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

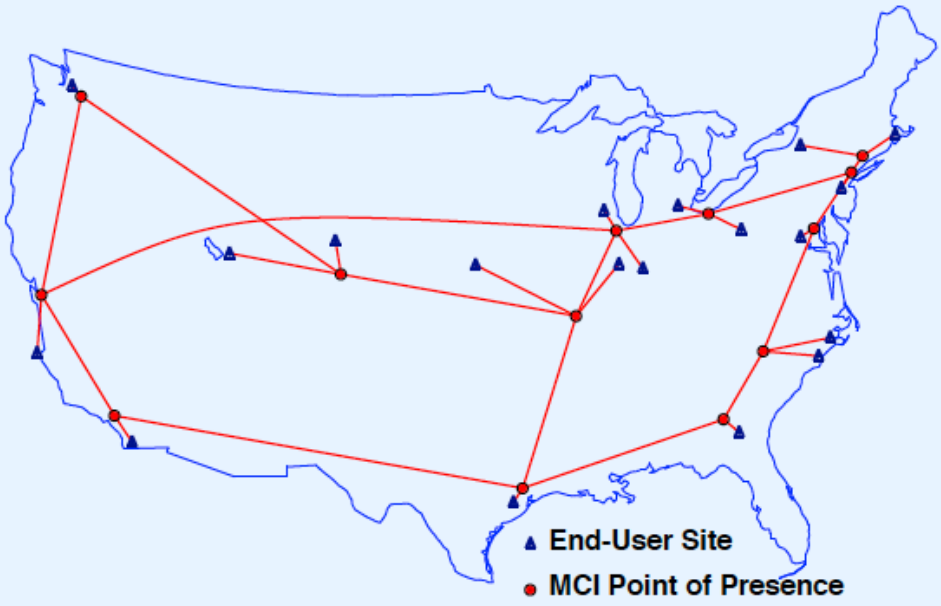
ARPANET (1969-1989)

- 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

02	07	01	00	27	ba	08	00	2b	0d	44	a7	08	00	45	00
00	54	82	68	00	00	ff	01	35	21	80	0a	02	03	80	0a
02	08	08	00	73	0b	d4	6d	00	00	04	3b	8c	28	28	20
0d	00	08	09	0a	0b	0c	0d	0e	0f	10	11	12	13	14	15
16	17	18	19	1a	1b	1c	1d	1e	1f	20	21	22	23	24	25
26	27	28	29	2a	2b	2c	2d	2e	2f	30	31	32	33	34	35
36	37														

- 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

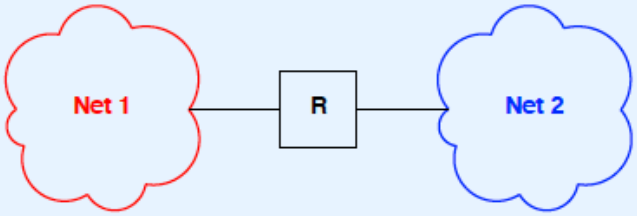
The TCP/IP Internet Concept

- 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

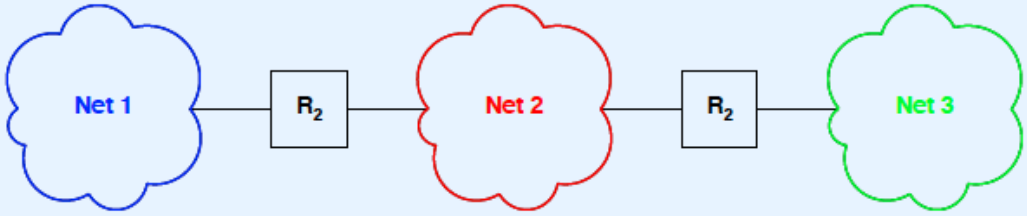


- Network technologies can differ
  - LAN and WAN
  - Connection-oriented and connectionless

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.

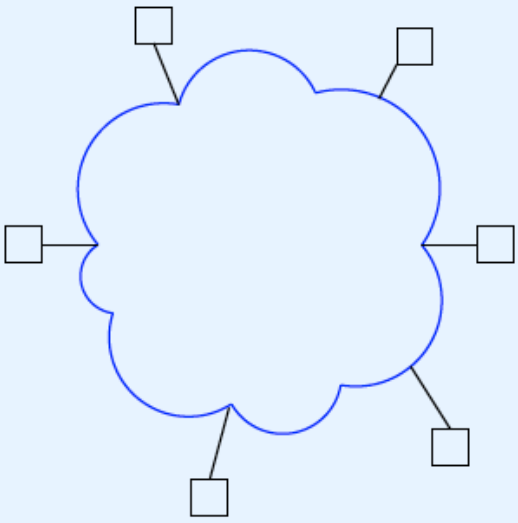
Equal Treatment

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

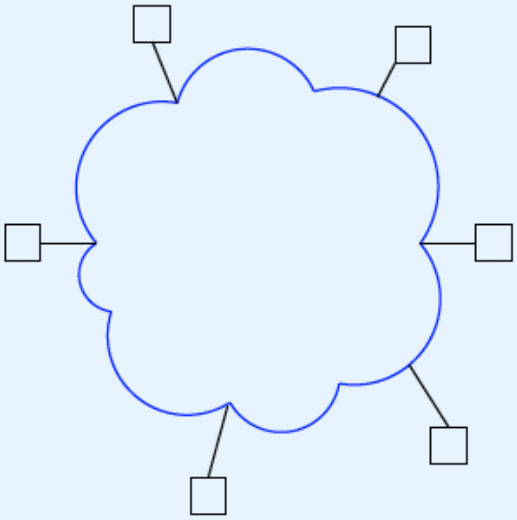


user's view

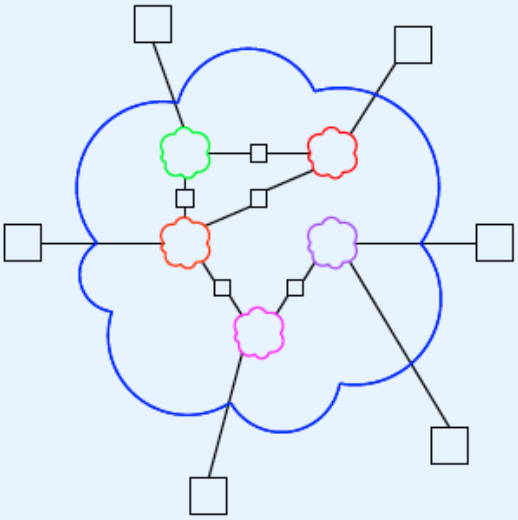
Actual Internet Architecture

- 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