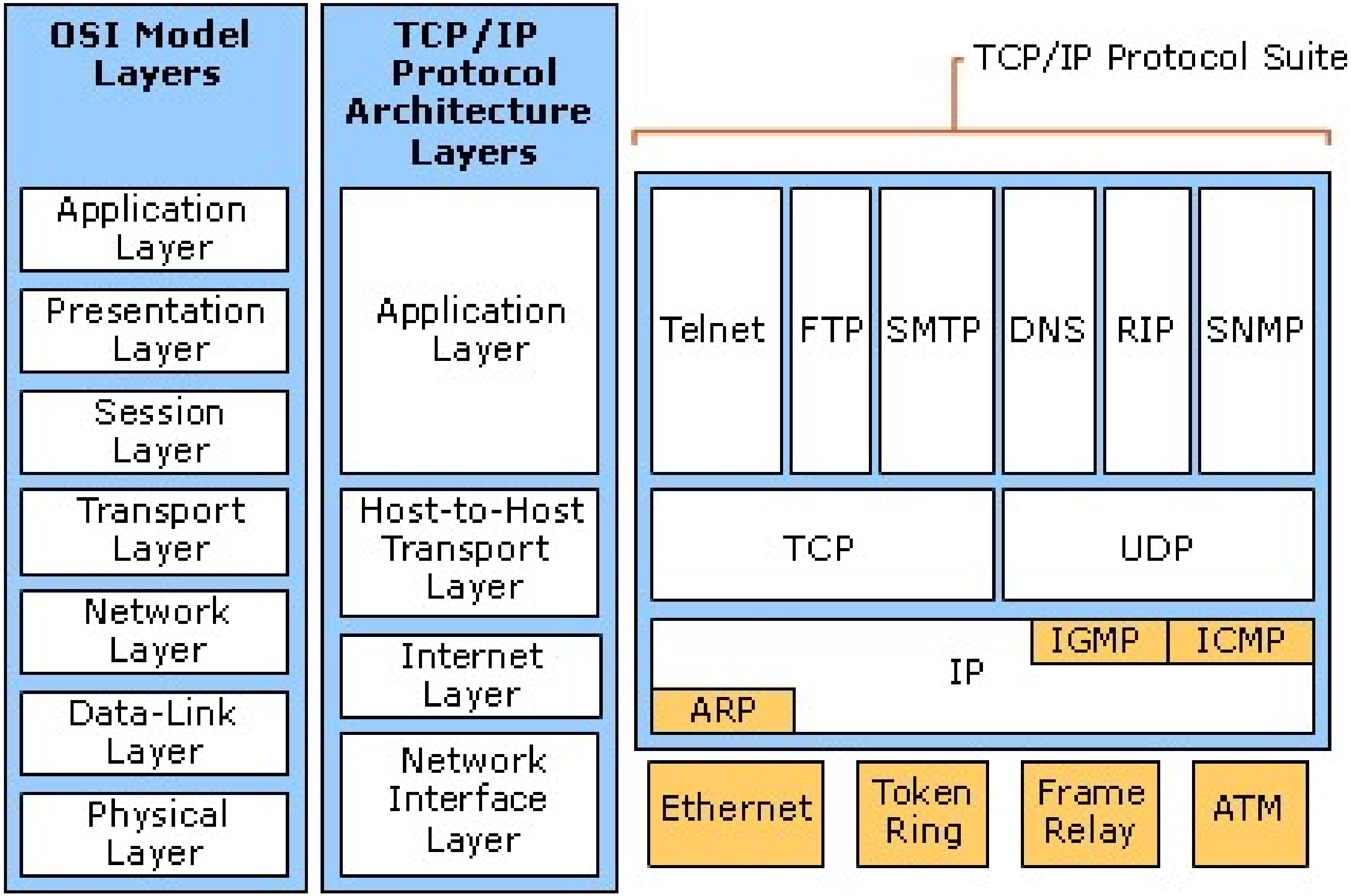


The TCP/IP Reference Model



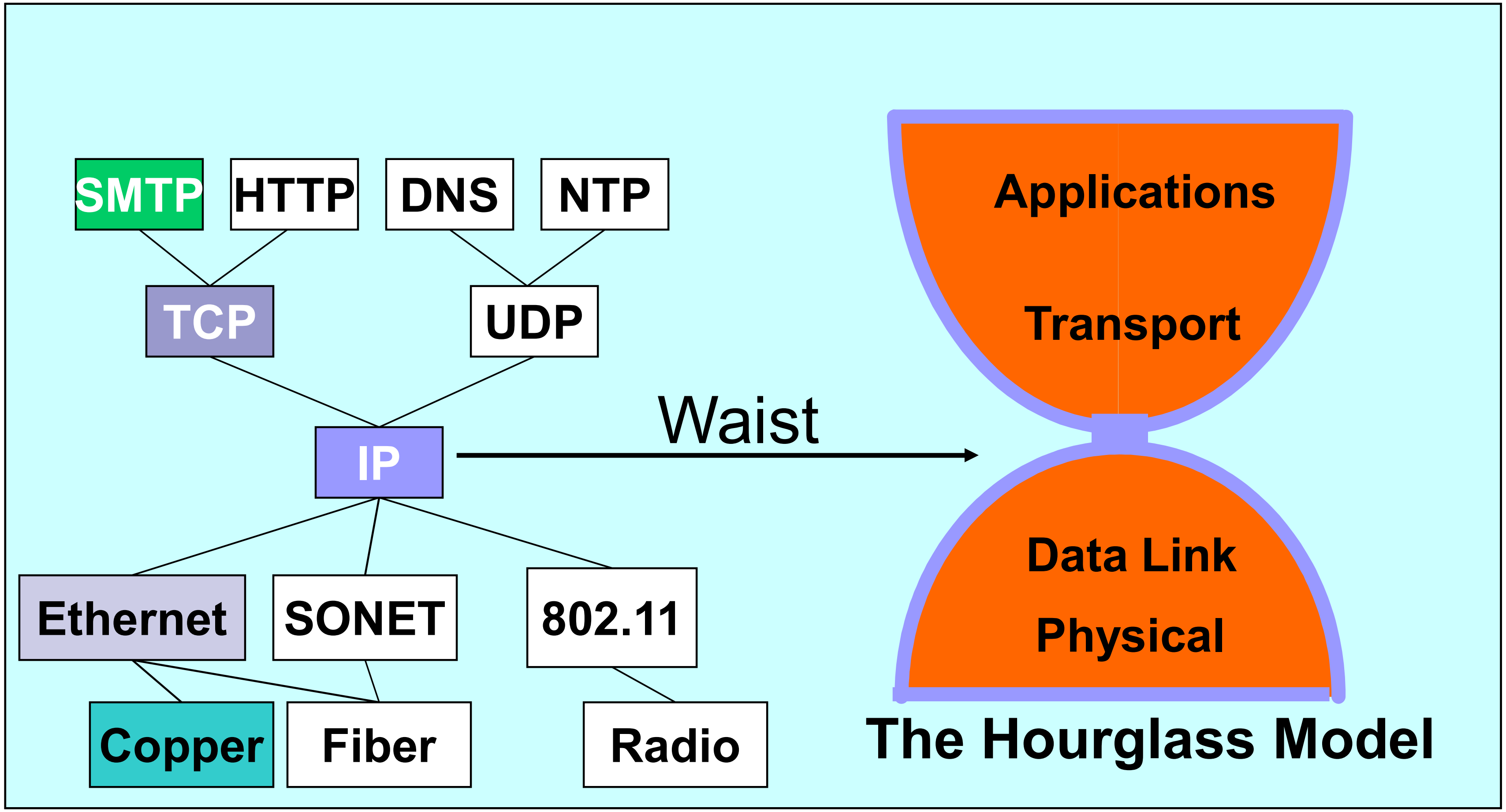
TCP/IP functions

The TCP/IP Reference Model



TCP/IP protocol suite

The Internet *Hourglass*

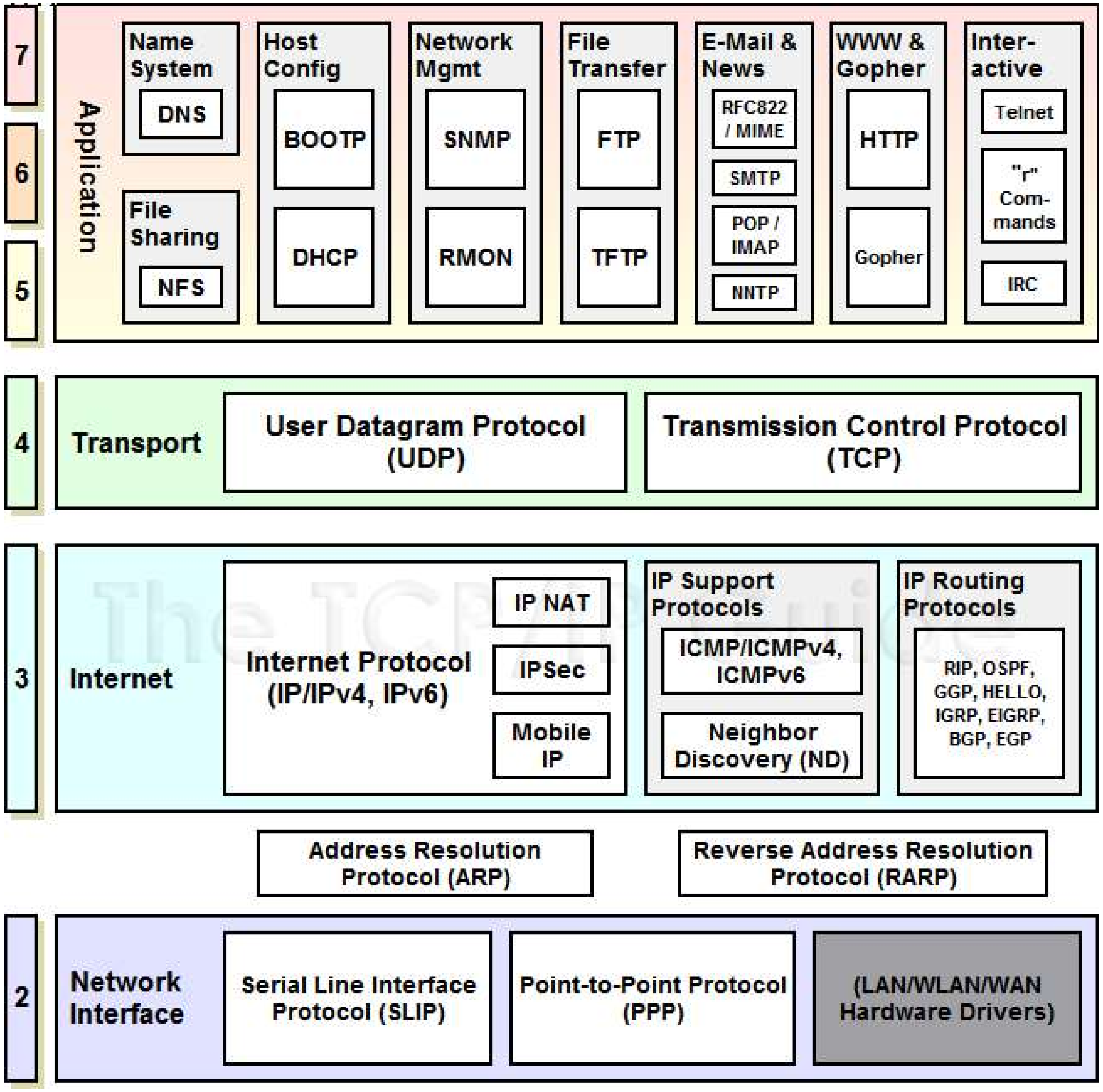


There is just one network-layer protocol, IP.
The "narrow waist" facilitates interoperability.

Internet protocols

- In addition, many "supporting actors"
  - mapping various identifiers: numbers and names
  - configuring end systems
  - managing network elements
  - providing security
  - setting up sessions
  - authorizing users
  - synchronizing clocks
- Typical router or host implements dozens of protocols

The TCP/IP Reference Model

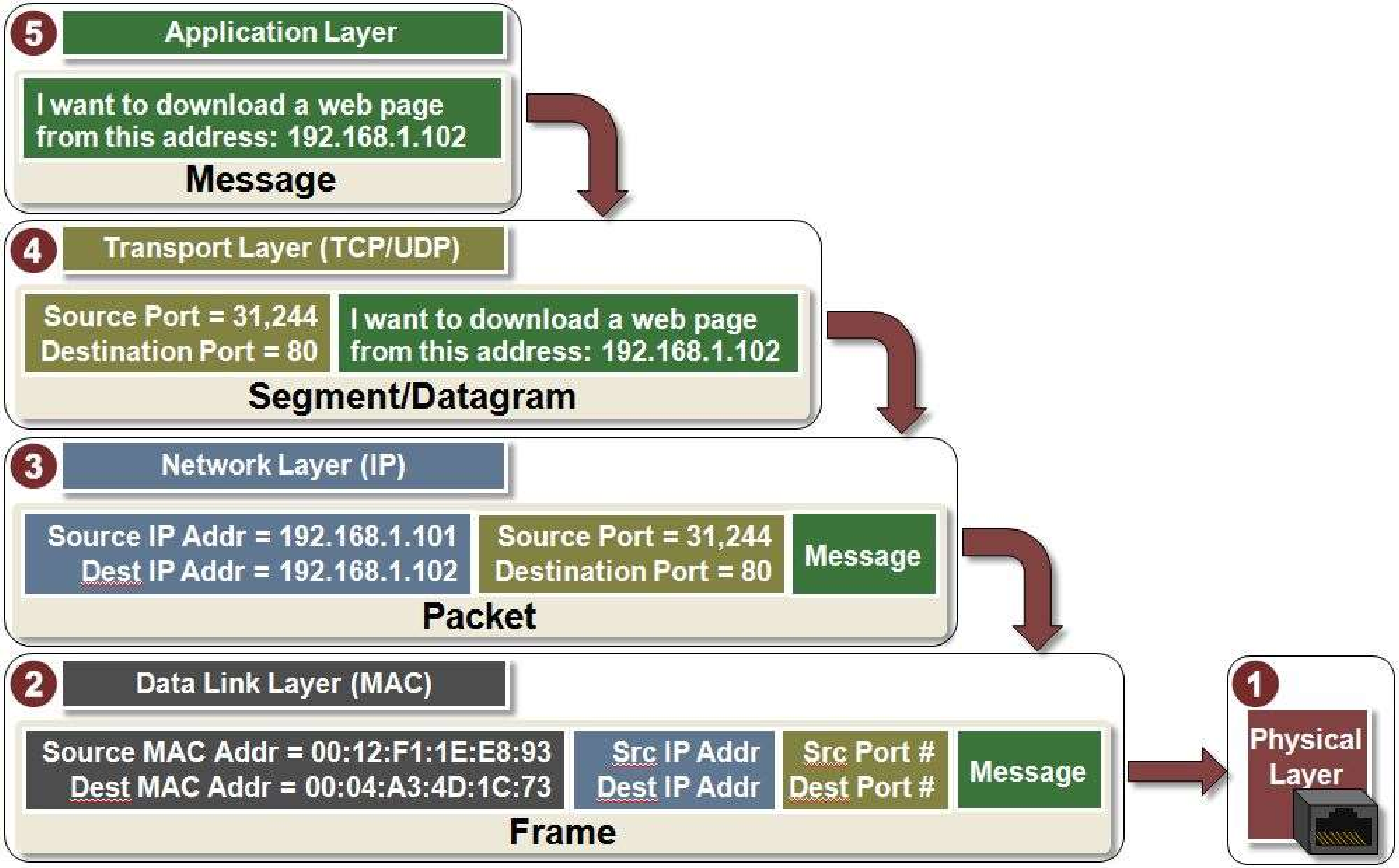


The TCP/IP Reference Model

Layer #	Layer Name	Protocol	Protocol Data Unit	Addressing
5	Application	HTTP, SMTP, etc…	Messages	n/a
4	Transport	TCP/UDP	Segments/ Datagrams	Port #s
3	Network or Internet	IP	Packets	IP Address
2	Data Link	Ethernet, Wi-Fi	Frames	MAC Address
1	Physical	10 Base T, 802.11	Bits	n/a

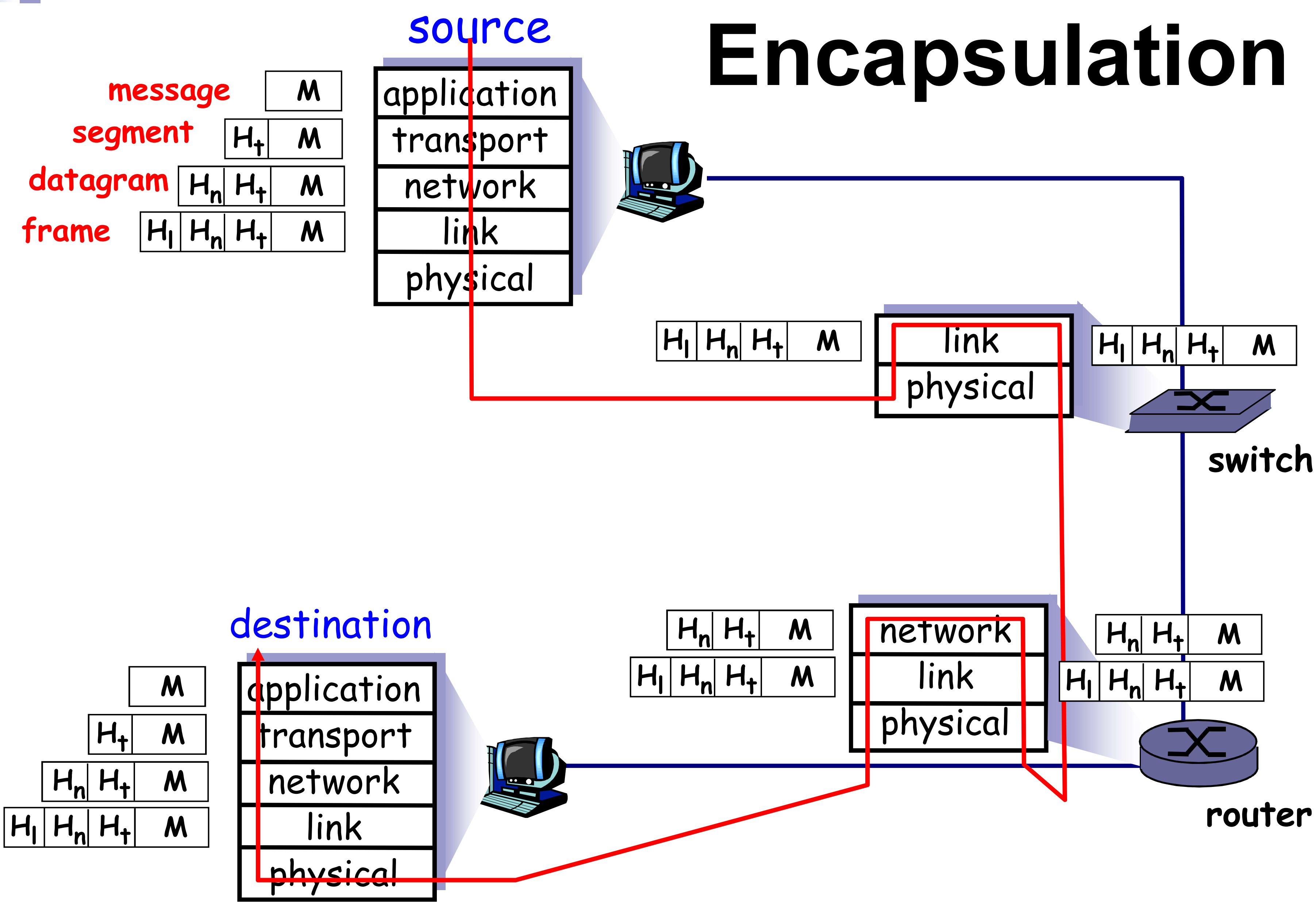
TCP/IP Terminology Reference

The TCP/IP Reference Model



Data Using Network Layers

Encapsulation



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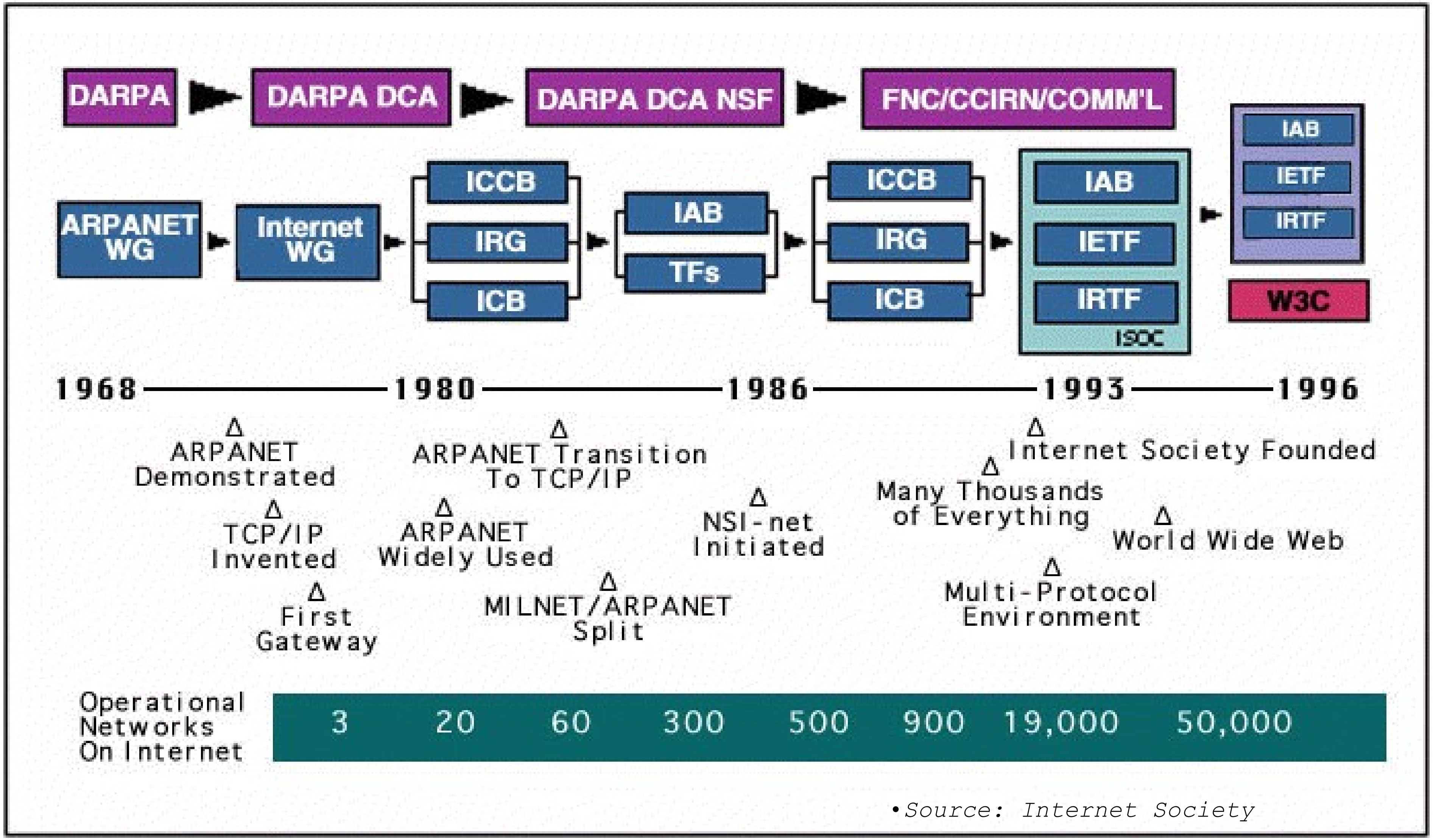
- 1.9 Internet History

Internet History

- 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



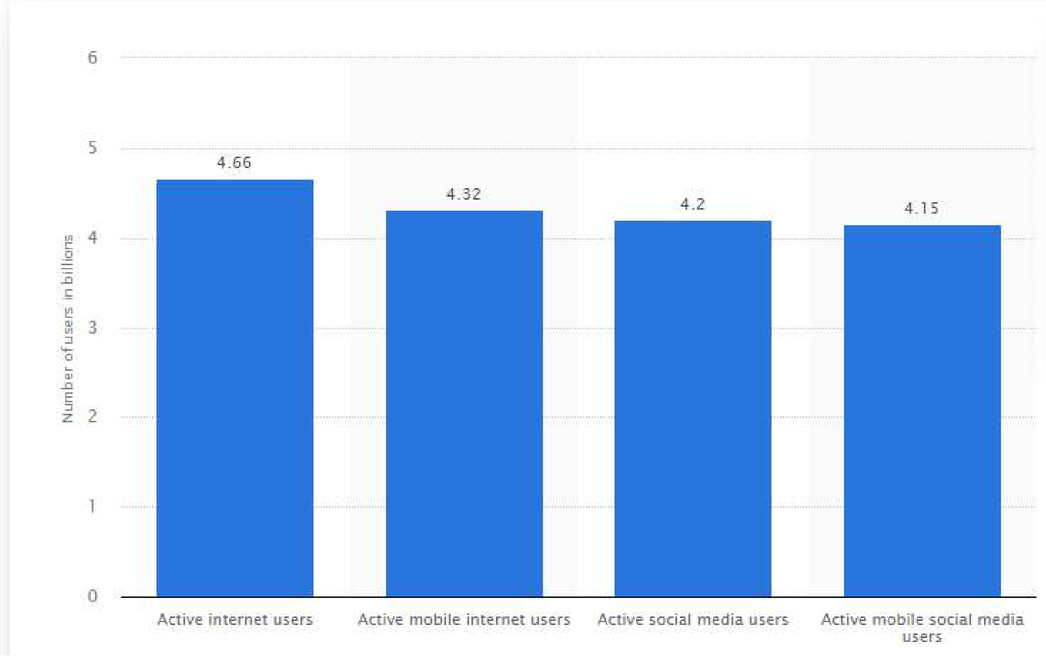
Growth of the Internet

DATE	NUMBER OF USERS	% WORLD POPULATION
June, 2010	1,966 millions	28.7 %
Sept, 2010	1,971 millions	28.8 %
Mar, 2011	2,095 millions	30.2 %
Jun, 2011	2,110 millions	30.4 %
Sept, 2011	2,180 millions	31.5 %
Dec, 2011	2,267 millions	32.7 %
Mar, 2012	2,336 millions	33.3 %
June, 2012	2,405 millions	34.3 %
Sept, 2012	2,439 millions	34.8 %
Dec, 2012	2,497 millions	35.7 %
Dec, 2013	2,802 millions	39.0 %
June, 2014	3,035 millions	42.3 %
Dec, 2014	3,079 millions	42.4 %
June, 2015	3,270 millions	45.0 %
Dec, 2015	3,366 millions	46.4 %
Jun. 2016	3,631 millions	49.5 %
Dec. 2016	3,696 millions	49.5 %
June, 2017	3,885 millions	51.7 %
Dec 2017	4,156 millions	54.4 %
Jun 2018	4,208 millions	55.1 %
Dec 2018	4,313 millions	55.6 %
Mar 2019	4,383 millions	56.8 %
Jun, 2019	4,536 millions	58.8 %
Jun, 2020	4,833 millions	62.0 %
Dec, 2020	5,053 millions	64.2 %
Mar, 2021	5,168 millions	65.6 %

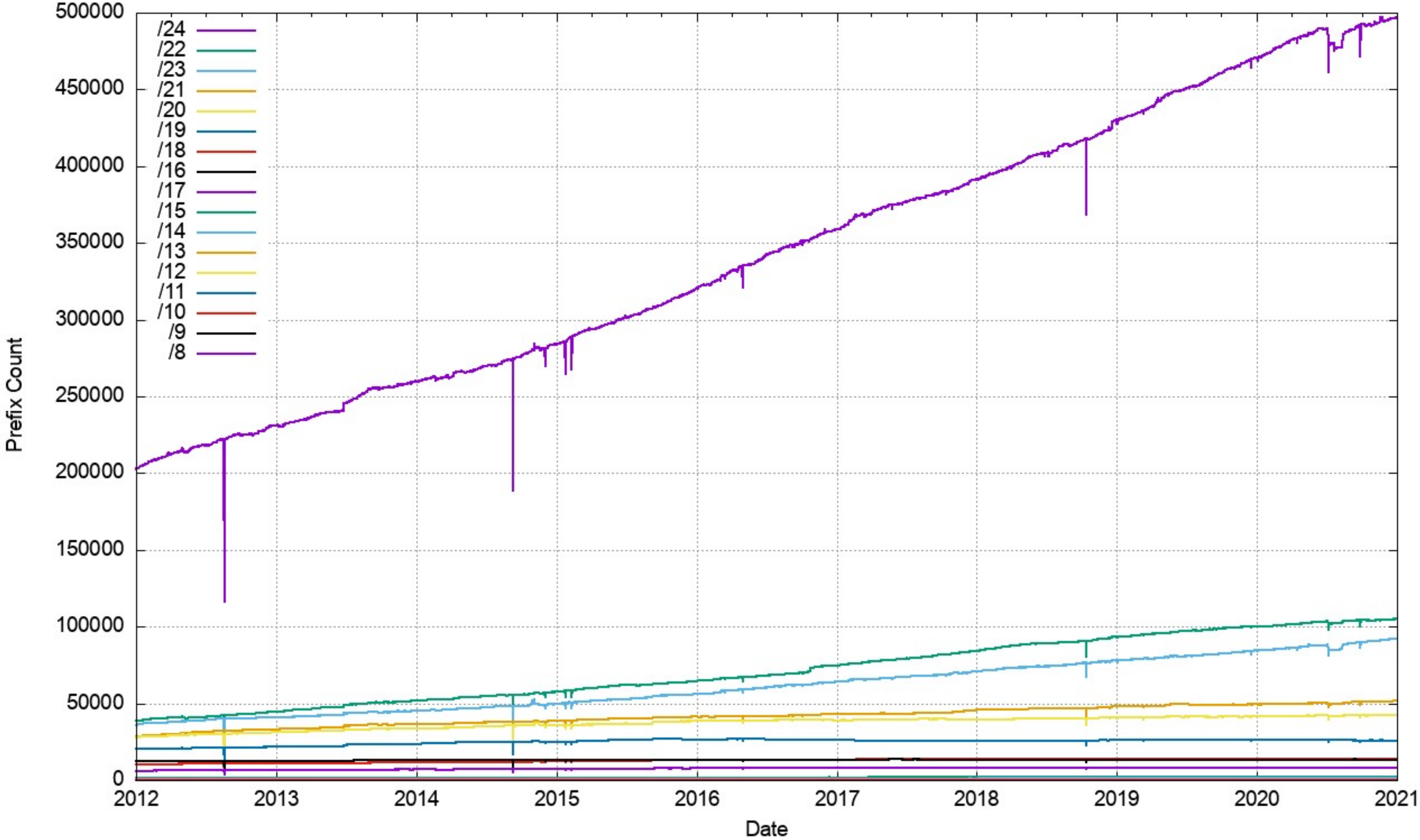
Internet › Demographics & Use

Global digital population as of January 2021

(in billions)



Growth of the Internet

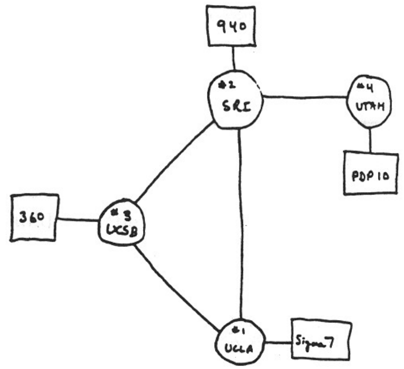


Internet History

1961-1972: Early packet-switching principles

- **1961:** Len Kleinrock - queuing theory shows effectiveness of packet-switching
- **1964:** Paul Baran - packet-switching in military networks
- **1967:** ARPAnet conceived by Advanced Research Projects Agency
- **1969:** first ARPAnet node operational

- **1972:**
  - ARPAnet demonstrated publicly
  - NCP (Network Control Protocol) first host-host protocol
  - first e-mail program
  - ARPAnet has 15 nodes



THE ARPA NETWORK

Internet History

1972-1980: Internetworking, new and proprietary nets

- **1970:** ALOHAnet satellite network in Hawaii
- **1973:** Metcalfe's PhD thesis proposes Ethernet
- **1974:** Cerf and Kahn - architecture for interconnecting networks
- **late70's:** proprietary architectures: DECnet, SNA, XNA
- **late 70's:** switching fixed length packets (ATM precursor)
- **1979:** ARPAnet has 200 nodes

Cerf and Kahn's internetworking principles:

- minimalism, autonomy - no internal changes required to interconnect networks
- best effort service model
- stateless routers
- decentralized control

define today's Internet architecture

Internet History

1980-1990: new protocols, a proliferation of networks

- 1983: deployment of TCP/IP
- 1982: smtp e-mail protocol defined
- 1983: DNS defined for name-to-IP-address translation
- 1985: ftp protocol defined
- 1988: TCP congestion control

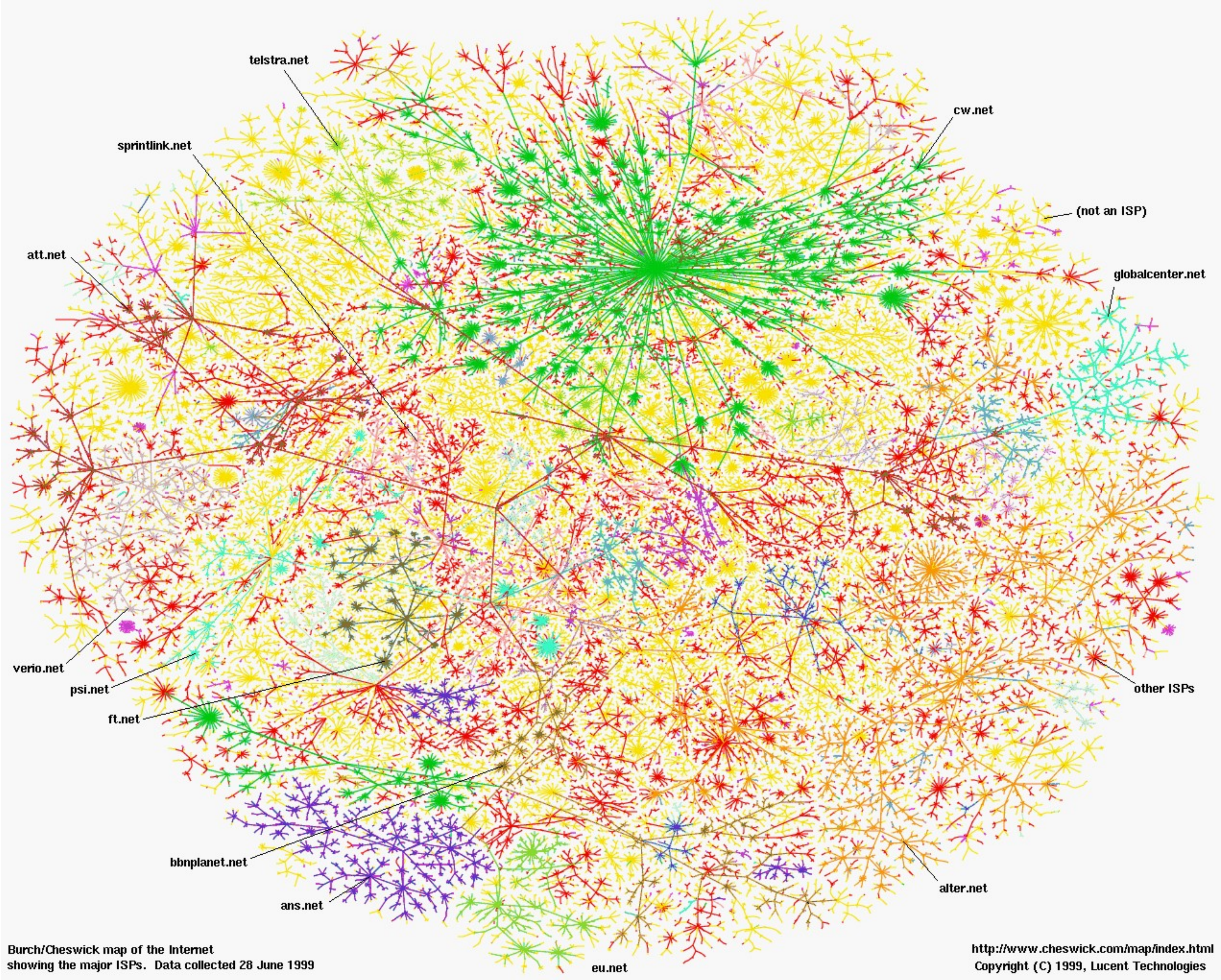
- new national networks: Csnet, BITnet, NSFnet, Minitel
- 100,000 hosts connected to confederation of networks

Internet History

1990's: commercialization, the WWW

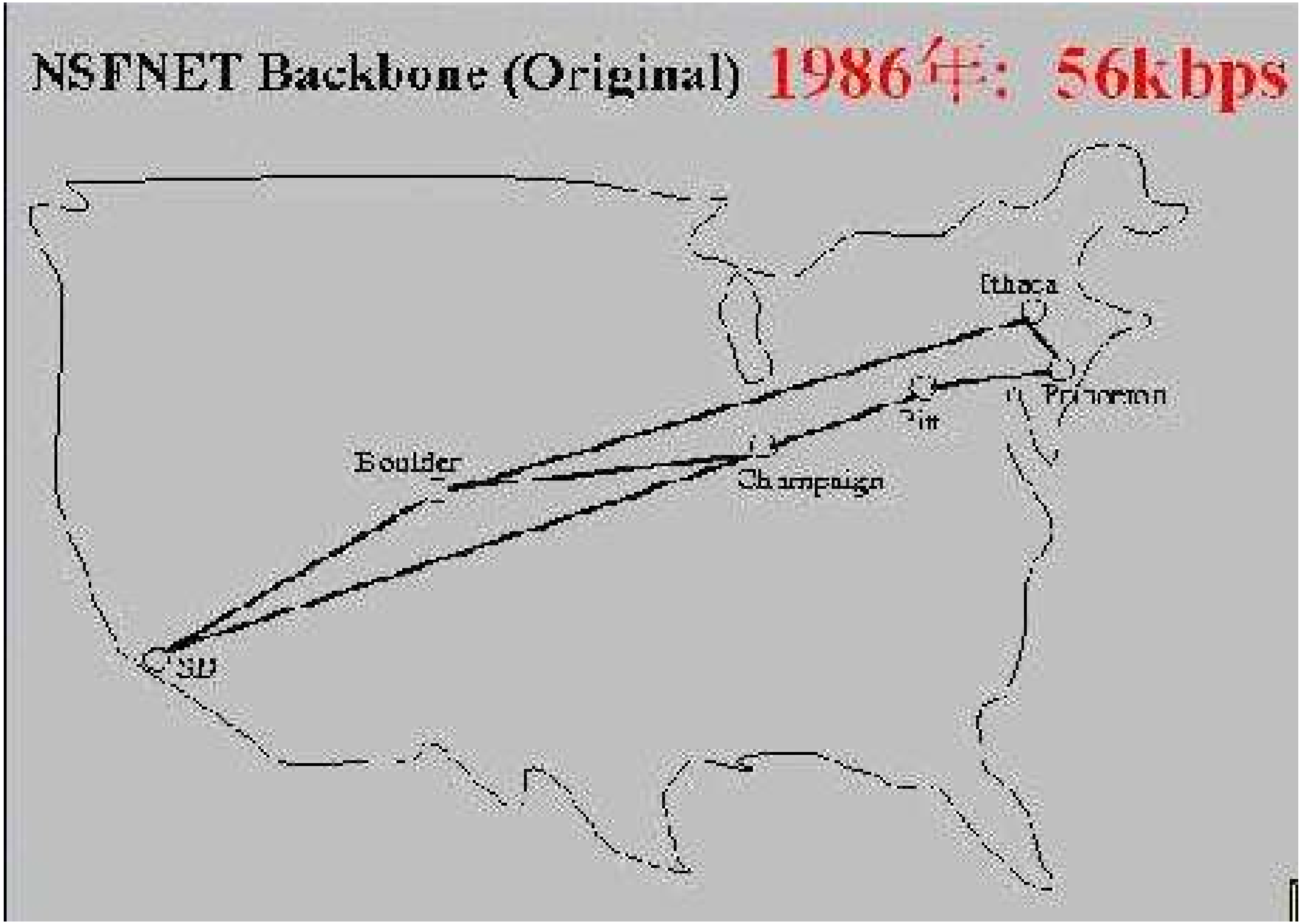
- Early 1990's: ARPAnet decommissioned
- 1991: NSF lifts restrictions on commercial use of NSFnet (decommissioned, 1995)
- early 1990s: WWW
  - hypertext [Bush 1945, Nelson 1960's]
  - HTML, http: Berners-Lee
  - 1994: Mosaic, later Netscape
  - late 1990's: commercialization of the web

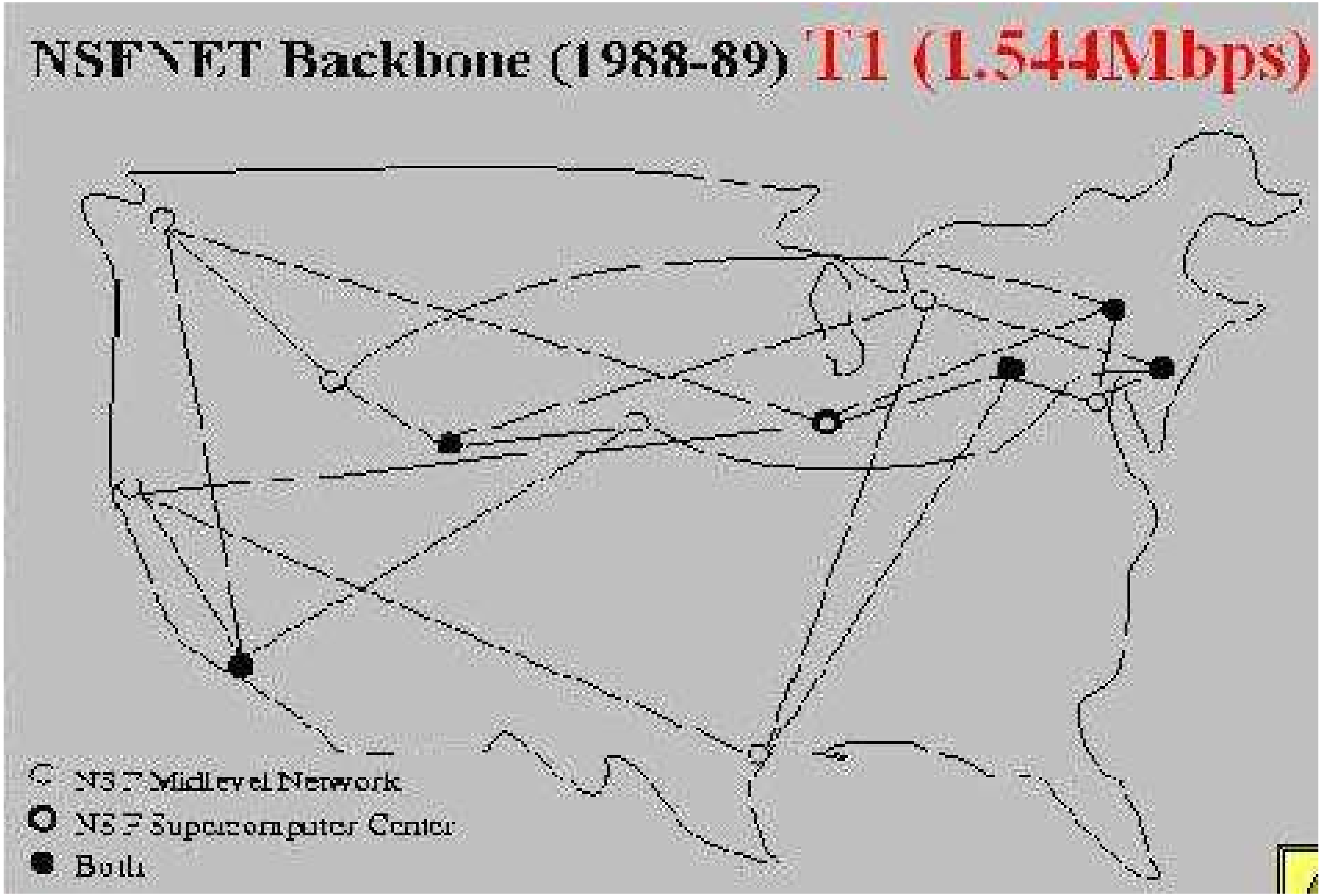
- Late 1990's:
  - est. 50 million computers on Internet
  - est. 100 million+ users
  - backbone links runnning at 1 Gb/s
- 2000's:
  - backbones at 10 Gb/s
  - wireless networks
  - broadband home
  - IP telephony


telstra.net
cw.net
sprintlink.net
(not an ISP)
att.net
globalcenter.net
verio.net
psi.net
ft.net
other ISPs
bbnplanet.net
ans.net
alter.net
Burch/Cheswick map of the Internet
showing the major ISPs. Data collected 28 June 1999
eu.net
http://www.cheswick.com/map/index.html
Copyright (C) 1999, Lucent Technologies

Today's Vision

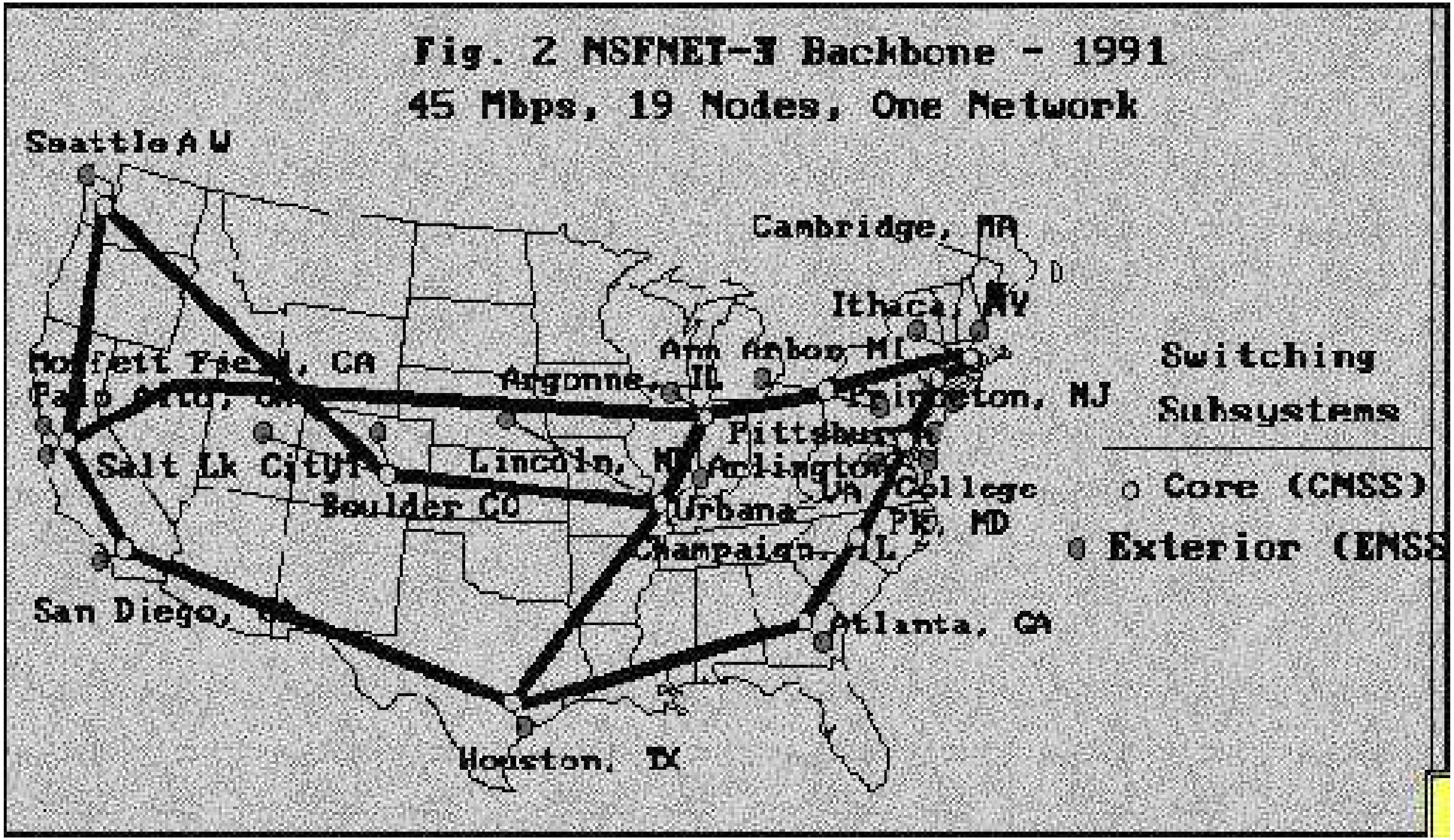
- **Everything is digital:** voice, video, music, pictures, live events
- **Everything is on-line:** bank statement, medical record, books, airline schedule, weather, highway traffic, toaster, refrigerator …
- **Everyone is connected:** doctor, teacher, broker, mother, son, friends, enemies


NSFNET Backbone (Original) 1986年: 56kbps
Ithaca
Princeton
Pitt
Boulder
Champaign
SD

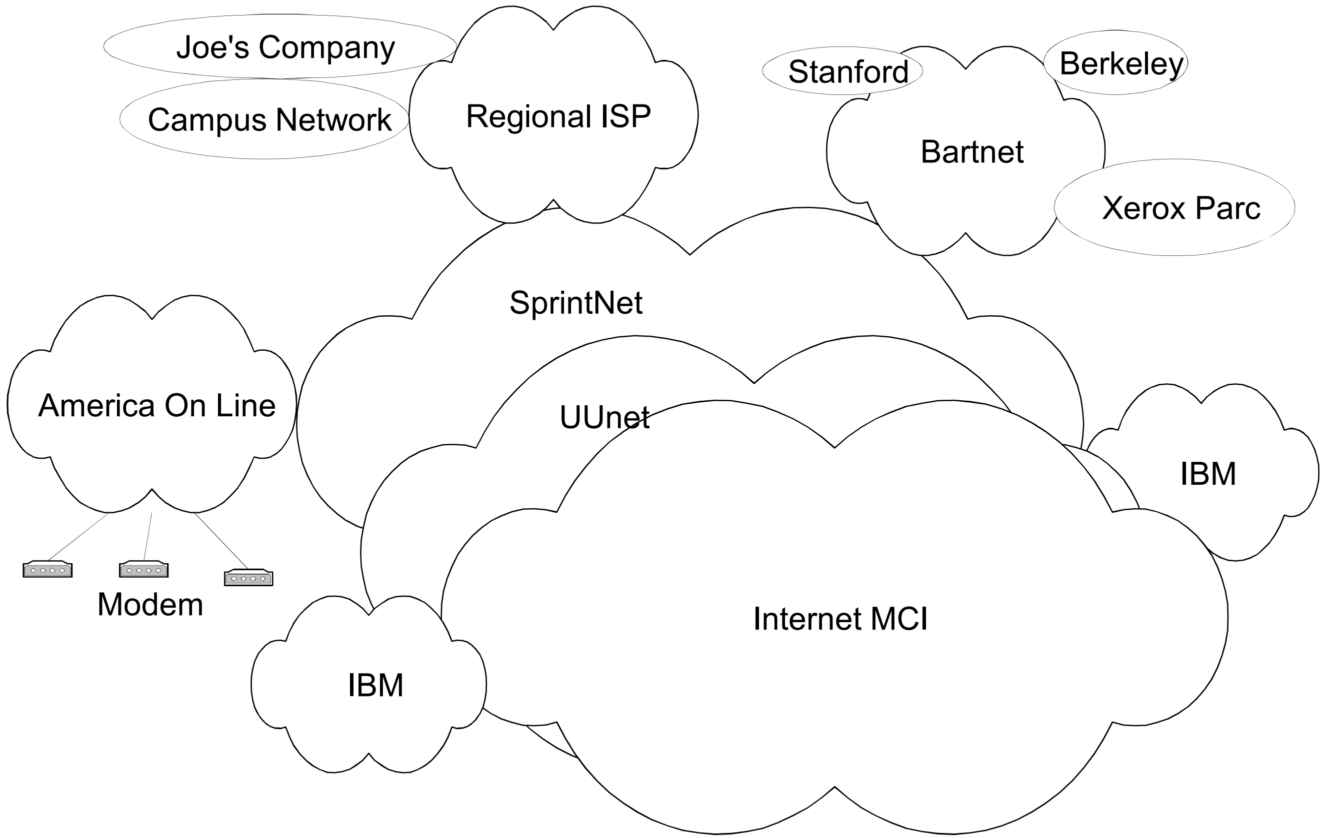


NSFNET Backbone (1988-89) T1 (1.544Mbps)
NSF Midlevel Network
NSF Supercomputer Center
Both

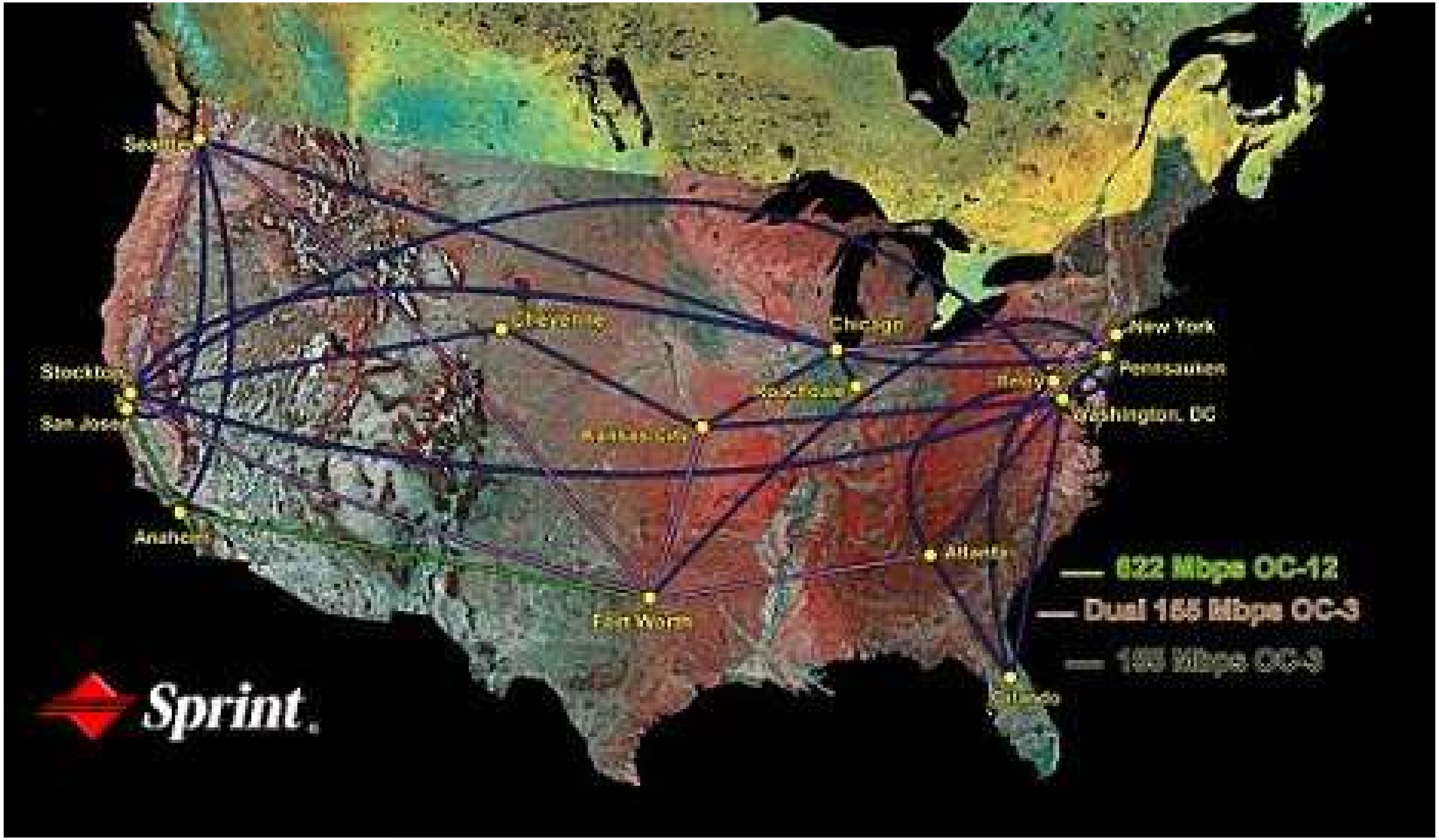
1991: T3 (45Mbps)



Commercial Internet after 1994

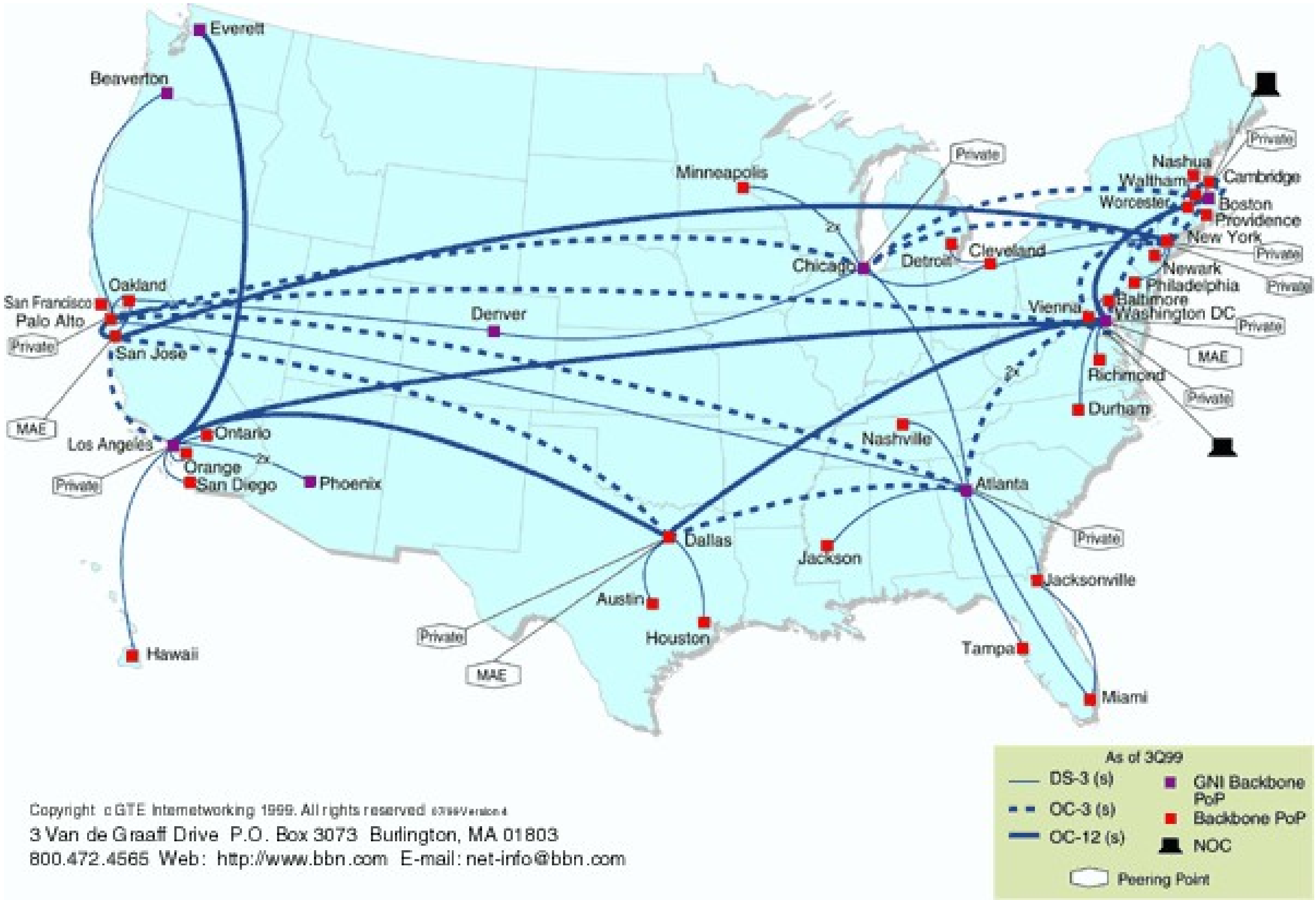


Commercial Internet after 1994

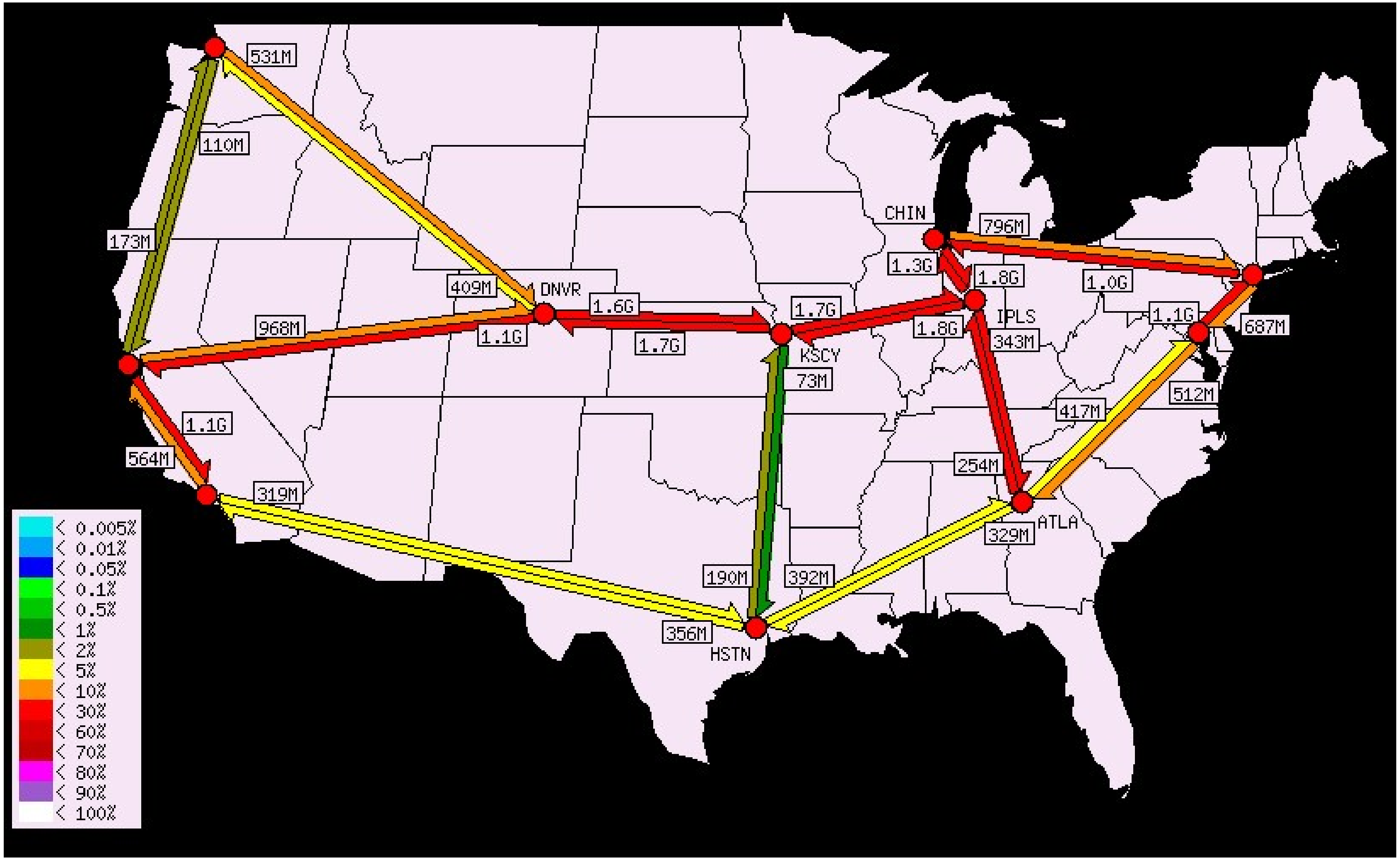


National Backbone Provider

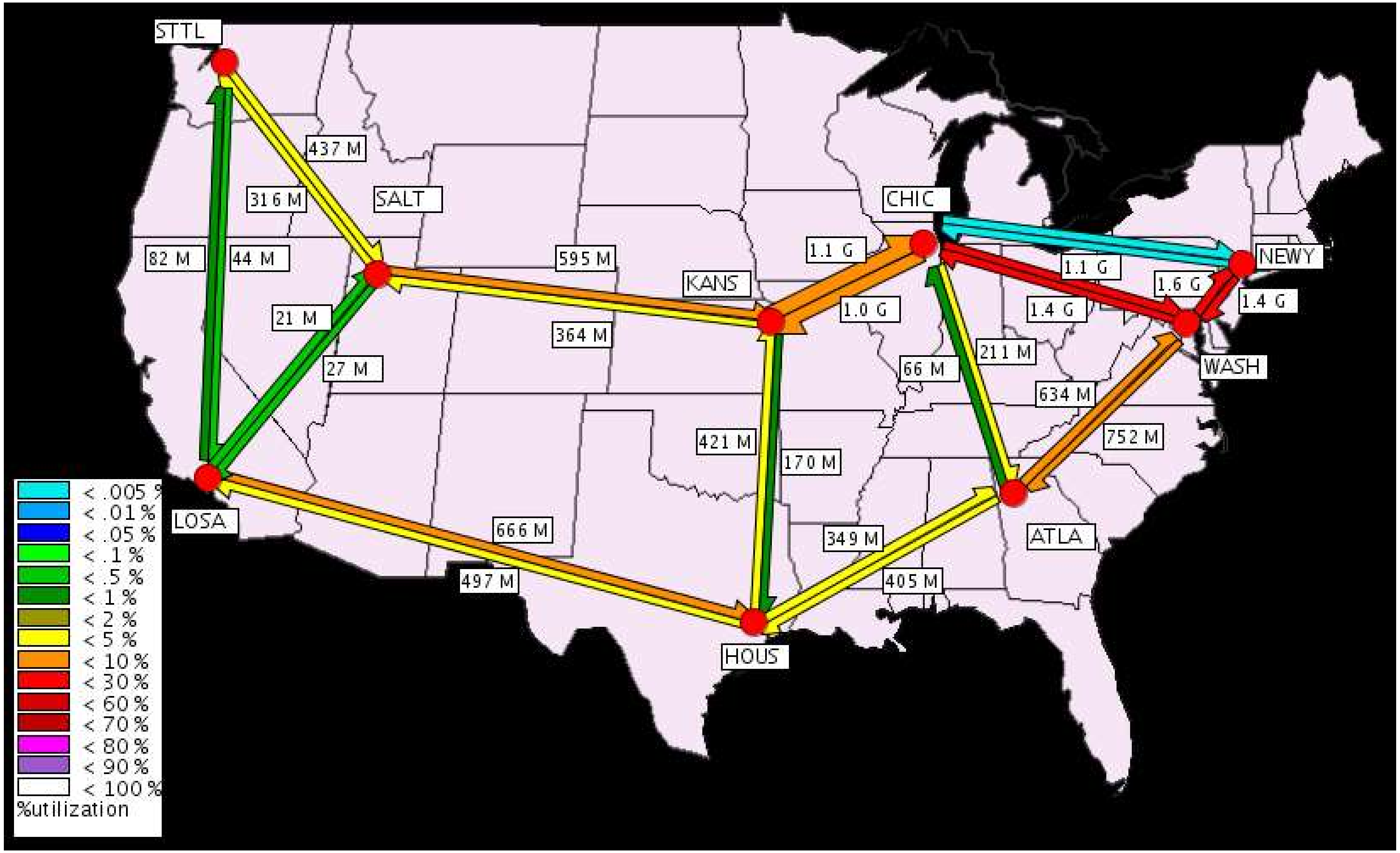
e.g. Genuity/GTE US backbone network



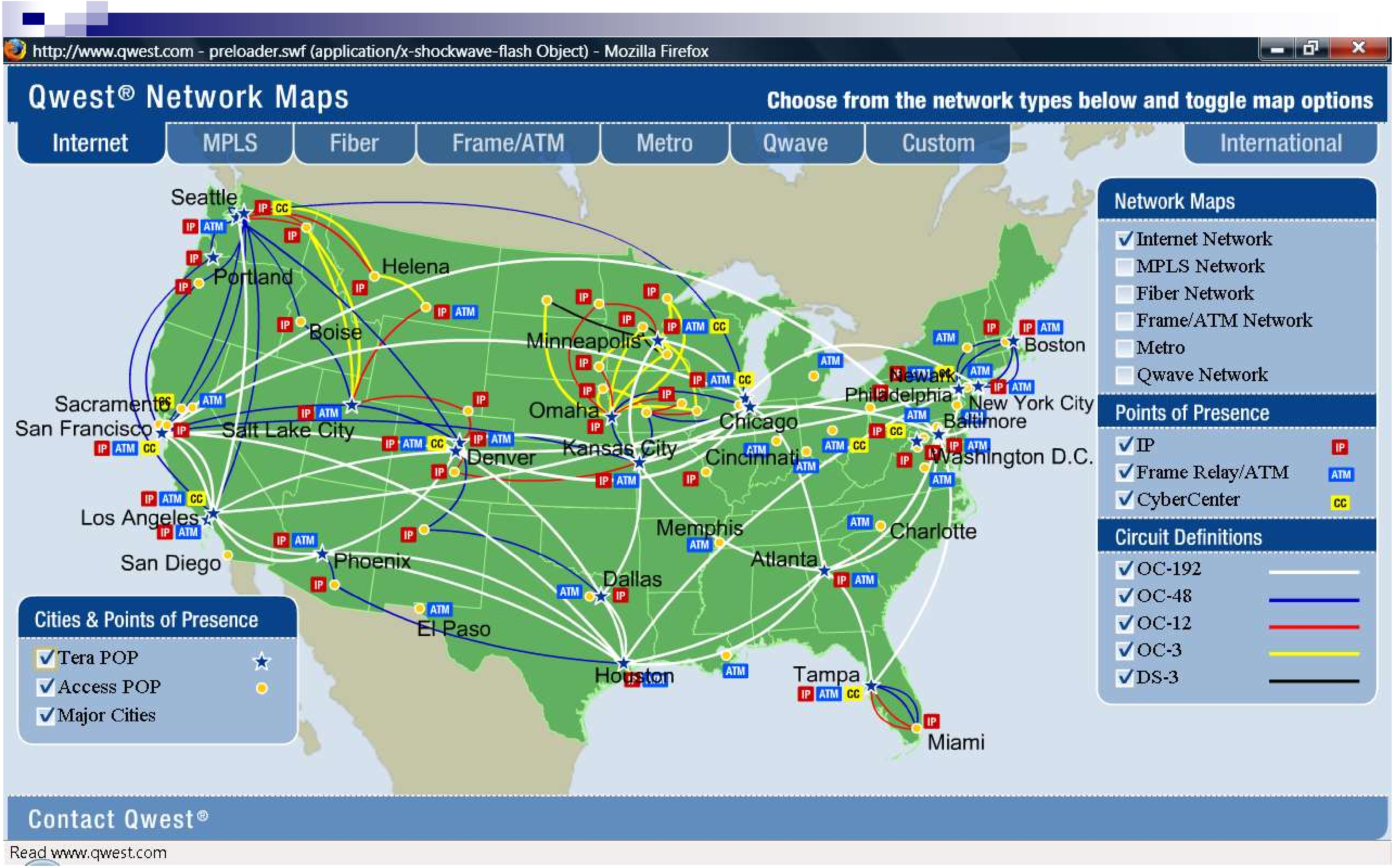
Internet2 weather map



Abilene I2 Backbone



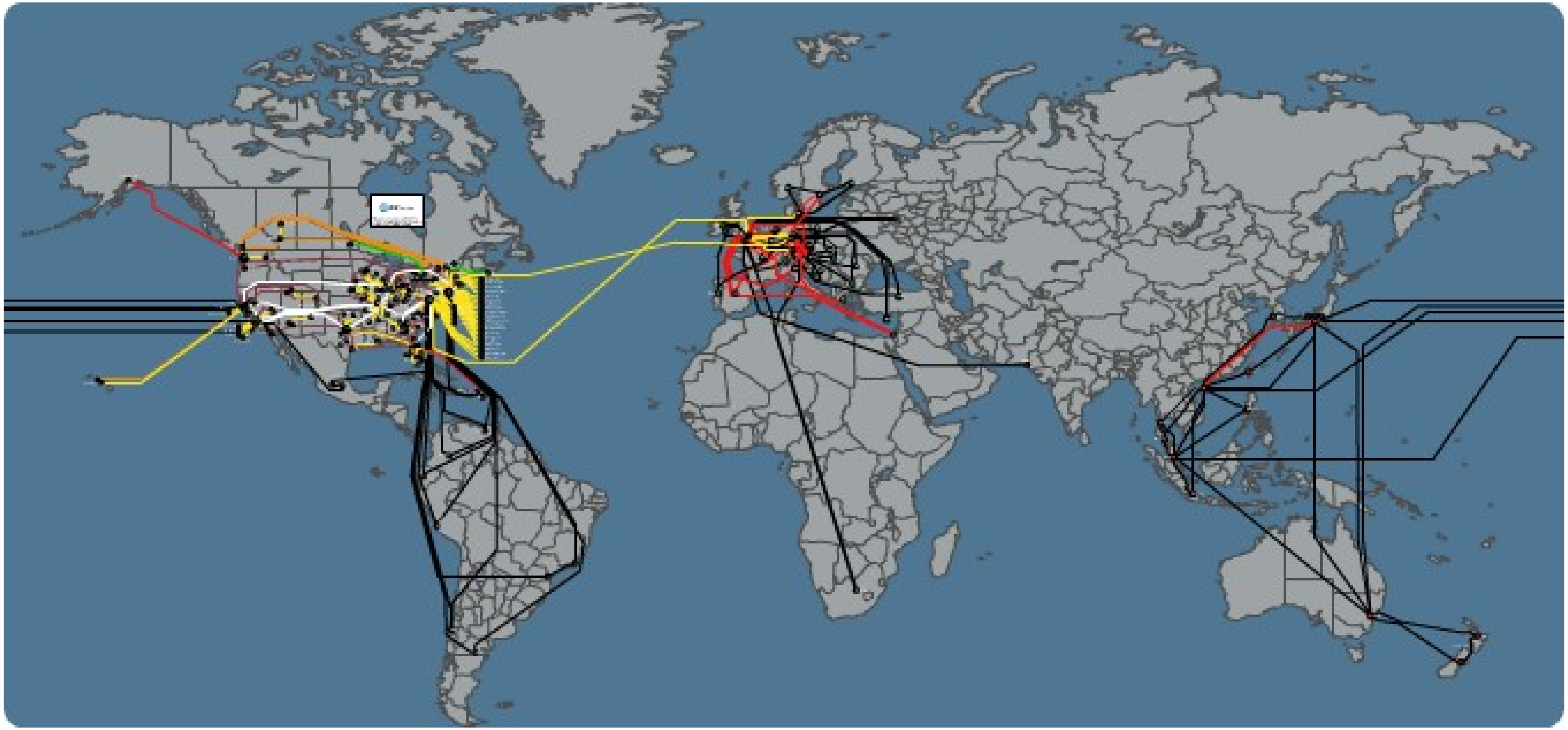
http://weathermap.grnoc.iu.edu/abilene_jpg.html



http://www.qwest.com/largebusiness/enterprisesolutions/networkMaps/preloader.swf

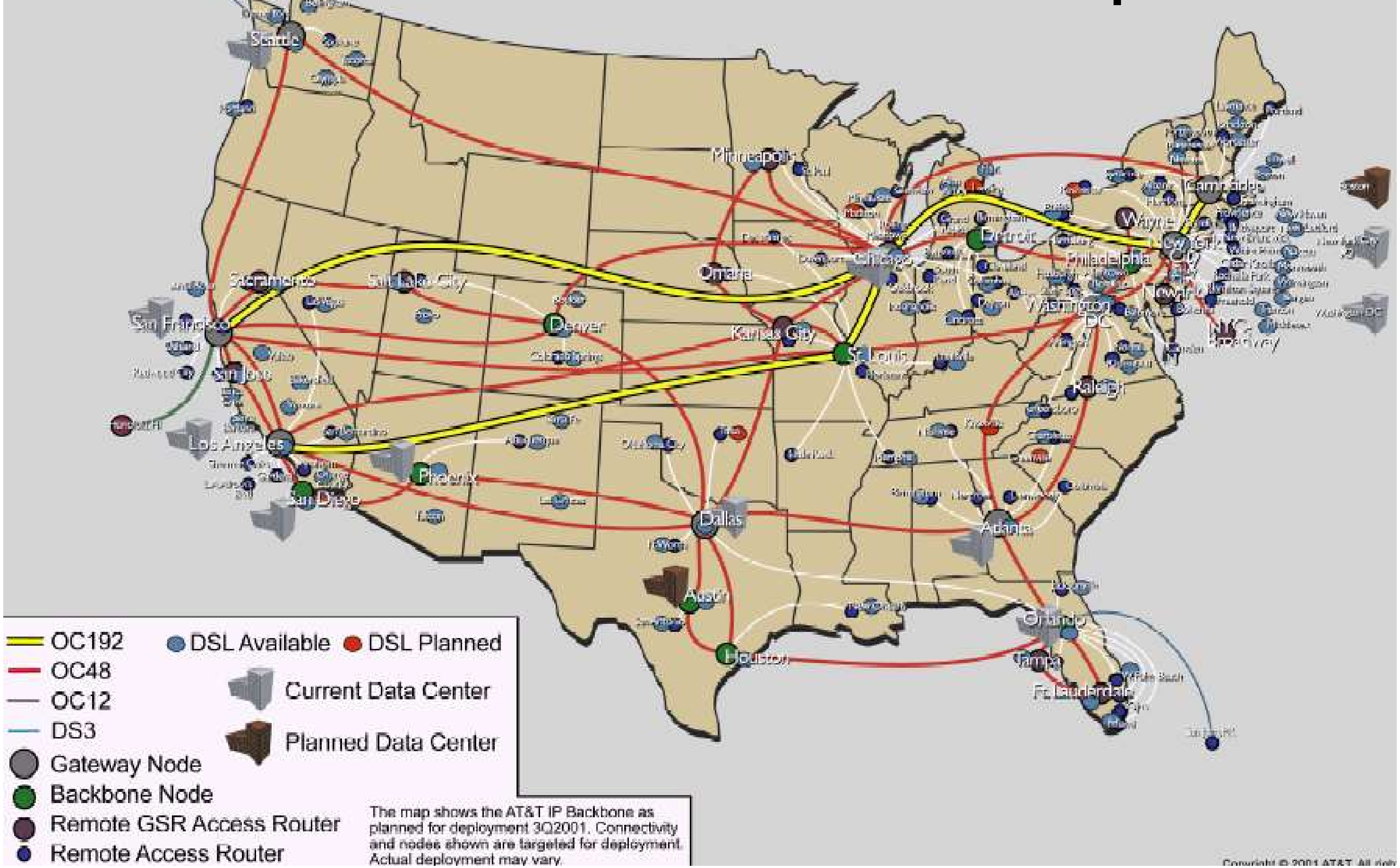
Qwest Backbone Map

ATT Global Backbone IP Network



From http://www.business.att.com

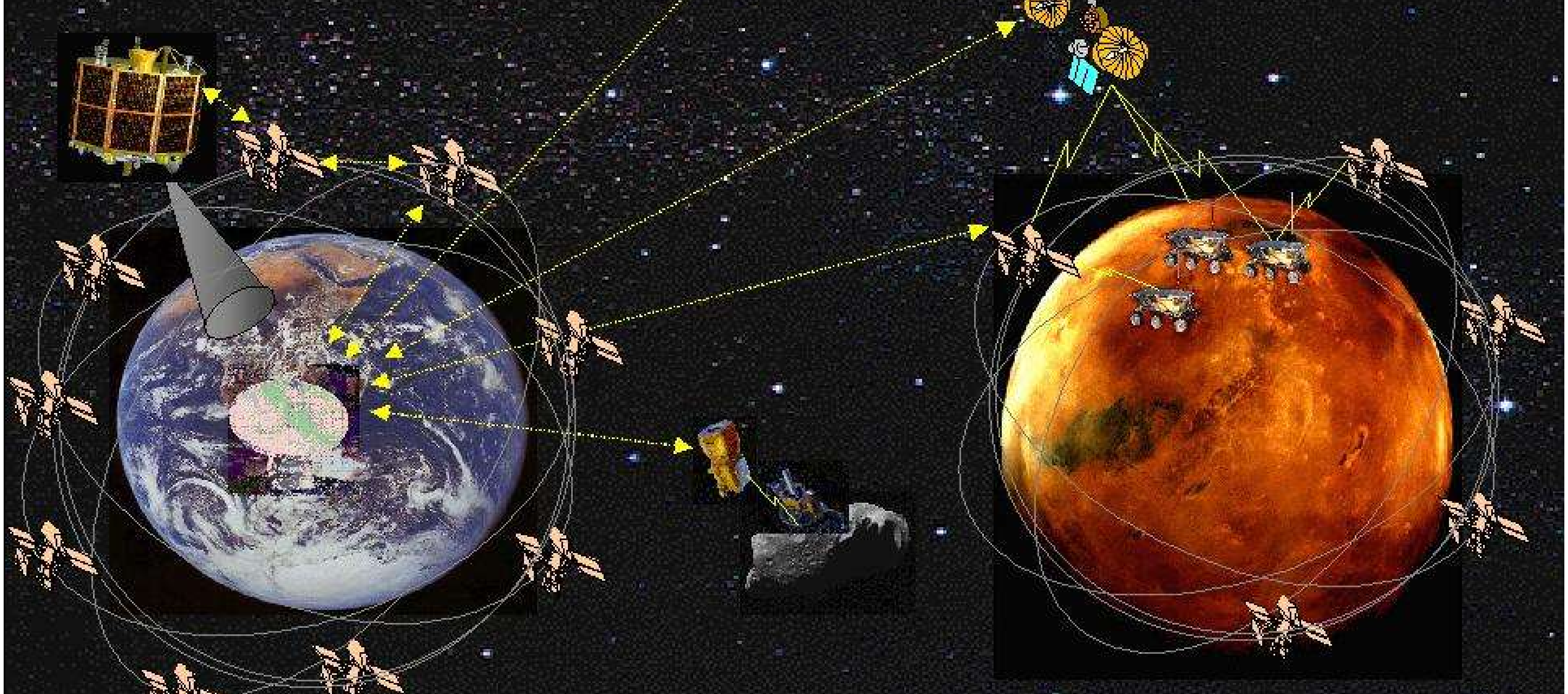
AT&T USA Backbone Map

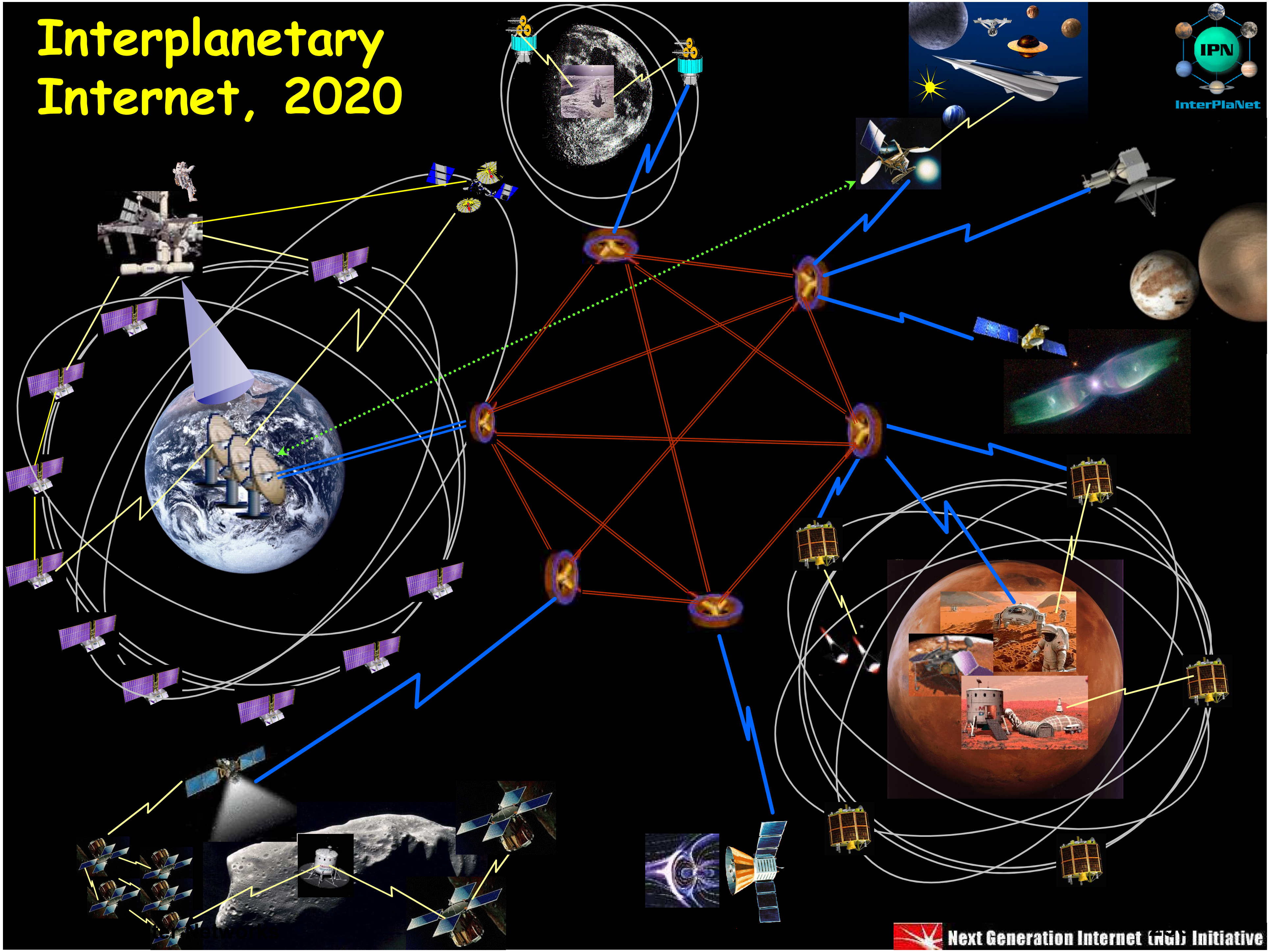


From AT&T web site.

Interplanetary Internet

- *End-to-end information flow across the solar system*
- *Layered architecture for evolvability and interoperability*
- *IP-like protocol suite tailored to operate over long round trip light times*
- *Integrated communications and navigation services*




Interplanetary Internet, 2020
IPN
InterPlaNet
Next Generation Internet (NGI) Initiative

Summary

- **What is a Computer Network?**
  - **Definition, Objectives, Components, Types**
- **How to connect computers together?**
  - **Types of Network Connections (Topologies)**
- **How to make computers to communicate?**
  - **Broadcasting, Switching (Circuit, Packet)**
- **How to evaluate communication performance?**
  - **Latency (delay), Bandwidth (capacity), Utilization, RTT, BDP**

Summary

- **How to design and organize a computer network system?**
  - **Layering, Hierarchical Network Model**
- **What does network architecture mean?**
  - **Describe how networks are organized**
  - **Layered Protocol Architectures**
- **In a computer network architecture, what is the role and function of each layer?**

Summary

Covered a “ton” of materials!

- **Network overview.**
- **What a protocol is.**
- **Network edge, core, and access network**
  - **packet-switching vs circuit-switching**
- **Type & Topology, Internet/ISP structure.**
- **Performance: loss, delay, utilization, BDP**
- **Layering and service models**
- **Architecture: OSI, TCP/IP**
- **History**

Summary

- Architecture of a complex system can be simplified by layering.
- Layer architecture simplifies the network design.
- A set of layers and protocols, together with interfaces between layers, is called Network Architecture.
- Service, Interface, Protocol, SAP, PDU