inst.eecs.berkeley.edu/~cs61c

CS61C : Machine Structures

Lecture 37
I/O : Networks

2007-04-20

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inst.eecs/~cs61c-te

Bad software upgrade causes service outage for Blackberry users

Software upgrade to improve Cache performance triggered a problem at RIM's hub for North American traffic… effecting more than five million users

http://www.nytimes.com/2007/04/20/technology/

I/O Review

- I/O gives computers their **5 senses**
- I/O speed range is **12.5-million to one**
- Differences in processor and I/O speed → synchronize with I/O devices before use
- **Polling** works, but expensive
  - processor *repeatedly queries devices*
- **Interrupts** works, more complex
  - device *causes an exception*, causing OS to run and deal with the device
- I/O control leads to **Operating Systems**

Why Networks?

- Originally *sharing I/O devices* between **computers**
  ex: printers
- Then *communicating* between **computers**
  ex: file transfer protocol
- Then *communicating* between **people**
  ex: e-mail
- Then *communicating* between **networks of computers**
  ex: file sharing, www, …

How Big is the Network (2007)?

~30 in **273 Soda**

~525 in **inst.cs.berkeley.edu**

~6,400 in **eecs & cs .berkeley.edu**

(1999) ~50,000 in **berkeley.edu**

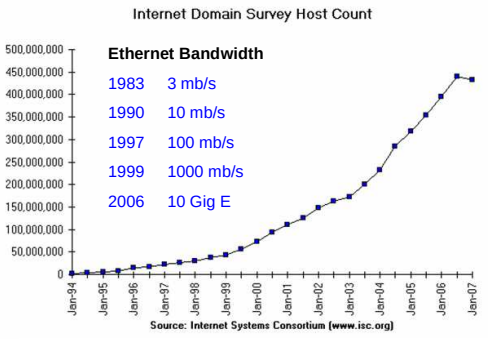
~10,000,000 in **.edu** (2005: ~9,000,000)

~258,941,310 in **US** (2005: ~217,000,000, 2006: ~286.5E6)
(.net .com .edu .arpa .us .mil .org .gov)

~433,190,000 in **the world**
(2005:~317,000,000, 2006: ~439,000,000)

Source: Internet Software Consortium: www.isc.org

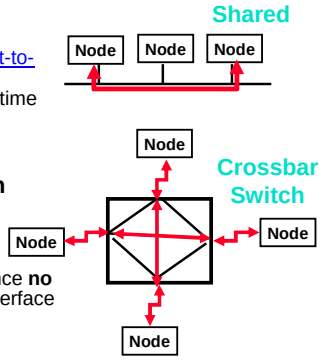
Growth Rate



en.wikipedia.org/wiki/10_gigabit_ethernet

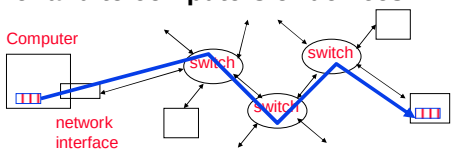
Shared vs. Switched Based Networks

- **Shared vs. Switched:**
  - **Switched:** pairs ("point-to-point" connections) communicate at same time
  - **Shared:** 1 at a time (CSMA/CD)
- **Aggregate bandwidth (BW) in switched network is many times shared:**
  - point-to-point faster since **no arbitration**, simpler interface



What makes networks work?

- links connecting switches to each other and to computers or devices



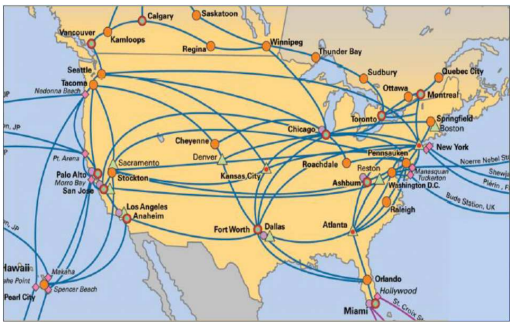
- ability to name the components and to route packets of information - messages - from a source to a destination

- Layering, redundancy, protocols, and encapsulation as means of abstraction (61C big idea)

Typical Types of Networks

- Local Area Network (Ethernet)
  - Inside a building: Up to 1 km
  - (peak) Data Rate: 10 Mbits/sec, 100 Mbits /sec,1000 Mbits/sec (1.25, 12.5, 125 MBytes/s)
  - Run, installed by network administrators
- Wide Area Network
  - Across a continent (10km to 10000 km)
  - (peak) Data Rate: 1.5 Mb/s to 10000 Mb/s
  - Run, installed by telecommunications companies (Sprint, UUNet[MCI], AT&T)
- Wireless Networks (LAN), ...

The Sprint U.S. Topology (2001)

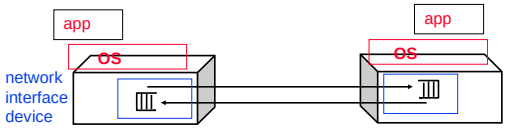


Administrivia

- Crunch time
  - Last Lecture and Course Surveys on Monday 2007-05-07
  - Final Review Session on Wed 2007-05-09
  - 3 weeks + 1 day until the Final …
    - Final Exam on Saturday 2007-05-12 12:30-3:30 @ 2050 VLSB. IS MANDATORY!
- Project 4 is out!
  - May work in pairs.

ABCs of Networks: 2 Computers

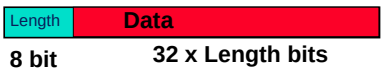
- Starting Point: Send bits between 2 computers



- Queue (First In First Out) on each end
- Can send both ways ("Full Duplex")
  - One-way information is called "Half Duplex"
- Information sent called a "message"
  - Note: Messages also called packets

A Simple Example: 2 Computers

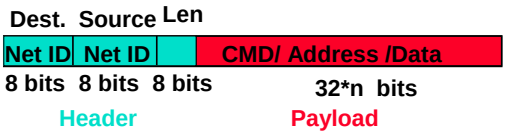
- What is Message Format?
  - Similar idea to Instruction Format
  - Fixed size? Number bits?



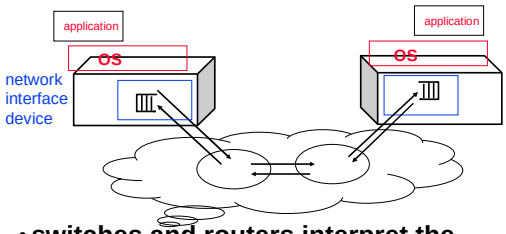
- Header (Trailer): information to deliver message
- Payload: data in message
- What can be in the data?
  - anything that you can represent as bits
  - values, chars, commands, addresses...

Questions About Simple Example

- What if more than 2 computers want to communicate?
  - Need computer "address field" in packet to know:
    - which computer should receive it (destination)
    - which computer to reply to (source)
  - Just like envelopes!



ABCs: many computers



- switches and routers interpret the header in order to deliver the packet
- source encodes and destination decodes content of the payload

Questions About Simple Example

- What if message is garbled in transit?
- Add redundant information that is checked when message arrives to be sure it is OK
- 8-bit sum of other bytes: called "Check sum"; upon arrival compare check sum to sum of rest of information in message. `xor` also popular.

Learn about Checksums in Math 55/CS 70…

Questions About Simple Example

- What if message never arrives?
- Receiver tells sender when it arrives
  - Send an ACK (ACKnowledgement) [like registered mail]
  - Sender retries if waits too long
- Don't discard message until it is ACK'ed
- If check sum fails, don't send ACK

Observations About Simple Example

- Simple questions (like those on the previous slides) lead to:
  - more complex procedures to send/receive message
  - more complex message formats
- Protocol: algorithm for properly sending and receiving messages (packets)

…an agreement on how to communicate

Software Protocol to Send and Receive

- SW Send steps
  1: Application copies data to OS buffer
  2: OS calculates checksum, starts timer
  3: OS sends data to network interface HW and says start
- SW Receive steps
  3: OS copies data from network interface HW to OS buffer
  2: OS calculates checksum, if OK, send ACK; if not, delete message (sender resends when timer expires)
  1: If OK, OS copies data to user address space, & signals application to continue

Protocol for Networks of Networks?

- **Abstraction to cope with complexity of communication** (compare to Abstraction for complexity of computation)
- **Networks are like onions**
  - **Hierarchy of layers:**
    - **Application (chat client, game, etc.)**
    - **Transport (TCP, UDP)**
    - **Network (IP)**
    - **Physical Link (wired, wireless, etc.)**

Networks are like onions.

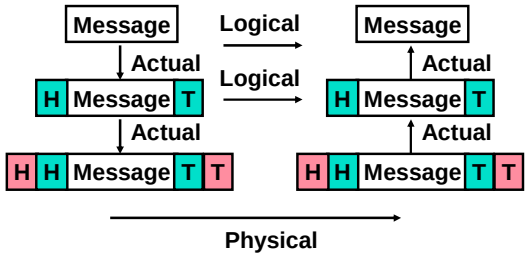
They stink?

Yes. No!

Oh, they make you cry.

No!... Layers. Onions have layers. Networks have layers.

Protocol Family Concept



Protocol Family Concept

- **Key to protocol families is that communication occurs logically at the same level of the protocol, called peer-to-peer…**

  …but is implemented via services at the next lower level

- **Encapsulation: carry higher level information within lower level "envelope"**
- **Fragmentation: break packet into multiple smaller packets and reassemble**

Protocol for Network of Networks

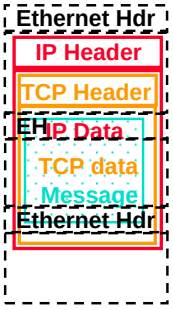
- **IP: Best-Effort Packet Delivery (Network Layer)**
- Packet switching
  - Send data in packets
  - Header with source & destination address
- "Best effort" delivery
  - Packets may be lost
  - Packets may be corrupted
  - Packets may be delivered out of order

Protocol for Network of Networks

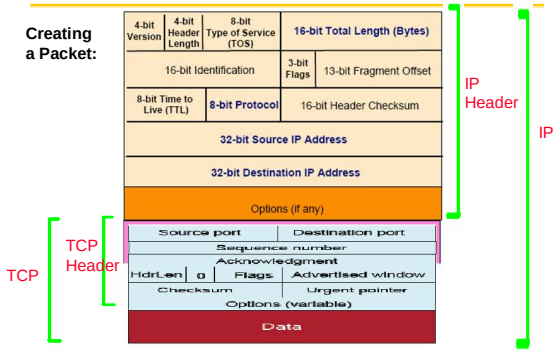
- **Transmission Control Protocol/Internet Protocol (TCP/IP)**
  (TCP :: a Transport Layer)
  - **This protocol family is the basis of the Internet, a WAN protocol**
  - **IP makes best effort to deliver**
  - **TCP guarantees delivery**
  - **TCP/IP so popular it is used even when communicating locally: even across homogeneous LAN**

TCP/IP packet, Ethernet packet, protocols

- **Application sends message**
- **TCP breaks into 64KiB segments, adds 20B header**
- **IP adds 20B header, sends to network**
- **If Ethernet, broken into 1500B packets with headers, trailers (24B)**
- **All Headers, trailers have length field, destination, …**



TCP/IP in action



Overhead vs. Bandwidth

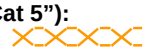
- Networks are typically advertised using peak bandwidth of network link: e.g., 100 Mbits/sec Ethernet (“100 base T”)
- Software overhead to put message into network or get message out of network often limits useful bandwidth
- Assume overhead to send and receive = 320 microseconds (µs), want to send 1000 Bytes over “100 Mbit/s” Ethernet
  - Network transmission time: 1000Bx8b/B /100Mb/s = 8000b / (100b/µs) = 80 µs
  - Effective bandwidth: 8000b/(320+80)µs = 20 Mb/s

And in conclusion…

- Protocol suites allow networking of heterogeneous components
  - Another form of principle of abstraction
  - Protocols ⇒ operation in presence of failures
  - Standardization key for LAN, WAN
- Integrated circuit (“Moore’s Law”) revolutionizing network switches as well as processors
  - Switch just a specialized computer
- Trend from shared to switched networks to get faster links and scalable bandwidth
- Interested?
  - EE122 (CS-based in Fall, EE –based in Spring)

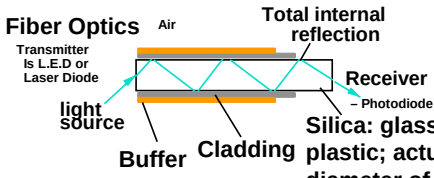
[Bonus] Example: Network Media

Twisted Pair (“Cat 5”):



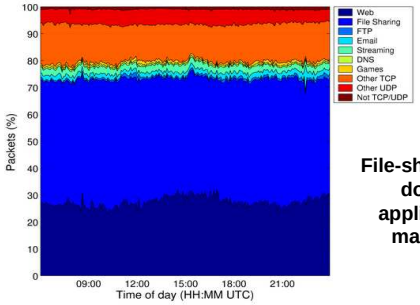
Copper, 1mm think, twisted to avoid antenna effect

Light: 3 parts are cable, light source, light detector



Silica: glass or plastic; actually < 1/10 diameter of copper

[Bonus] Backbone Link App Composition



File-sharing is the dominant application on many links!