USA Today and Avantegarde report that it took less than 4 min for an unprotected PC running XP SP1 to be compromised. The Mac and Linux box were attacked but didn't fall.


Buses in a PC: connect a few devices (2002)

- **CPU**
- **Memory bus**
- **PCI: Internal (Backplane)**
- **I/O bus**
- **SCSI: External I/O bus**

- **Data rates (P4)**
  - Memory: 400 MHz, 8 bytes ⇒ 3.2 GB/s (peak)
  - PCI: 100 MHz, 8 bytes wide ⇒ 0.8 GB/s (peak)
  - SCSI: “Ultra4” (160 MHz), Gigabit “Wide” (2 bytes) ⇒ 0.3 GB/s (peak)
  - Gigabit Ethernet: ⇒ 0.125 GB/s (peak)

Shared vs. Switched Based Networks

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

Why Networks?

- Originally sharing I/O devices between computers (e.g., printers)
- Then communicating between computers (e.g., file transfer protocol)
- Then communicating between people (e.g., email)
- Then communicating between networks of computers ⇒ File sharing, WWW, ...

How Big is the Network (1999)?

- ~30 Computers in 273 Soda
- ~400 in inst.cs.berkeley.edu
- ~4,000 in eecs&cs.berkeley.edu
- ~50,000 in berkeley.edu
- ~5,000,000 in .edu
- ~46,000,000 in US
  - (.com .net .edu .mil .us .org)
- ~56,000,000 in the world

Source: Internet Software Consortium

Growth Rate

- Ethernet Bandwidth
  - 1983 3 mb/s
  - 1990 10 mb/s
  - 1997 100 mb/s
  - 1999 1000 mb/s
  - 2004 10 Gig E (to come)

Source: Internet Software Consortium
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, 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), ...

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")
- 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?
  - Length 8 bit 32 x Length bits
  - Data 8 bits 8 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), and to which computer it came from for reply (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.

<table>
<thead>
<tr>
<th>Header</th>
<th>Payload</th>
<th>Trailer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net ID</td>
<td>Net ID</td>
<td>Len CMD/ Address/Data</td>
</tr>
<tr>
<td>Checksum</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Math 55 talks about what a Check sum is...

Questions About Simple Example

• What if message never arrives?
  • Receiver tells sender when it arrives (ack) [ala registered mail], sender retries if waits too long
  • Don’t discard message until get “ACK” (for ACKnowledgment); Also, if check sum fails, don’t send ACK

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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?

• Internetworking: allows computers on independent and incompatible networks to communicate reliably and efficiently:
  • Enabling technologies: SW standards that allow reliable communications without reliable networks
  • Hierarchy of SW layers, giving each layer responsibility for portion of overall communications task, called protocol families or protocol suites
  • Abstraction to cope with complexity of communication vs. Abstraction for complexity of computation

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 64KB 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

Peer Instruction

<table>
<thead>
<tr>
<th>TRUE</th>
<th>FALSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: B always</td>
<td>5: The same!</td>
</tr>
<tr>
<td>2: C always</td>
<td>6: B always</td>
</tr>
<tr>
<td>3: B small</td>
<td>7: C always</td>
</tr>
<tr>
<td>4: B big</td>
<td>8: B small</td>
</tr>
<tr>
<td>7: C small</td>
<td>9: B big</td>
</tr>
<tr>
<td>8: B big</td>
<td>9: The same!</td>
</tr>
</tbody>
</table>

And in conclusion…

• Protocol suites allow heterogeneous networking
  - 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