inst.eecs.berkeley.edu/~cs61c

CS61C : Machine Structures

Lecture 36
I/O : Networks

TA Sameer "The Yellow Dart" Iyengar

inst.eecs/~cs61c-ti

Next year: Forget Elmo… Get a Robot buddy

New human-like robots that can recognize faces, hold simple conversations and even play hide and seek will sell for $3000

cnn.com/2006/TECH/11/23/robots.tooreal.ap/

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 (2006)?

~30 in **273 Soda**

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

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

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

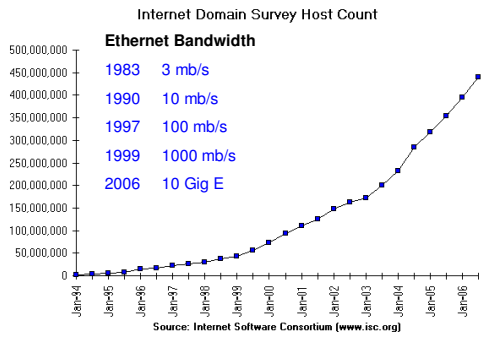
~10,000,000 in **.edu** (2005: ~9,000,000)

~286,500,000 in **US** (2005: ~217,000,000)
(.net .com .edu .arpa .us .mil .org .gov)

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

Source: Internet Software Consortium: www.isc.org

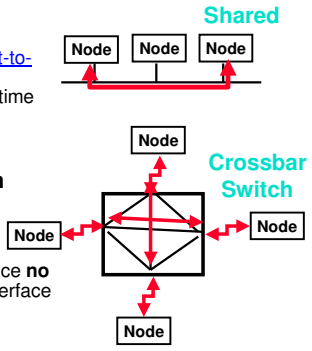
Growth Rate



en.wikipedia.org/wiki/10_gigabit_ethernet

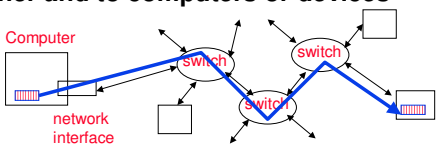
Shared vs. Switched Based Networks

- **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), ...

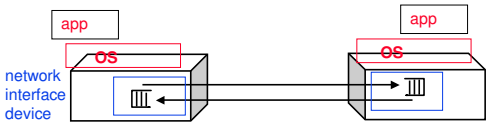
The Sprint U.S. Topology (2001)

Administrivia

- It's the final countdown…
  - <2 weeks left!
  - Last Lecture and Course Surveys on Friday 12/08
  - Final Review Session on Sunday 12/10
  - Final Exam on Thursday 12/14
- Project 3 grading this week
  - Wednesday, Thursday, Friday
  - Sign up for time slot online

ABCs of Networks: 2 Computers

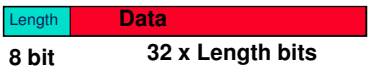
- Starting Point: Send bits between 2 computers



- 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?



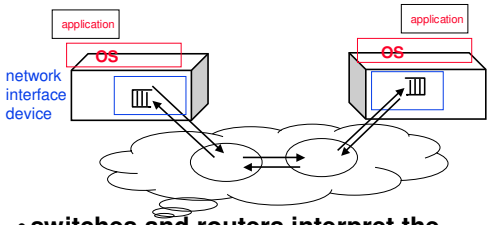
8 bit 32 x Length bits

- 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)

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.

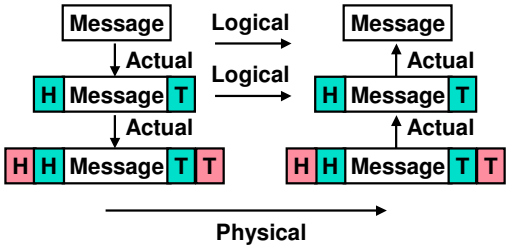
They stink?

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…

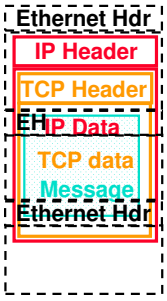
  …but is implemented via services at the next lower level
- Encapsulation: carry higher level information within lower level "envelope"
- Fragmentation: break packet into multiple smaller packets and reassemble

Protocol for Network of Networks

- Transmission Control Protocol/Internet Protocol (TCP/IP)
  - 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, …



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…

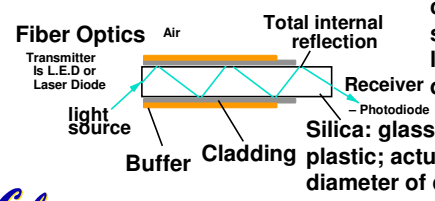
- Protocol suites allow networking of heterogeneous components
  - Another form of principle of abstraction
  - Protocols ⇒ operation in presence of failures
  - Standardization key for LAN, WAN
- Integrated circuit ("Moore's Law") revolutionizing network switches as well as processors
  - Switch just a specialized computer
- Trend from shared to switched networks to get faster links and scalable bandwidth

[Bonus] Example: Network Media

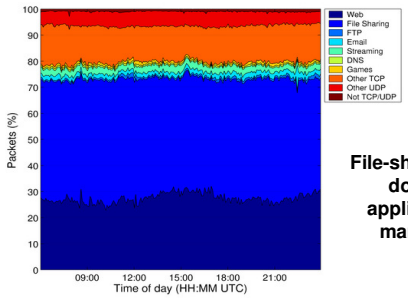
Twisted Pair ("Cat 5"):

Copper, 1mm think, twisted to avoid antenna effect

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



[Bonus] Backbone Link App Composition



File-sharing is the dominant application on many links!