CISC 151
The UNIX Operating System

Lecture 5

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Week 5

- Topics:
  - An Introduction to Networking UNIX
  - A Short History of TCP/IP
    - Computer Networking and BBN Technologies
    - The ARPANET
    - TCP/IP

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Networking & UNIX

- Chapters that deal with networking:
  - Chapter 12 Networking with TCP/IP
  - Chapter 13 The Internet
  - Chapter 24 Client-Server Computing
    - mostly about NFS
  - Chapter 25 Network Administration

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BBN Technologies, Cambridge, MA

- 1948: Two professors at MIT, Richard Bolt and Leo Beranek, established a small acoustics consulting firm, and soon added a former student of Bolt's, Robert Newman.
- 1949: BBN won its first major consulting contract, designing the acoustics for the United Nations General Assembly Hall.
- 1960: Leased Digital Equipment Corporation's first PDP-1, serial number 1.
- 1962: Performed first public demonstration of computer time-sharing.
- 1963: Designed and demonstrated the first voice modem, called DataDial, to enable remote communication with computers by telephone.

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BBN Technologies, Cambridge, MA

- 1969: Launched the ARPANET.
- 1971: Sent first person-to-person email message using the @ sign.
- 1971: Developed a geographically distributed facility for the monitoring and control of a packet-switched computer network, the first network operations center.
- 1972: Performed initial development of INTERLISP, a list processing programming language useful in artificial intelligence research.
- 1973: Developed the Private Line Interface (PLI) to encrypt messages over the ARPANET, demonstrating the first secure traffic sent over a packet switch network.

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BBN Technologies, Cambridge, MA

- 1977: Developed the first Transmission Control Protocol (TCP) for Unix.
- 1977: Developed first Internet routers in collaboration with Stanford University and University College, London.
- 1978: Demonstrated Packet Broadcast Satellite communications over the Atlantic Ocean.
- 1981: Built the Butterfly computer, the first parallel-processor with 128 processors and global memory.
- 1982: Won contract to build and operate the worldwide Defense Data Network for DoD.
- 1983: Launched BBN Communications, which built the communications infrastructures for major commercial customer networks, including MasterCard and MCI.

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BBN Technologies, Cambridge, MA

- 1985: bbn.com became the second commercial domain name registered on the Internet.
- 1997: Purchased by GTE
- 2000: BBN Technologies' parent, GTE, merged with Bell Atlantic to form Verizon.
- 2003: Dr. Leo Beranek, one of the three co-founders of BBN, received the National Medal of Science. one of the highest honors bestowed on scientists in this country.
- 2004: Principal Engineer Ray Tomlinson received the IEEE Internet Award for his key role in the conceptualization, first implementation, and standardization of networked email.

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The ARPANET & BBN

- In 1968, the Advanced Research Projects Agency (ARPA) sent out a Request for Quotation (RFQ) to build a network of four Interface Message Processors (IMPs).
  - Many the large computer and telecomm companies didn't respond thinking it impossible.
- BBN's detailed proposal filled 200 pages, with flowcharts, equations, and tables detailing timing, routing, transmission delays, and packet queuing.
- Although a dozen companies bid on the contract, ARPA awarded it to BBN in January 1969.
- Two major teams were formed:
  - The Software Team
  - The Hardware Team

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The ARPANET & BBN

- The software team wrote the code that would run the IMPs, pull packets into the machine, figure out how to route them, and send them on their way.
  - They spent the summer devising a routing scheme that would automatically route data packets around troubled links in the network and update itself several times per second
- The hardware team worked with an off-the-shelf Honeywell 516 to design the high speed I/O devices that would need to be added to the basic model.
- Two weeks before the UCLA installation deadline, the next IMP arrived from Honeywell, was quickly updated and shipped to UCLA.
  - It was installed September 30th, 1969.

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The First IMP at UCLA

Dr. Leonard Kleinrock
Professor, UCLA Computer Science Department with IMP, Node 1 of the Internet

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The Initial Four IMPs

- UCLA, where Kleinrock had established a Network Measurement Center using a Scientific Data System's Sigma 7, a 32-bit high-end scientific machine which was also used by NASA for Apollo .
- The Stanford Research Institute's Augmentation Research Center: where Douglas Engelbart had created the ground-breaking NLS system, a very important early hypertext system with an SDS 940, a 24-bit timesharing machine, similar in application to the PDP-10, that ran NLS, named 'Genie'.
- UCSB, at the Culler-Fried Interactive Mathematics Center suing an IBM 360/75, running OS/MVT
- University of Utah's Graphics Department, where using a DEC PDP-10 running TENEX.

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The Initial Four IMPs

- The first ARPANET link was established on November 21, 1969, between the IMP at UCLA and the IMP at SRI. By December 5, 1969, the entire 4-node network was connected.
- The network quietly expanded to thirteen sites by January 1971 and twenty-three by April 1972.
- The first packet-switching network

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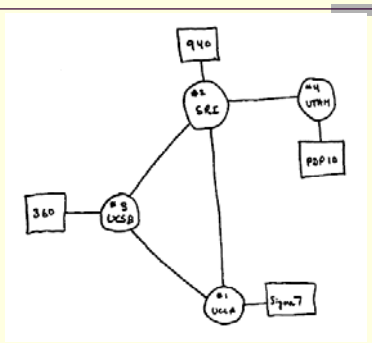
The First 4 Nodes of the ARPANET



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The First 4 Nodes of the ARPANET

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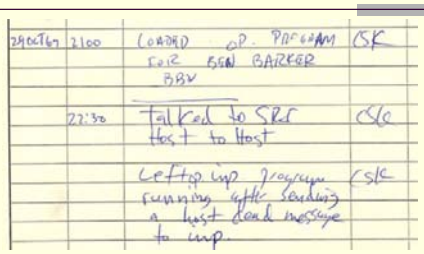
First ARPANET IMP Log



First ARPANET IMP log - a record of the first message ever sent over the ARPANET; it took place at 10:30PM on October 29, 1969. This record is an excerpt from the "IMP Log" kept at UCLA, and describes setting up a message transmission to go from the UCLA SDS Sigma 7 Host computer to the SRI SDS 940 Host computer.

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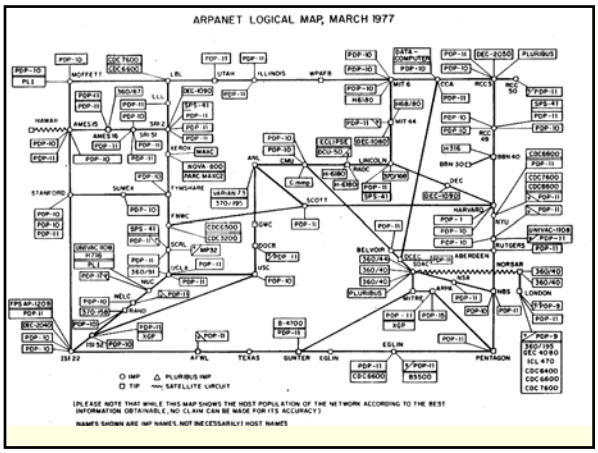

The INWG and the Development of TCP/IP

- In 1972 a group of computer network researchers organized themselves into the International Packet Network Working Group (INWG) with Dr. Vinton Cerf as its first Chair.
  - Alex McKenzie of BBN, actively participated, serving as Chair from 1979-1982 and Secretary from 1983.
  - The idea was to improve BBN's ARPNET core protocols
- In January 1974 INWG became Working Group 6.1 (WG6.1) and Technical Committee 6.1 (TC6) of the International Federation for Information Processing (IFIP), but continued to be referred to as INWG.
  - The concepts which led to Transmission Control Protocol/Internet Protocol (TCP/IP) were first discussed in this group.

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Why a New Protocol Suite?

- Connecting diverse networking technologies was not possible using NCP (Network Control Program), the original protocol suite written by BBN for use on the ARPANET
- On the ARPANET, the physical layer, the data link layer, and the network layer protocols were all specified by the Host/IMP Protocol described in BBN Report 1822, AKA the "1822 Protocol".
  - 1822 described how to connect a host to the IMP
- The NCP transport layer used the Host-to-Host Protocol, together with the Initial Connection Protocol. Higher layers combined with the application
  - See RFC 1, 7 April 1969, Steven Crocker
- In order to connect heterogeneous hosts and networks a wholly new kind of networking architecture was needed.

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NCP

- The Network Control Protocol (NCP) was finalized and deployed in December 1970 by the Network Working Group (NWG), led by Steve Crocker
- NCP standardized the ARPANET network interface, making it easier to establish, and enabling more and more DARPA sites to join the network.
- In October 1971, every site on the ARPANET logged into every other site (with one exception) over NCP at a meeting at the Massachusetts Institute of Technology.

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NCP

- By the end of 1971 fifteen sites were using NCP:
  - Bolt, Baranek, and Newman (BBN)
  - Carnegie Mellon University
  - Case Western Reserve University
  - Harvard University
  - Lincoln Laboratories
  - Massachusetts Institute of Technology
  - NASA at AMES
  - RAND Corporation
  - Stanford Research Institute
  - Stanford University
  - System Development Corporation
  - University of California at Los Angeles
  - University of California of Santa Barbara
  - University of Illinois at Urbana
  - University of UTAH

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NCP

- RFC's describing NCP:
  - RFC 1; Crocker; 7 Apr 1969
  - RFC 33; Crocker, S.; Carr, S.; Cerf, V.; New HOST-HOST Protocol; 12 Feb 1970.
  - RFC 36; Crocker, S.; Protocol Notes; 16 Mar 1970 .
  - RFC 78; Harslem, E.; Heafner, J.; White, J.; NCP Status Report: UCSB/RAND; Nov 1970.

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Vinton Cerf

- A graduate student at UCLA in Computer Science, 1967 – 1972
  - Had a friend from high school, Steve Crocker, who was already at UCLA as a grad student
- Leonard Kleinrock, a professor at UCLA (originally from MIT) had proposed to DARPA that UCLA become a Network Measurement Center for the new ARPANET.
- Cerf worked at the center as a grad student doing network congestion studies on the original ARPANET 4-node network.
  - Software for the IMPs (NCP) was written by BBN
- Steve Crocker came up with an initiative to design new protocols for hosts

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Vinton Cerf (cont'd)

- In April 1969, Steve Crocker issued the very first Request For Comment (RFC).
  - He observed that they were just graduate students at the time and so had no authority. They needed to find a way to document what they were doing without acting like they were imposing anything on anyone.
  - He came up with the RFC methodology to say, "Please comment on this, and tell us what you think."
- In November 1972, Cerf took an assistant professorship in computer science and electrical engineering at Stanford.

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Vinton Cerf (cont'd)

- The very earliest work on the TCP protocols was done at three places:
  - The initial design work was done at Cerf's lab at Stanford. The first draft came out in September 1973 for review by INWG members(*A Partial Specification for an International Transmission Protocol*)
  - A paper by Bob Kahn and Cerf appeared in May 1974 in IEEE Transactions on Communications (*A Protocol for Packet Network Intercommunication,* in IEEE Transactions on Communication, vol. C22, No. 5. May 1974, pp. 637-648.
  - The first specification of the TCP protocol was published as an Internet Experiment Note in December 1974 (now RFC 675)

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Robert Kahn

- Kahn obtained a Ph.D. degree from Princeton University in 1964, worked for a while at AT&T Bell Laboratories, and then became an Assistant Professor of Electrical Engineering at MIT.
- He later went to work at Bolt Beranek and Newman, (BBN) and helped build the Interface Message Processor.
- In 1972, Kahn was hired by Lawrence Roberts at the IPTO to work on networking technologies, and in October he gave a demonstration of an ARPANET network connecting 40 different computers at the International Computer Communication Conference, making the network widely known for the first time to people from around the world.

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Robert Kahn

- At the IPTO, Kahn worked on an existing project to establish a satellite packet network, and initiated a project to establish a ground-based radio packet network.
- These experiences convinced him of the need for development of an open-architecture network model, where any network could communicate with any other independent of individual hardware and software configuration.
- Kahn therefore set four goals for the design of what would become the Transmission Control Protocol (TCP):

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Robert Kahn

- Network connectivity.
  - Any network could connect to another network through a gateway.
- Distribution.
  - There would be no central network administration or control.
- Error recovery.
  - Lost packets would be retransmitted.
- Black box design.
  - No internal changes would have to be made to a network to connect it to other networks.

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Robert Kahn

- In the spring of 1973, Vinton Cerf joined Kahn on the project.
- They started by conducting research on reliable data communications across packet radio networks, factored in lessons learned from the Networking Control Protocol, and then developed the next generation Transmission Control Protocol (TCP)

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TCP/IP Protocol

- July, 1977, The Triple Network Internet was demonstrated for the first time.
  - Cerf, Kahn and others link-up 3 networks using TCP: packet radio, ARPANET and SATNET.
  - Messages travel 94,000 miles from San Francisco to London to California "without dropping a single bit".
- On January 1, 1983, the ARPANET changed its core networking protocols from NCP to the more flexible and powerful TCP/IP protocol suite, marking the start of the Internet as we know it today.
- DARPA got BBN to build a UNIX implementation of TCP/IP and wanted that ported into the Berkeley UNIX release in v4.2.
  - In 1983, the Berkeley TCP/IP implementation for 4.2BSD becomes public domain code

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TCP/IP Protocol (cont'd)

- The significant growth in Internet products didn't come until 1985 or so, when UNIX and local area networks started joining up.
- Once that happened, vendors such as Sun started using BSD as the base of commercial products.
- Present version standardized in September, 1981 (RFC 793).

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TCP/IP Protocol (cont'd)

Vinton Cerf

Steve Crocker

Robert Kahn

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The Triple Network Internet

- "The earliest demonstration of the triple network Internet was in July 1977. We had several people involved. In order to link a mobile packet radio in the Bay Area, Jim Mathis was driving a van on the San Francisco Bayshore Freeway with a packet radio system running on an LSI-11. This was connected to a gateway developed by Virginia Strazisar at BBN. Ginny was monitoring the gateway and had artificially adjusted the routing in the system. It went over the Atlantic via a point-to-point satellite link to Norway and down to London, by land line, and then back through the Atlantic Packet Satellite network (SATNET) through a Single Channel Per Carrier (SCPC) system, which had ground stations in Etam, West Virginia, Goonhilly Downs England, and Tanum, Sweden.

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The Triple Network Internet

The German and Italian sites of SATNET hadn't been hooked in yet. Ginny was responsible for gateways from packet radio to ARPANET, and from ARPANET to SATNET. Traffic passed from the mobile unit on the Packet Radio network across the ARPANET over an internal point-to-point satellite link to University College London, and then back through the SATNET into the ARPANET again, and then across the ARPANET to the USC Information Sciences Institute to one of their DEC KA-10 (ISIC) machines.

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The Triple Network Internet

So what we were simulating was someone in a mobile battlefield environment going across a continental network, then across an intercontinental satellite network, and then back into a wireline network to a major computing resource in national headquarters. Since the Defense Department was paying for this, we were looking for demonstrations that would translate to militarily interesting scenarios. So the packets were traveling 94,000 miles round trip, as opposed to what would have been an 800-mile round trip directly on the ARPANET. We didn't lose a bit!"

From *How the Internet Came to Be* by Vinton Cerf, as told to Bernard Aboba

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Networking Models

- Networking models use the layering approach to explain how a computer network distributes information from a source to a destination
- Two main models:
  - OSI (Open System Interconnection) – released in 1984 by the International Organization for Standardization (ISO)
  - TCP/IP – historical and technical standard of the Internet. Created by U.S. Department of Defense (DoD) as a network that could survive any conditions, including a nuclear war

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The OSI Model

- Developed by the ISO to address the problem of network incompatibility
- Wanted to distill a general set of rules for all networks by comparing existing models like:
  - DECnet
  - SNA
  - TCP/IP
- Created a network model that helps vendors create networks that are compatible with other networks

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The OSI Model

- Benefits of the OSI model:
  - Reduces complexity
  - Standardizes interfaces
  - Facilitates modular engineering
  - Ensures interoperable technology
  - Accelerates evolution
  - Simplifies teaching and learning
- OSI model is the primary model for describing network communications
- Most vendors relate products to the OSI reference model
  - Especially when they want to educate users
  - Considered the best tool available for teaching people about sending and receiving data on a network.

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The OSI Model

7 Application	**Network services to applications**
6 Presentation	**Data representation, formatting**
5 Session	**Interhost communications - manages sessions between applications**
4 Transport	**End-to-end connections - virtual circuits**
3 Network	**Network address & best path determination**
2 Data Link	**Direct Link Control - Access to media Physical addressing (MAC addresses)**
1 Physical	**Binary transmission: wires, connectors, voltages**

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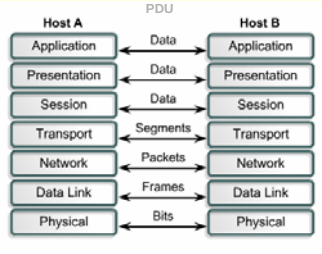
Peer-to-Peer Communications

- For data to travel from the source to the destination, each layer of the OSI model at the source must communicate with its peer layer at the destination
- The protocols of each layer exchange protocol data units (PDUs)
- Each layer of communication on the source computer communicates with a layer-specific PDU, and with its peer layer on the destination computer



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The TCP/IP Model

- TCP/IP developed as an open standard
  - Included in UNIX distributions
  - Anyone was free to use TCP/IP
  - Helped to speed up the development of TCP/IP as a standard
- Four layers:
  - Application layer
  - Transport layer
  - Internet layer
  - Network access layer
- Created a network model that helps vendors create networks that are compatible with other networks

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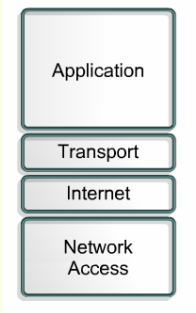
The TCP/IP Model

- **Application layer**: includes OSI session and presentation layers. Handles data representation, encoding, and dialog control (FTP; HTTP; DNS; SMTP; TFTP)
- **Transport layer**: Reliability, flow control, and error correction (TCP; UDP)
- **Internet layer**: Divides TCP segments into packets and sends them from any network (IP)
- **Network Access layer**: Physical and logical components required to make a physical link. Includes all the details in the OSI physical and data link layers



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Application Layer

- TCP/IP Application Layer handles:
  - High-level protocols
  - Data representation issues
  - Data encoding
  - Dialog control
- Combines all application-related issues in one layer
  - Assures data properly packaged before passing it to next layer
- Also includes specs for common applications
  - Protocols for file transfer, e-mail, remote login and other applications

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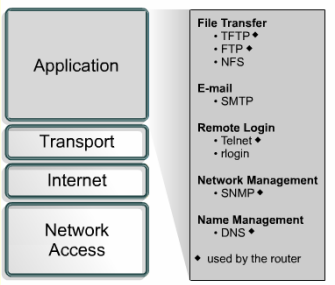
Application Layer Protocols

- The Application Layer of TCP/IP includes the following applications and protocols:



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Transport Layer

- Provides transport services from the source host to the destination host
- Constitutes a logical connection between those endpoints of the network
- Transport protocols segment and reassemble upper-layer applications into the same data stream between endpoints
- The transport layer data stream provides end-to-end transport services:
  - End-to-end control, provided by sliding windows
  - Reliability - uses sequencing numbers and acknowledgments
  - End-to-end connectivity between host applications

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Transport Layer Protocols

- UDP (User Datagram Protocol)
  - Segments upper-layer application data
  - Sends segments from one end device to another end device
  - A simple, but unreliable and connectionless protocol
- TCP (Transmission Control Protocol)
  - Segments upper-layer application data (like UDP)
  - Sends segments from one end device to another end device (like UDP)
  - Establishes end-to-end operations
  - Flow control provided using sliding windows
  - Reliability provided by sequence numbers and acknowledgment
  - A reliable, connection-oriented protocol

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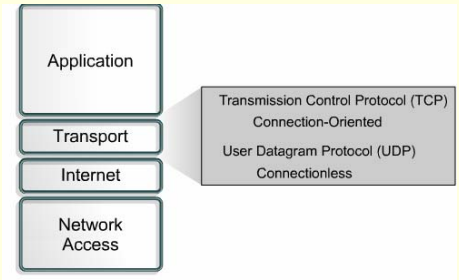
Transport Layer Protocols (cont'd)

- The Transport Layer of TCP/IP includes the following protocols:



Internet Layer

- The purpose of the Internet layer is to select the best path for packets to travel through the network
- Main Internet layer protocol – the Internet Protocol (IP)
- Best-path determination and packet switching occur at this layer
- Performs the following operations:
  - Defines a packet and an addressing scheme
  - Transfers data between the Internet layer and the Network Access layers
  - Routes packets to remote hosts

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Internet Layer Protocols

- Internet Protocol (IP)
  - Provides connectionless, best-effort delivery routing of packets
  - Looks for a path to the destination
- Internet Control Message Protocol (ICMP)
  - Provides control and messaging capabilities.
- Address Resolution Protocol (ARP)
  - Finds a MAC address for a known IP address
- Reverse Address Resolution Protocol (RARP)
  - Finds an IP address for a know MAC address

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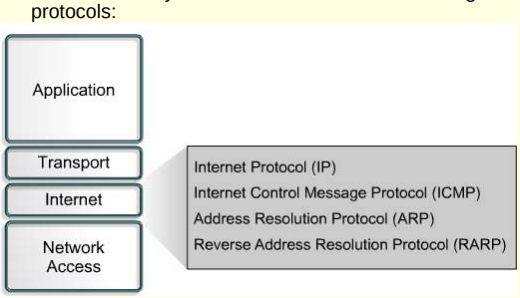
Internet Layer Protocols (cont'd)

- The Internet Layer of TCP/IP includes the following protocols:



Network Access Layer

- Also called the host-to-network layer
- Concerned with all issues to make a physical link to the network media
- Includes LAN **and** WAN technology details
- Combines the OSI physical and data-link layers
- Serial Line Internet Protocol (SLIP) and Point-to-Point Protocol (PPP)
  - Provide network access through a modem connection
- Many protocols at this layer
- Most of the best known TCP/IP protocols operate at the Transport and Internet layers

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Network Access Layer Functions

- Network access layer functions include
  - Mapping IP addresses to physical hardware addresses
  - Encapsulation of packets into frames
- Defines the connection with media
  - Based on the hardware type and network interface
- Example of network access layer functions:
  - Set up a Windows system using a third party NIC
  - Plug-and-play automatically detects NIC
  - Proper drivers also installed automatically

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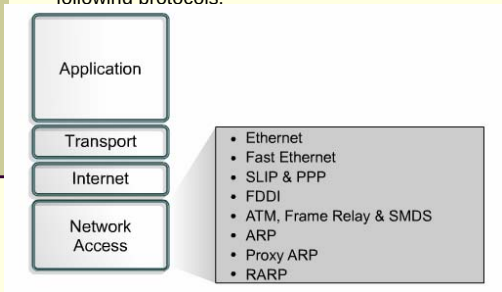
Network Access Layer Protocols

- The Network Access Layer of TCP/IP includes the following protocols:



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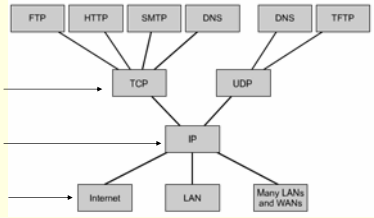
Common TCP/IP Protocols

Application layer:

Transport layer:

Internet layer:

Network Access layer:



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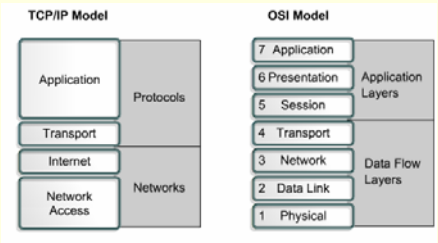
Comparing TCP/IP with OSI

- Internet developed using TCP/IP protocols
  - Networks typically not built on the OSI protocols
  - OSI a guide for understanding the communication process



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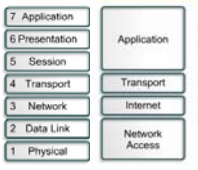
Comparing TCP/IP with OSI



Similarities include:

- **Both have layers**
- **Both have application layers, but with different services**
- **Both have transport and network layers**
- **Both models need to be known**
- **Both assume packets are switched. This means that individual packets may take different paths to reach the same destination. This is contrasted with circuit-switched networks where all the packets take the same path**

Differences include:

- TCP/IP combines presentation and session layers into its application layer
- TCP/IP combines OSI data link and physical layers into the network access layer
- TCP/IP appears simpler because it has fewer layers
- TCP/IP protocols are the standards around which the Internet developed, so the TCP/IP model gains credibility just because of its protocols. Networks are not built on the OSI protocol, use the OSI model as a guide

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Data Encapsulation

- To send data to another computer, it must first be packaged through encapsulation
- Encapsulation wraps data with the necessary protocol information before network transit
- As the data packet moves down through the layers of the OSI model, it receives headers, trailers, and other information

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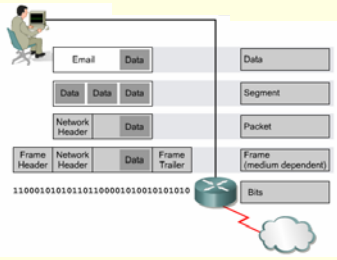
Data Encapsulation Example



1. Build the data
2. Package the data into segments for end-to-end transport
3. Create packets and add the network IP addresses to the header
4. Create a frame and add data link layer header and trailer
5. Convert to bits for transmission
6. The process is reversed at the destination

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UNIX Commands for TCP/IP Networking

- TCP/IP user commands are a major networking capability provided in UNIX
- Used to establish connections and provide a set of user-level networking tasks
- Most versions of UNIX include two sets of commands for networking services
  - DARPA Commands
    - Independent of any Operating System (including UNIX)
    - Used in networks with using mixed O/Ss
  - Berkeley Remote Commands
    - For UNIX-to-UNIX remote use

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UNIX Commands for TCP/IP Networking

- Networking tasks include:
  - Berkeley remote commands:
    - remote file copying
    - remote login
    - remote shell emulation
    - getting information on remote users and systems
  - DARPA commands:
    - terminal emulation
    - file transfer
    - mail

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UNIX Commands for TCP/IP Networking

- Networking tasks include:
  - Commands for getting information on network users and hosts
    - rwho
    - finger
    - ruptime
    - ping (aTPC/IP command)
    - traceroute

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The Berkeley Remote Commands

- Developed as part of BSD UNIX
- For UNIX-to-UNIX use only
- Allow you to use services on other machines
- Begin with "r"
  - rcp (remote copy)
  - rsh (remote shell)
  - rlogin (remote login)
- Allows you to use a network of computers like a single UNIX machine
  - A Distributed File System, like NFS, also allows networked computers to share filesystems (see Chapter 23)

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The Berkeley Commands & Security

- Notoriously vulnerable protocols – no security provided
- Many UNIX installations turn them off
- A secure version of the Berkeley remote commands developed at Helsinki University of Technology
- Most well-known: ssh (secure shell)
  - Uses public and private key cryptography for encryption and authentication
  - Both free and commercial versions
- Also slogin, and scp also available
- Standardized by the IETF
  - Versions available for MAC, and Windows

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The DARPA Commands

- DARPA commands include commands for the following TCP/IP applications:
  - ftp – File Transport Protocol
  - tftp – Trivial File Transport Protocol
  - telnet – for remote login
- Commands for obtaining information about Users and Hosts:
  - rwho (not available on Mesa server – use who)
  - finger
  - ruptime (not available on Mesa server)
  - ping (TCP/IP app)
  - traceroute (TCP/IP app)

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Checking Network Configuration

- To check ip configuration use ifconfig with no options or parameters
  - Also used to set-up network connection
- Returns stats for each NIC, including:
  - MAC address
  - IP address
  - subnet mask
  - ipv6 address
  - Ethernet statistics like:
    - Number of packets transmitted & received
    - Collisions

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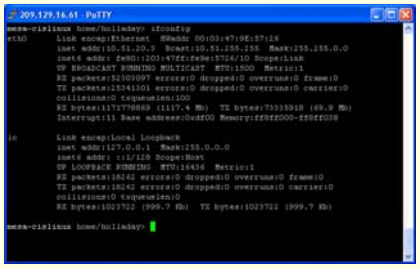
ifconfig



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Monitoring Network Performance

- netstat
  - Used to display network statistics
  - netstat –s will display all protocols running
  - netstat –s –p tcp displays TCP/IP only

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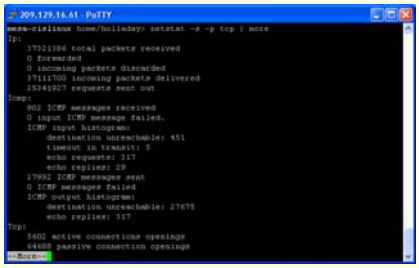
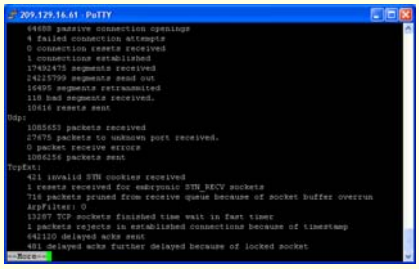
netstat



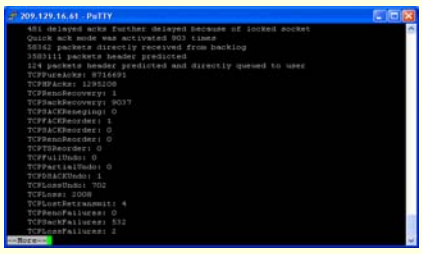
67

netstat



68

netstat



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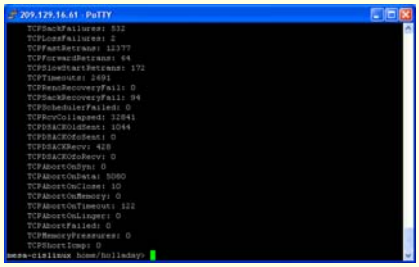
netstat



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Next Week

- Lecture:
  Chapter 14: Text Utilities grep, sort, find, sed

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