REVIEW OF NETWORK HARDWARE AND PHYSICAL ADDRESSING

The TCP/IP Concept

- Use existing network hardware
- Interconnect networks
- Add abstractions to hide heterogeneity

The Challenge

- Accommodate *all* possible network hardware
- Question: what kinds of hardware exist?

Network Hardware Review

- We will
  - Review basic network concepts
  - Examine example physical network technologies
  - Introduce physical (hardware) addressing

Two Basic Categories Of Network Hardware

- Connection oriented
- Connectionless

Connection Oriented (Circuit Switched Technology)

- Paradigm
  - Form a ‘‘connection’’ through the network
  - Send / receive data over the connection
  - Terminate the connection
- Can guarantee bandwidth
- Proponents argue that it works well with real-time applications
- Example: ATM network

Connectionless (Packet Switched Technology)

- Paradigm
  - Form ‘‘packet’’ of data
  - Pass to network
- Each packet travels independently
- Packet includes identification of the destination
- Each packet can be a different size
- The maximum packet size is fixed (some technologies limit packet sizes to 1,500 octets or less)

Broad Characterizations Of Packet Switching Networks

- Local Area Network (LAN)
- Wide Area Network (WAN)
- Categories are informal and qualitative

Local Area Networks

- Engineered for
  - Low cost
  - High capacity
- Direct connection among computers
- Limited distance

Wide Area Networks (Long Haul Networks)

- Engineered for
  - Long distances
  - Indirect interconnection via special-purpose hardware
- Higher cost
- Lower capacity (usually)

Examples Of Packet Switched Networks

- Wide Area Nets
  - ARPANET, NSFNET, ANSNET
  - Common carrier services
- Leased line services
  - Point-to-point connections
- Local Area Nets
  - Ethernet
  - Wi-Fi

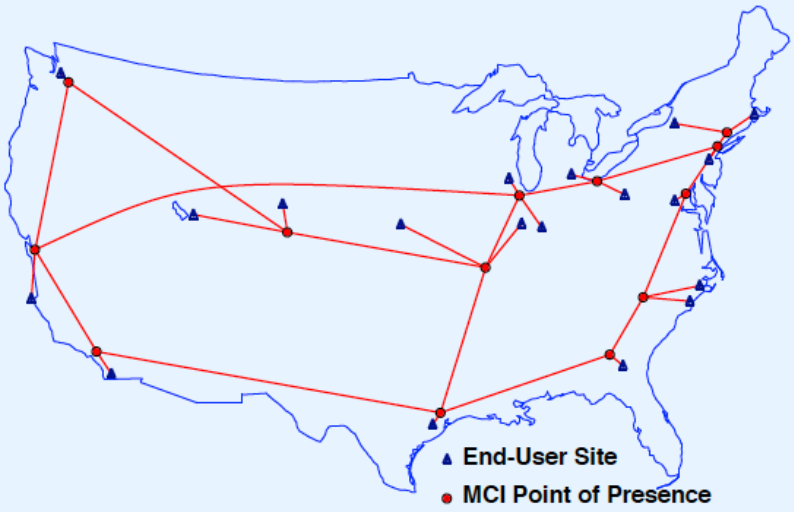
ARPANET (1969-1989)

- Original backbone of Internet
- Wide area network around which TCP/IP was developed
- Funding from Advanced Research Project Agency
- Initial speed 50 Kbps

NSFNET (1987-1992)

- Funded by National Science Foundation
- Motivation: Internet backbone to connect all scientists and engineers
- Introduced Internet hierarchy
  - Wide area backbone spanning geographic U.S.
  - Many mid-level (regional) networks that attach to backbone
  - Campus networks at lowest level
- Initial speed 1.544 Mbps

ANSNET (1992-1995)



- Backbone of Internet before commercial ISPs
- Typical topology

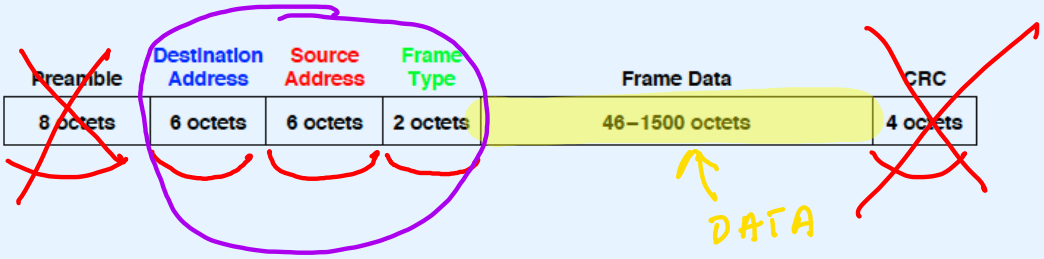
Wide Area Networks Available From Common Carriers

- Point-to-point digital circuits
  - T-series (e.g., T1 = 1.5 Mbps, T3 = 45 Mbps)
  - OC-series (e.g., OC-3 = 155 Mbps, OC-48 = 2.4 Gbps)
- Packet switching services also available
  - Examples: ISDN, SMDS, Frame Relay, ATM

Example Local Area Network: Ethernet

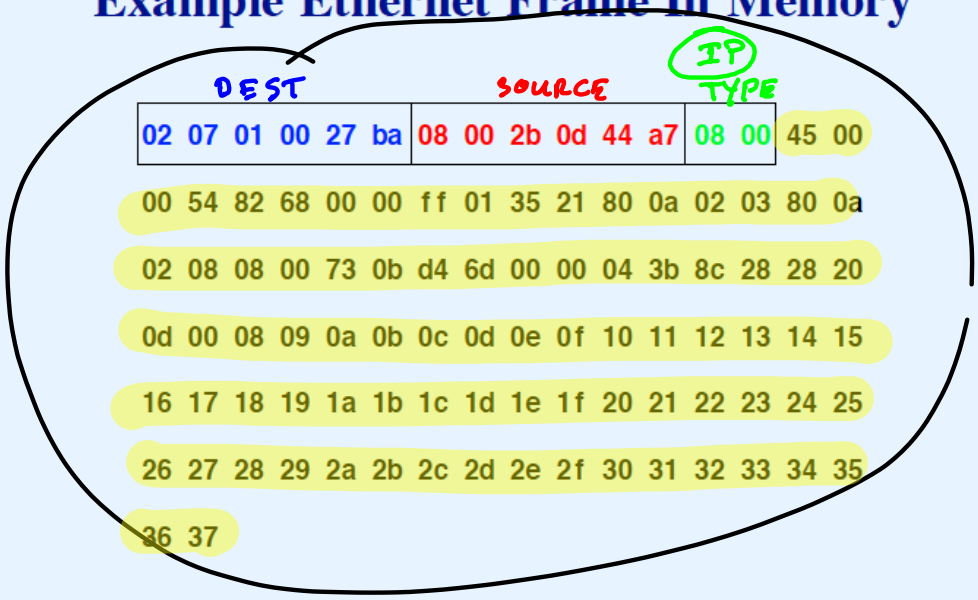
- Extremely popular
- Can run over
  - Copper (twisted pair)
  - Optical fiber
- Three generations
  - *10Base-T* operates at 10 Mbps
  - *100Base-T* (fast Ethernet) operates at 100 Mbps
  - *1000Base-T* (gigabit Ethernet) operates at 1 Gbps
- IEEE standard is 802.3

Ethernet Frame Format



- Header format fixed (Destination, Source, Type fields)
- Frame data size can vary from packet to packet
  - Maximum 1500 octets
  - Minimum 46 octets
- Preamble and CRC removed by framer hardware before frame stored in computer's memory

Example Ethernet Frame In Memory



- Octets shown in hexadecimal
- Destination is 02.07.01.00.27.ba
- Source is 08.00.2b.0d.44.a7
- Frame type is 08.00 (IP)

Point-to-Point Network

- Any direct connection between two computers
  - Leased line
  - Connection between two routers
  - Dialup connection
- Link-level protocol required for framing
- TCP/IP views as an independent network

Note: some pundits argue the terminology is incorrect because a connection limited to two endpoints is not technically a ‘‘network’’

Hardware Address

- Unique number assigned to each machine on a network
- Used to identify destination for a packet

Hardware Address Terminology

- Known as
  - MAC (Media Access Control) address
  - Physical address
  - Hardware unicast address
- Hardware engineers assign fine distinctions to the above terms
- We will treat all terms *equally*

Use Of Hardware Address

- Sender supplies
  - Destination's address
  - Source address (in most technologies)
- Network hardware
  - Uses destination address to forward packet
  - Delivers packet to proper machine.
- Important note: each technology defines its own addressing scheme

Three Types Of Hardware Addressing Schemes

- Static
  - Address assigned by hardware vendor
- Configurable
  - Address assigned by customer
- Dynamic
  - Address assigned by software at startup

Examples Of Hardware Address Types

- Configurable: proNET-10 (Proteon)
  - 8-bit address per interface card
  - All 1s address reserved for broadcast
  - Address assigned by customer when device installed
- Dynamic MAC addressing: LocalTalk (Apple)
  - Randomized bidding
  - Handled by protocols in software

Examples Of Hardware Address Types (continued)

- Static MAC addressing: Ethernet
  - 48-bit address
  - Unicast address assigned when device manufactured
  - All 1s address reserved for broadcast
  - One-half address space reserved for multicast (restricted form of broadcast)
- Ethernet's static addressing is now most common form

Bridge

- Hardware device that connects multiple LANs and makes them appear to be a single LAN
- Repeats all packets from one LAN to the other and vice versa
- Introduces delay of 1 packet-time
- Does not forward collisions or noise
- Called *Layer 2 Interconnect* or *Layer 2 forwarder*
- Makes multiple LANs appear to be a single, large LAN
- Often embedded in other equipment (e.g., DSL modem)

Bridge
(continued)

- Watches packets to learn which computers are on which side of the bridge
- Uses hardware addresses to filter

Layer 2 Switch

- Electronic device
- Computers connect directly
- Applies bridging algorithm
- Can separate computers onto virtual networks (*VLAN switch*)

Physical Networks As Viewed By TCP/IP

- TCP/IP protocols accommodate
  - Local Area Network
  - Wide Area Network
  - Point-to-point link
  - Set of bridged LANs

The Motivation For Heterogeneity

- Each network technology has advantages for some applications
- Consequence: an internet may contain combinations of technologies

Heterogeneity And Addressing

- Recall: each technology can define its own addressing scheme
- Heterogeneous networks imply potential for heterogeneous addressing
- Conclusion: cannot rely on hardware addressing

Summary

- TCP/IP is designed to use all types of networks
  - Connection-oriented
  - Connectionless
  - Local Area Network (LAN)
  - Wide Area Network (WAN)
  - Point-to-point link
  - Set of bridged networks

Summary
(continued)

- Each technology defines an addressing scheme
- TCP/IP must accommodate heterogeneous addressing schemes

PART III

INTERNETWORKING CONCEPT AND ARCHITECTURAL MODEL

Accommodating Heterogeneity

- Approach 1
  - Application gateways
  - Gateway forwards data from one network to another
  - Example: file transfer gateway
- Approach 2
  - Network-level gateways
  - Gateway forwards individual packets
- Discussion question: which is better?

Desired Properties

- Universal service
- End-to-end connectivity
- Transparency

Agreement Needed To Achieve Desired Properties

- Data formats
- Procedures for exchanging information
- Identification
  - Services
  - Computers
  - Applications
- Broad concepts: naming and addressing

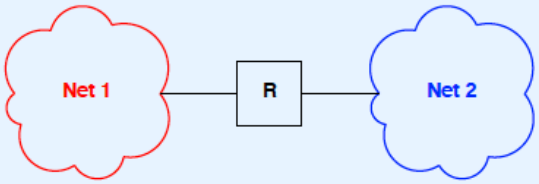
The TCP/IP Internet Concept

- Use available networks
- Interconnect physical networks
  - Network of networks
  - Revolutionary when proposed
- Devise abstractions that hide
  - Underlying architecture
  - Hardware addresses
  - Routes

Network Interconnection

- Uses active system
- Each network sees an additional computer attached
- Device is *IP router* (originally called *IP gateway*)

Illustration Of Network Interconnection

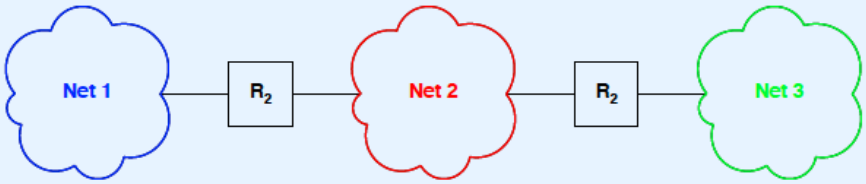


- Network technologies can differ
  - LAN and WAN
  - Connection-oriented and connectionless

Building An Internet

- Use multiple IP routers
- Ensure that each network is reachable
- Do not need router between each pair of networks

Example Of Multiple Networks



- Networks can be heterogeneous
- No direct connection from network 1 to network 3

Physical Connectivity

In a TCP/IP internet, special computers called IP routers *or* IP gateways *provide interconnections among physical networks.*

Packet Transmission Paradigm

- Source computer
  - Generates a packet
  - Sends across one network to a router
- Intermediate router
  - Forwards packet to ‘‘next’’ router
- Final router
  - Delivers packet to destination

An Important Point About Forwarding

Routers use the destination network, not the destination computer, when forwarding packets.

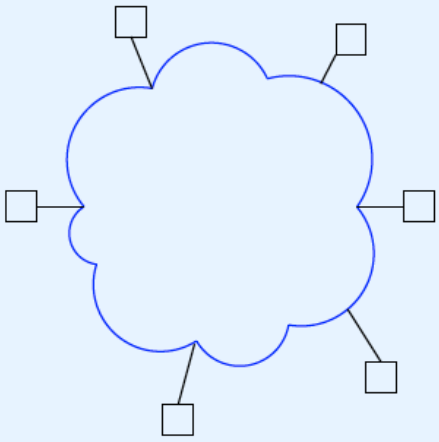
Equal Treatment

The TCP/IP internet protocols treat all networks equally. A Local Area Network such as an Ethernet, a Wide Area Network used as a backbone, or a point-to-point link between two computers each count as one network.

User's View Of Internet

- Single large (global) network
- User's computers all attach directly
- No other structure visible

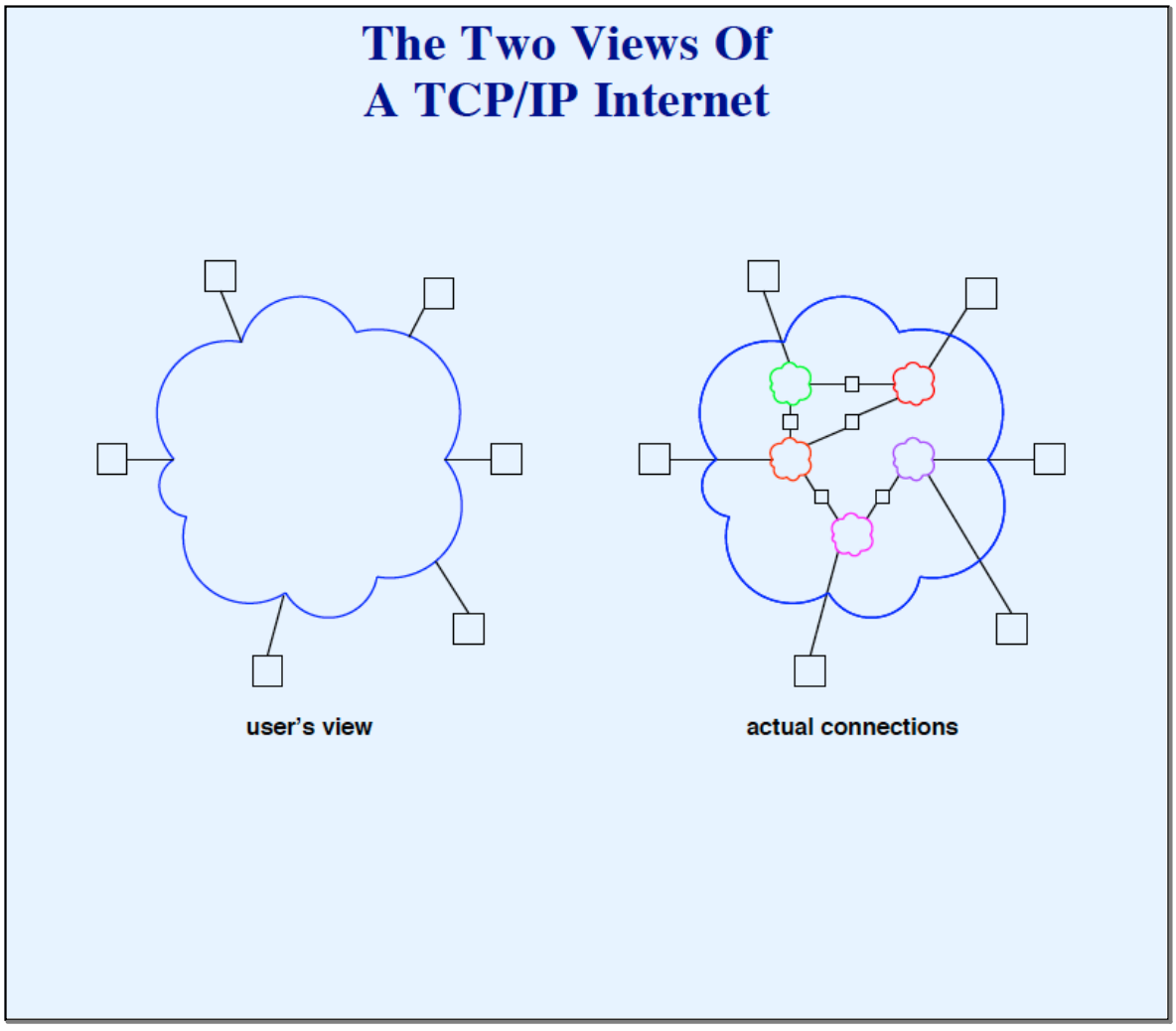
Illustration Of User's View Of A TCP/IP Internet



user's view

Actual Internet Architecture

- Multiple physical networks interconnected
- Each host attaches to one network
- Single *virtual* network achieved through software that implements abstractions


The Two Views Of
A TCP/IP Internet
user's view
actual connections

Architectural Terminology

- End-user system is called *host* computer
  - Connects to physical network
  - Possibly many hosts per network
  - Possibly more than one network connection per host
- Dedicated systems called *IP gateways* or *IP routers* interconnect networks
  - Router connects two or more networks

Many Unanswered Questions

- Addressing model and relationship to hardware addresses
- Format of packet as it travels through Internet
- How a host handles concurrent communication with several other hosts

Summary

- Internet is set of interconnected (possibly heterogeneous) networks
- Routers provide interconnection
- End-user systems are called host computers
- Internetworking introduces abstractions that hide details of underlying networks