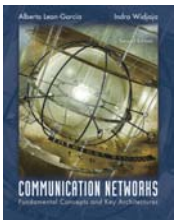
Introduction to CSE 3213



CSE 3213

Fall 2007

Course Contents

3 general areas: data communications, networking, protocols

1. Data communications: basic concepts of digital communications including signal transmission, signal encoding, multiplexing, error detection and error correction schemes.
2. Networking: technology and architecture of communications networks; generally divided into WANs, LANs
3. Protocols: a set of rules that governs how two communicating parties are to interact (IP, TCP, DNS, HTTP, FTP, etc.)

Simplified Communications Model

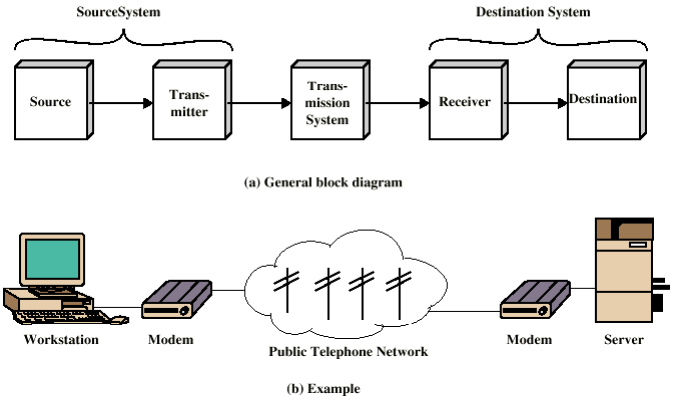


Figure 1.1 Simplified Communications Model

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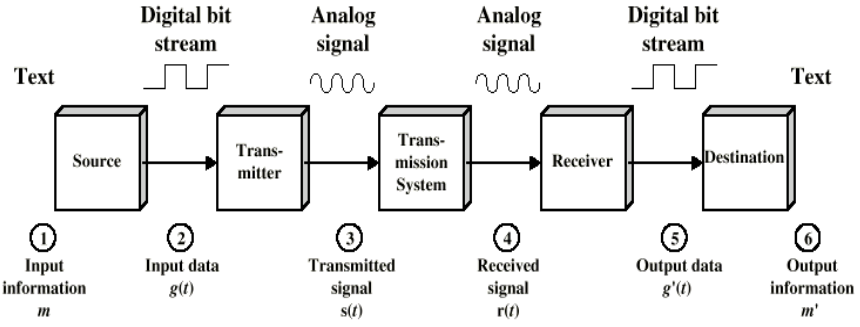
1. Data Communications



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2. Networking

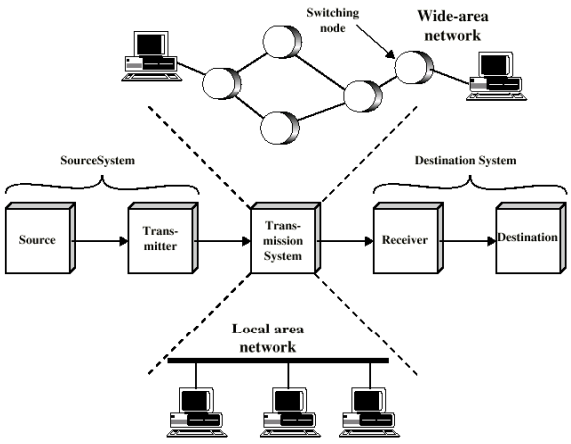

Figure 1.3 Simplified Network Models

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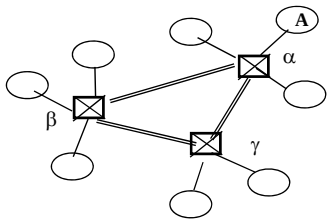
Wide Area Networks (WANs)

- Large geographical areas
- Interconnecting various LANs using switches (routers) and transmission lines
- Crossing public rights of way
- Relying in part on common carrier circuits
- Alternative technologies
  - **Circuit switching** *
  - **Packet switching** *
  - Frame relay
  - ATM



National network (WAN) consists of several regional subnetworks α, β, γ.

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Circuit Switching

- Example application: telephone networks (real-time voice communications, constant bit rate)
- Circuit switching: dedicated communications path established for the duration of the conversation
- Connection-oriented:
  - Requires a session connection be established before any data can be sent (the capacity is occupied for the lifetime of the connection)
  - Uses the same route for all data units
  - Guarantees data will arrive in the same order
- Not efficient for data communications in general (why?)

MSOffice1

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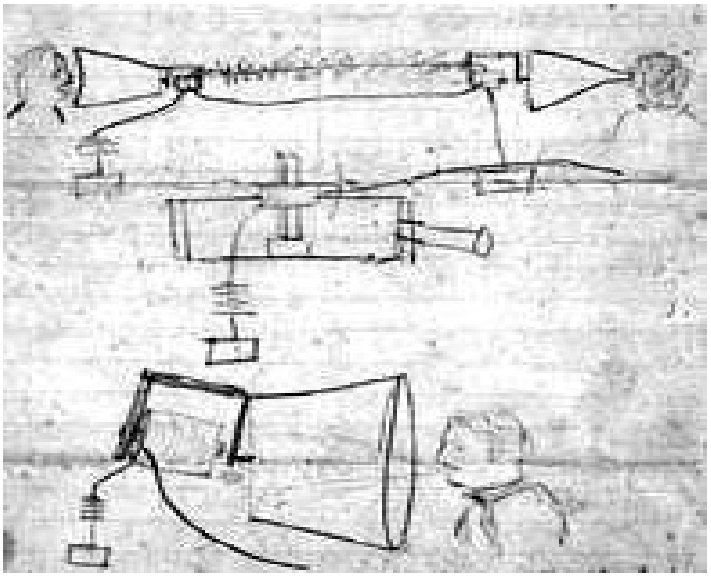
Bell's Sketch of Telephone



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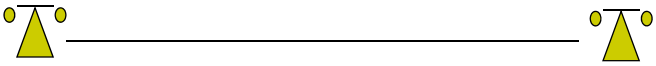
MSOffice1 long setup delay, poor utilization with bursty traffic, maintaining state info on all connections, less flexible when nodes fail.

Signaling

- Signaling required to establish a call
  - Flashing light and ringing devices to alert the called party of incoming call
  - Called party information to operator to establish calls



Signaling + voice signal transfer

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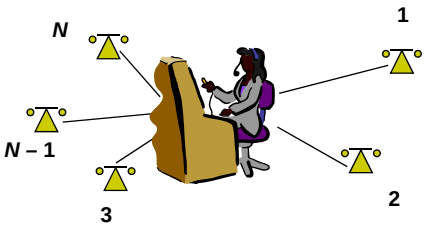
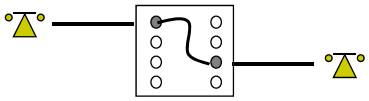
Early Circuit Switching

- Patchcord panel switch invented in 1877
- Operators connect users on demand
  - Establish *circuit* to allow electrical current to flow from inlet to outlet
- Only *N* connections required to central office





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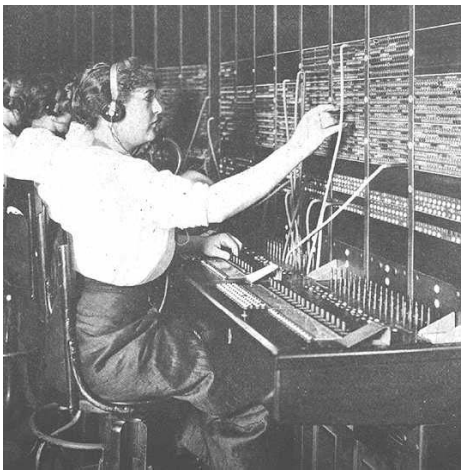
Manual Switching



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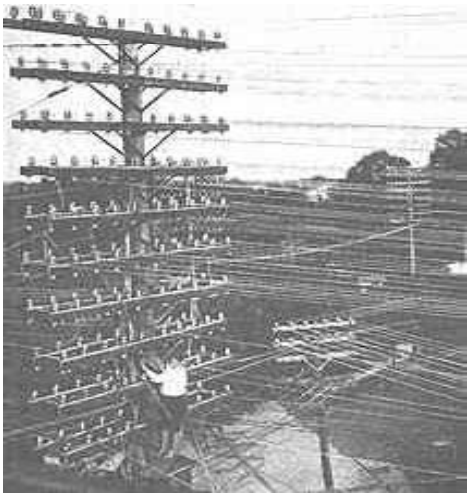
Telephone Pole Congestion



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Digitization of Telephone Network

- Pulse Code Modulation digital voice signal
  - Voice gives 8 bits/sample x 8000 samples/sec = 64×10^3 bps
- Time Division Multiplexing for digital voice
  - T-1 multiplexing (1961): 24 voice signals = 1.544×10^6 bps
- Digital Switching (1980s)
  - Switch TDM signals without conversion to analog form
- Digital Cellular Telephony (1990s)
- Optical Digital Transmission (1990s)
  - One OC-192 optical signal = 10×10^9 bps
  - One optical fiber carries 160 OC-192 signals = 1.6×10^{12} bps!

All digital transmission, switching, and control

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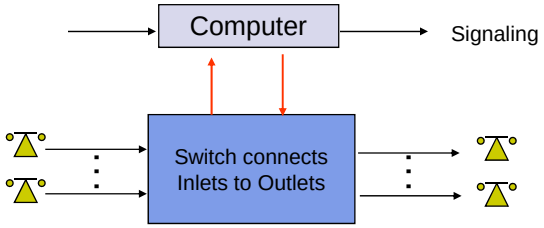
Computer Connection Control

- A computer controls connection in telephone switch
- Computers exchange *signaling messages* to:
  - Coordinate set up of telephone connections
  - To implement new services such as caller ID, voice mail, . . .
  - To enable *mobility and roaming in* cellular networks
- "Intelligence" inside the network
- A separate *signaling network* is required



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Circuit Switching

- Example application: telephone networks (real-time voice communications, constant bit rate)
- Circuit switching: dedicated communications path established for the duration of the conversation
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  - Uses the same route for all data units
  - Guarantees data will arrive in the same order
- Not efficient for data communications in general (why?)

MSOffice2

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Store-and-forward

- No dedicated circuit/connection
- Data units are relayed one hop at a time, stored, processed and then forwarded to the next switch.
- Requires routing protocols and routing tables
- Message switching
  - messages were routed in their entirety, one hop at a time
  - first introduced by Leonard Kleinrock in 1961
  - long messages induce high delay on interactive messages
  - mostly implemented over packet-switched or circuit-switched networks nowadays
- Packet switching

MSOffice2 long setup delay, poor utilization with bursty traffic, maintaining state info on all connections, less flexible when nodes fail.

Packet Switching

- Network should support multiple applications
  - Transfer arbitrary message size
  - Low delay for interactive applications
  - But in store-and-forward operation, long messages induce high delay on interactive messages
- Packet switching introduced
  - Network transfers packets using store-and-forward
  - Packets have maximum length
  - Break long messages into multiple packets

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Packet Switching (2)

- Example application: the Internet
- A message/file is segmented into packets
- Unit of data transmission is packets
- Packets passed from node to node between source and destination (store-and-forward)
- Used for computer to computer communications (bursty traffic)
- Can be connection-oriented (virtual circuit) or connectionless (datagram service)
- ARPANET testbed led to many innovations
  - created by the US Dept. of Defense Advanced Research Projects Agency in the early 70s

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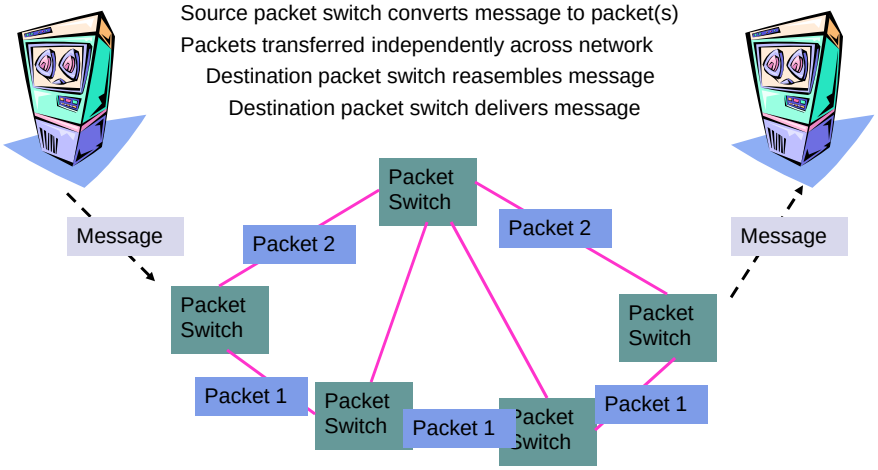
ARPANET Packet Switching

Host generates message
Source packet switch converts message to packet(s)
Packets transferred independently across network
Destination packet switch reassembles message
Destination packet switch delivers message



ARPA: Advanced Research Projects Agency

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The Internet

- Different network types emerged for data transfer between computers
- ARPA also explored packet switching using satellite and packet radio networks
- Each network has its protocols and is possibly built on different technologies
- *Internetworking protocols* required to enable communications between computers attached to *different* networks
- ***Internet***: a network of networks

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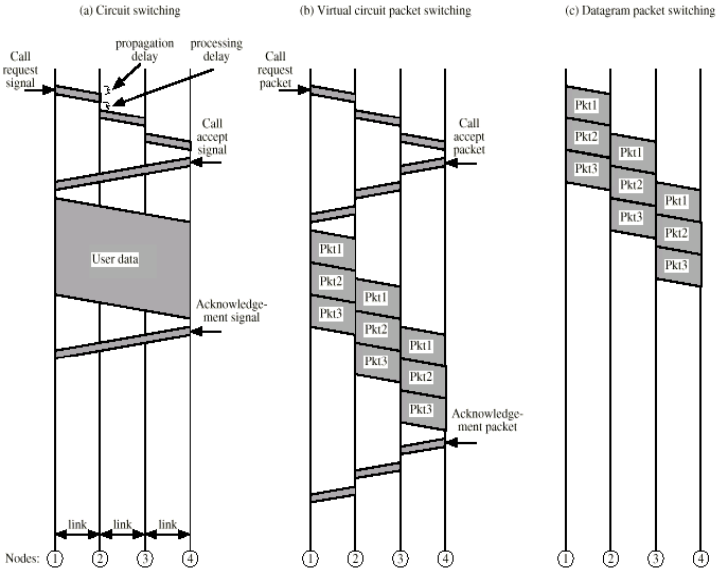
Circuit Switching versus Packet Switching



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Connectionless & Connection-Oriented Services

- Connection-Oriented
  - Three-phases:
    1. Connection setup between two SAPs to initialize state information
    2. Data unit transfer
    3. Connection release
  - E.g. TCP, ATM
- Connectionless
  - Immediate data unit transfer
  - No connection setup
  - E.g. UDP, IP
- Layered services need not be of same type
  - TCP operates over IP
  - IP operates over ATM

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Connection-oriented versus Connectionless Communications

Connectionless:

- Does not requires a session connection be established before sending data
- Sender simply starts sending packets (datagrams) to the receiver
- Different packets may take different routes
- Data packets may arrive out-of-order.
- Less reliable than connection-oriented services

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Examples of Connection-oriented Connectionless Communications

- Internet:
  - One big connectionless packet switching network in which all packet deliveries are handled by IP (unreliable)
  - TCP adds connection-oriented services on top of IP (for reliable delivery)
  - UDP provides connectionless services on top of IP
- ATM: connection-oriented packet switching networks
- LANs:
  - Connectionless systems
  - TCP can be used to provide connection-oriented (reliable) services
- Reference: www.linktionary.com/c/connections.html

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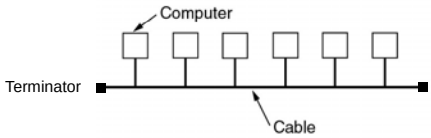
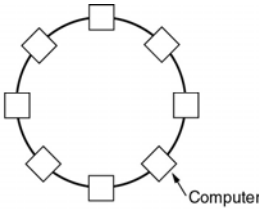
Local Area Networks (LANs)

- Small scope: building or small campus
- Usually owned by same organization as attached devices
- Data rates much higher than those in WANs
- Usually broadcast systems
- Now some switched systems and ATM are being introduced



(a)
Token Bus



(b)
Token Ring

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Ethernet Local Area Network

- In 1980s, affordable workstations available
- Need for low-cost, high-speed networks
  - To interconnect local workstations
  - To access local shared resources (printers, storage, servers)
- Low cost, high-speed communications with low error rate possible using coaxial cable
- Ethernet is the standard for high-speed wired access to computer networks

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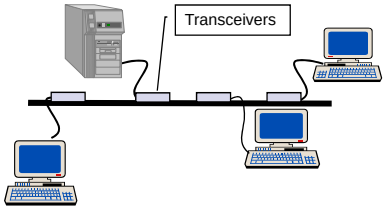
Ethernet Medium Access Control

- Network interface card (NIC) connects workstation to LAN
- Each NIC has globally unique address
- Frames are broadcast into coaxial cable
- NICs listen to medium for frames with their address
- Transmitting NICs listen for collisions with other stations, and abort and reschedule retransmissions



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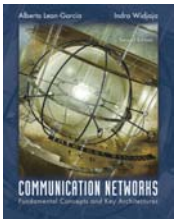
Applications and Layered Architectures



Protocols, Services & Layering

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Layers, Services & Protocols

- The overall communications process between two or more machines connected across one or more networks is very complex
- ***Layering*** partitions related communications functions into groups that are manageable
- Each layer provides a ***service*** to the layer above
- Each layer operates according to a ***protocol***
- Let's use examples to show what we mean

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OSI and TCP/IP Models

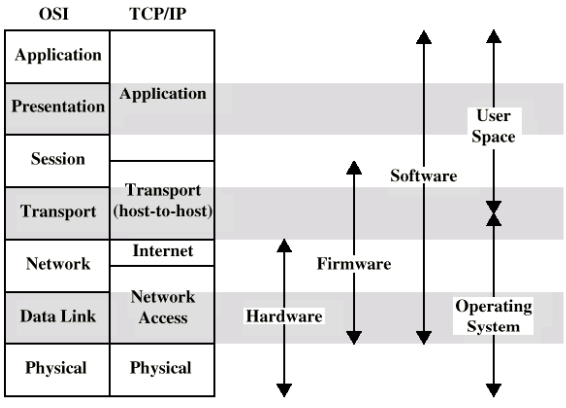

Figure 1.11 A Comparison of the TCP/IP and OSI Protocol Architectures

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Web Browsing Application

- World Wide Web allows users to access resources (i.e. documents) located in computers connected to the Internet
- Documents are prepared using HyperText Markup Language (HTML)
- A browser application program is used to access the web
- The browser displays HTML documents that include *links* to other documents
- Each link references a *Uniform Resource Locator* (URL) that gives the name of the machine and the location of the given document
- Let's see what happens when a user clicks on a link

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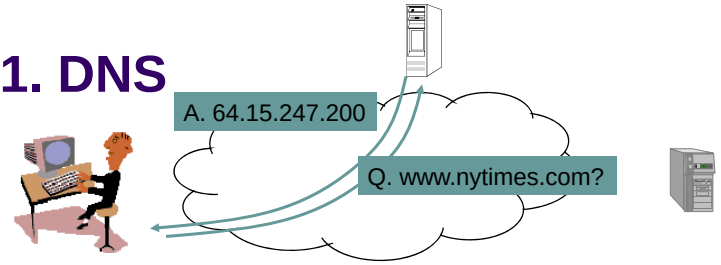
1. DNS



- User clicks on http://www.nytimes.com/
- URL contains Internet name of machine (www.nytimes.com), but not Internet address
- Internet needs Internet address to send information to a machine
- Browser software uses Domain Name System (DNS) protocol to send query for Internet address
- DNS system responds with Internet address

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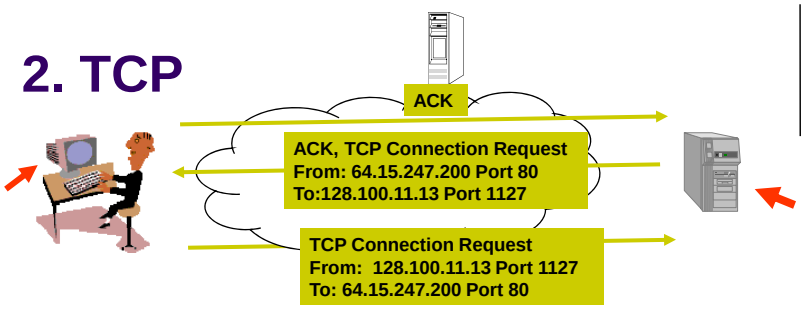
2. TCP



- Browser software uses Hyper Text Transfer Protocol (HTTP) to send request for document
- HTTP server waits for requests by listening to a well-known port number (80 for HTTP)
- HTTP client sends request messages through an “ephemeral port number,” e.g. 1127 (lasts for the duration of the connection)
- HTTP needs a Transmission Control Protocol (TCP) connection between the HTTP client and the HTTP server to transfer messages reliably

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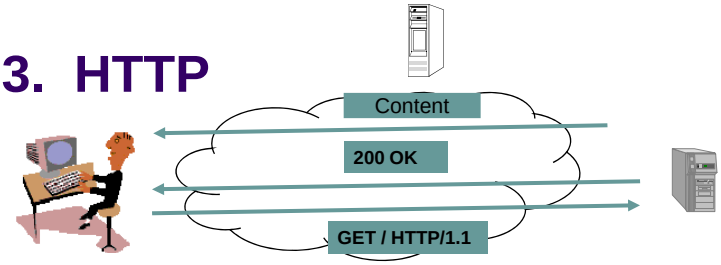
3. HTTP



- HTTP client sends its request message: “GET …”
- HTTP server sends a status response: “200 OK”
- HTTP server sends requested file
- Browser displays document

- Clicking a link sets off a chain of events across the Internet!
- Let’s see how protocols & layers come into play…

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Protocols

- A *protocol* is a set of rules that governs how two or more communicating entities in a layer are to interact
- *Messages* that can be sent and received
- *Actions* that are to be taken when a certain event occurs, e.g. sending or receiving messages, expiry of timers
- **The purpose of a protocol is to provide a service to the layer above**

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Layers

- A set of related communication functions that can be managed and grouped together
- Application Layer: communications functions that are used by application programs
  - HTTP, DNS, SMTP (email)
- Transport Layer: end-to-end communications between two processes in two machines
  - TCP, User Datagram Protocol (UDP)
- Network Layer: node-to-node communications between two machines
  - Internet Protocol (IP)

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Why Layering?

- Layering simplifies design, implementation, and testing by partitioning overall communications process into parts
- Protocol in each layer can be designed separately from those in other layers
- Protocol makes “calls” for services from layer below
- Layering provides flexibility for modifying and evolving protocols and services without having to change layers below
- Monolithic non-layered architectures are costly, inflexible, and soon obsolete

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Applications and Layered Architectures

OSI Reference Model

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Open Systems Interconnection

- Network architecture:
  - Definition of all the layers
  - Design of protocols for every layer
- By the 1970s every computer vendor had developed its own proprietary layered network architecture
- Problem: computers from different vendors could not be networked together
- Open Systems Interconnection (OSI) was an international effort by the International Organization for Standardization (ISO) to enable multivendor computer interconnection

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OSI Reference Model

- Describes a seven-layer abstract reference model for a network architecture
- Purpose of the reference model was to provide a framework for the development of protocols
- OSI also provided a unified view of layers, protocols, and services which is still in use in the development of new protocols
- Detailed standards were developed for each layer, but most of these are not in use
- TCP/IP protocols preempted deployment of OSI protocols

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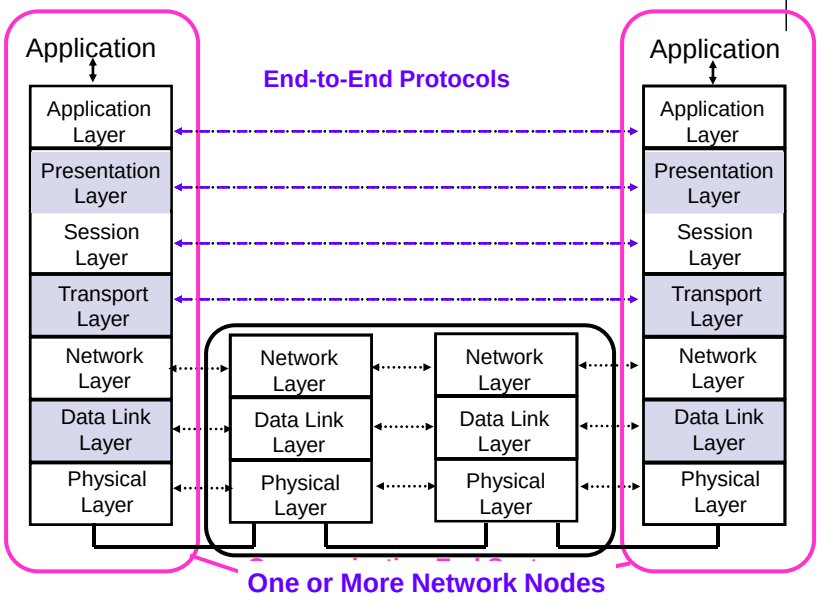
7-Layer OSI Reference Model



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OSI and TCP/IP Models

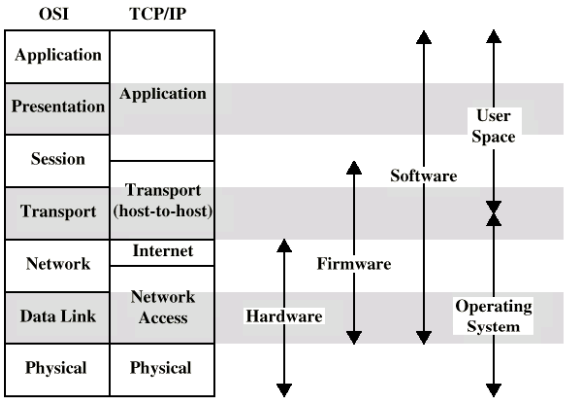

Figure 1.11 A Comparison of the TCP/IP and OSI Protocol Architectures

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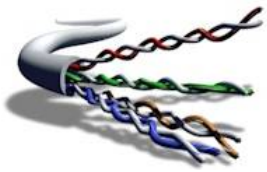
Physical Layer



- Transfers bits across link
- Definition & specification of the physical aspects of a communications link
  - Mechanical: cable, plugs, pins...
  - Electrical/optical: modulation, signal strength, voltage levels, bit times, …
  - functional/procedural: how to activate, maintain, and deactivate physical links…
- Ethernet, DSL, cable modem, telephone modems…
- Twisted-pair cable, coaxial cable optical fiber, radio, infrared, …

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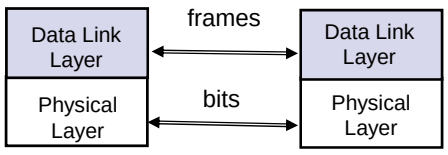
Data Link Layer

- Transfers *frames* across *direct* connections
- Groups bits into frames
- Detection of bit errors; Retransmission of frames
- Activation, maintenance, & deactivation of data link connections
- Medium access control for local area networks
- Flow control



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Network Layer

- Transfers *packets* across multiple links and/or multiple networks
- Addressing must scale to large networks
- Nodes *jointly* execute routing algorithm to determine paths across the network
- Forwarding transfers packet across a node
- Congestion control to deal with traffic surges
- Connection setup, maintenance, and teardown when connection-based

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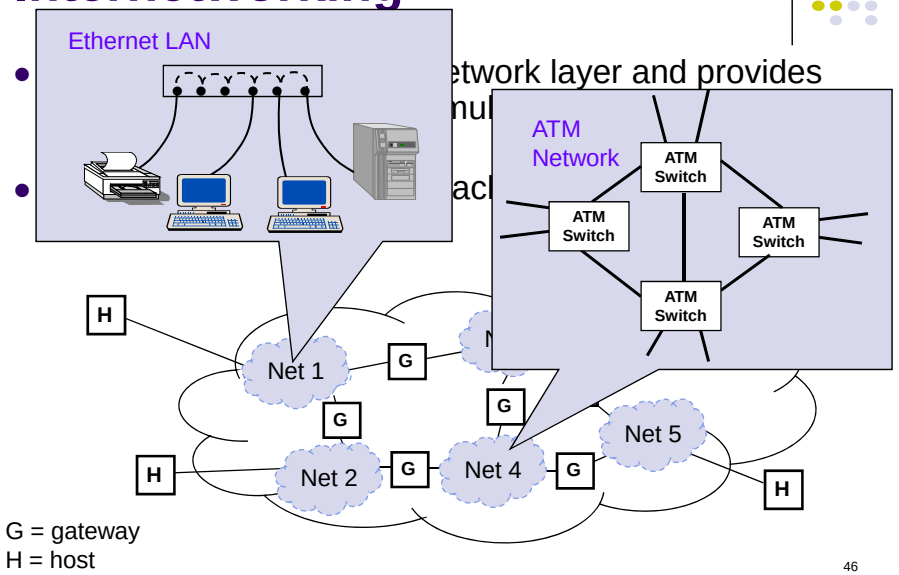
Internetworking

- etwork layer and provides
- ac



G = gateway
H = host

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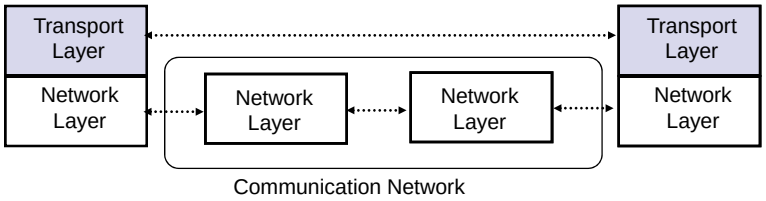
Transport Layer

- Transfers data end-to-end from process in a machine to process in another machine
- Reliable stream transfer or quick-and-simple single-block transfer
- Port numbers enable multiplexing
- Message segmentation and reassembly
- Connection setup, maintenance, and release



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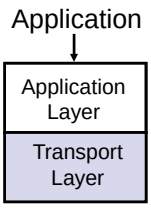
Application & Upper Layers

- Application Layer: Provides services that are frequently required by applications: DNS, web acess, file transfer, email…
- Presentation Layer: machine-independent representation of data…
- Session Layer: dialog management, recovery from errors, …

Incorporated into Application Layer



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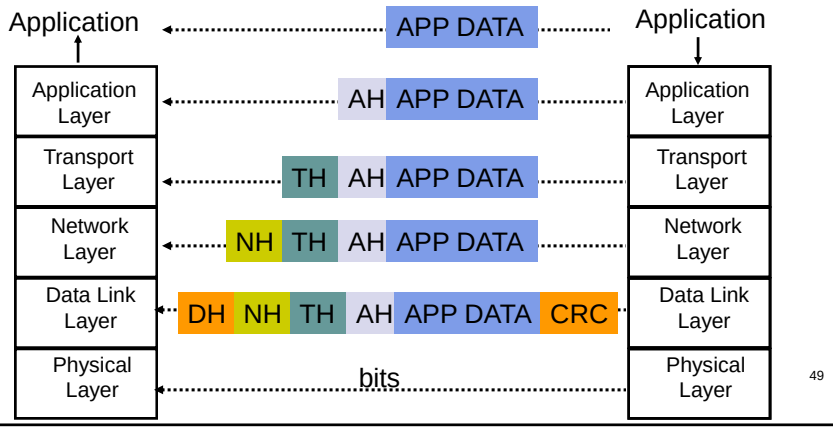
Headers & Trailers

- Each protocol uses a header that carries addresses, sequence numbers, flag bits, length indicators, etc…
- CRC check bits may be appended for error detection



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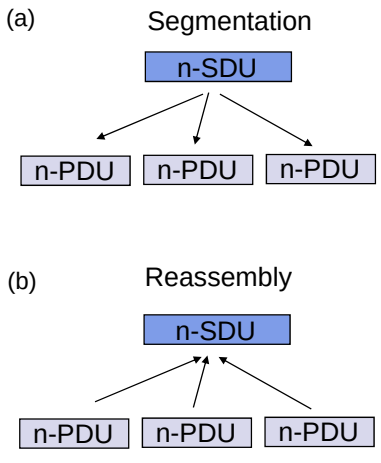
Segmentation & Reassembly

- A layer may impose a limit on the size of a data block that it can transfer for implementation or other reasons
- Thus a layer-n SDU may be too large to be handled as a single unit by layer-(n-1)
- Sender side: SDU is segmented into multiple PDUs
- Receiver side: SDU is reassembled from sequence of PDUs



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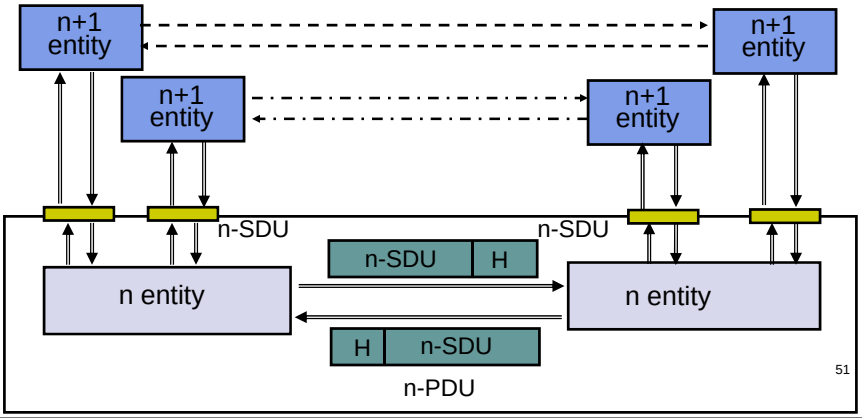
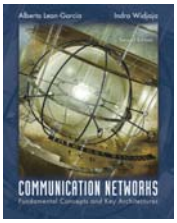
Multiplexing

- Sharing of layer n service by *multiple* layer n+1 users
- Multiplexing tag or ID required in each PDU to determine which users an SDU belongs to



Applications and Layered Architectures



TCP/IP Architecture

How the Layers Work Together

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OSI and TCP/IP Models

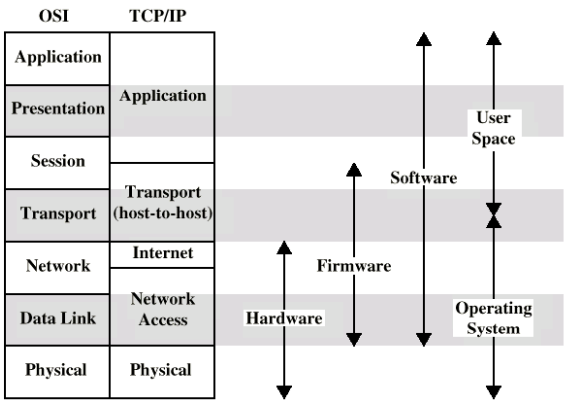

Figure 1.11 A Comparison of the TCP/IP and OSI Protocol Architectures

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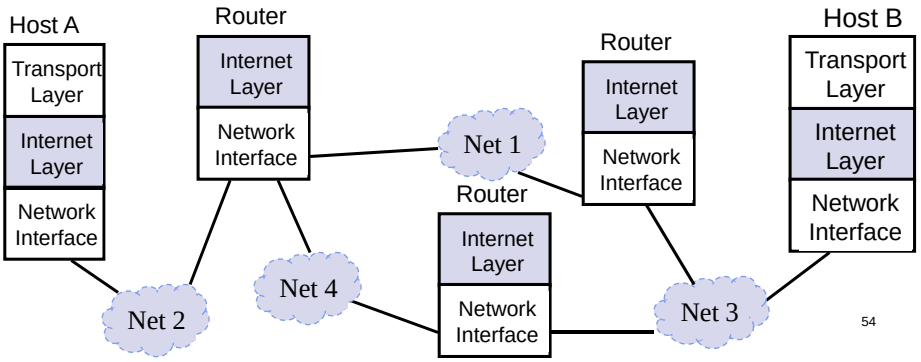
Internet Protocol Approach

- IP packets transfer information across Internet
  Host A IP → router→ router…→ router→ Host B IP
- IP layer in each router determines next hop (router)
- Network interfaces transfer IP packets across networks



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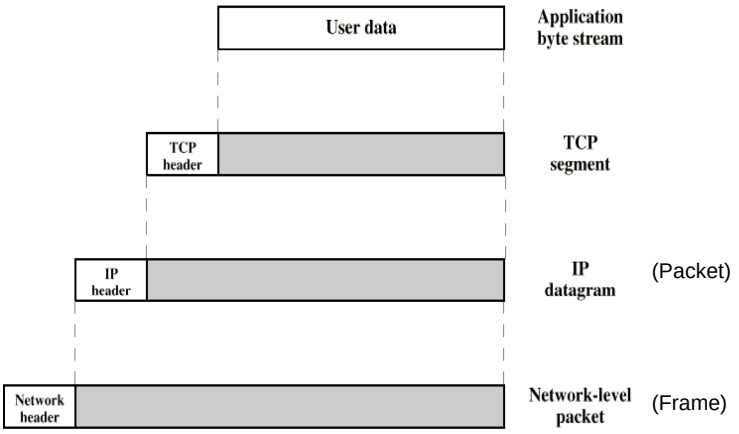
TCP/IP Encapsulation



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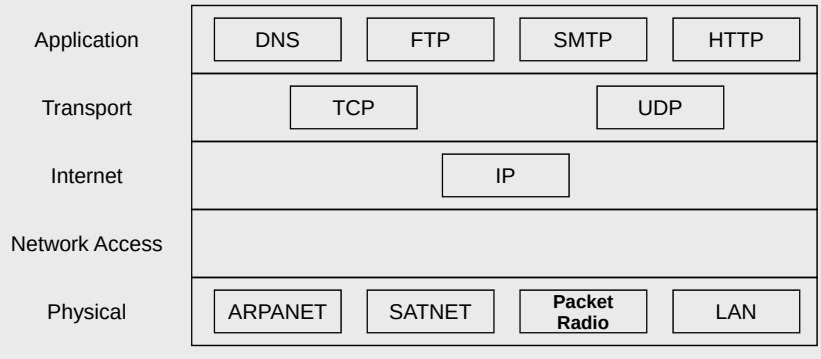
TCP/IP Model and Example Protocols

A list of protocols used in TCP/IP:



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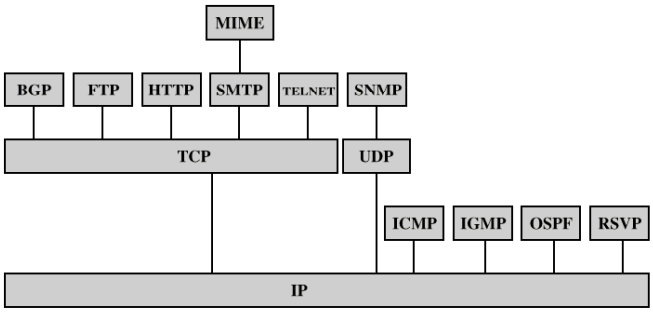
TCP/IP Protocols



BGP = Border Gateway Protocol
FTP = File Transfer Protocol
HTTP = Hypertext Transfer Protocol
ICMP = Internet Control Message Protocol
IGMP = Internet Group Management Protocol
IP = Internet Protocol
MIME = Multi-Purpose Internet Mail Extension
OSPF = Open Shortest Path First
RSVP = Resource ReSerVation Protocol
SMTP = Simple Mail Transfer Protocol
SNMP = Simple Network Management Protocol
TCP = Transmission Control Protocol
UDP = User Datagram Protocol

Figure 2.12 Some Protocols in the TCP/IP Protocol Suite

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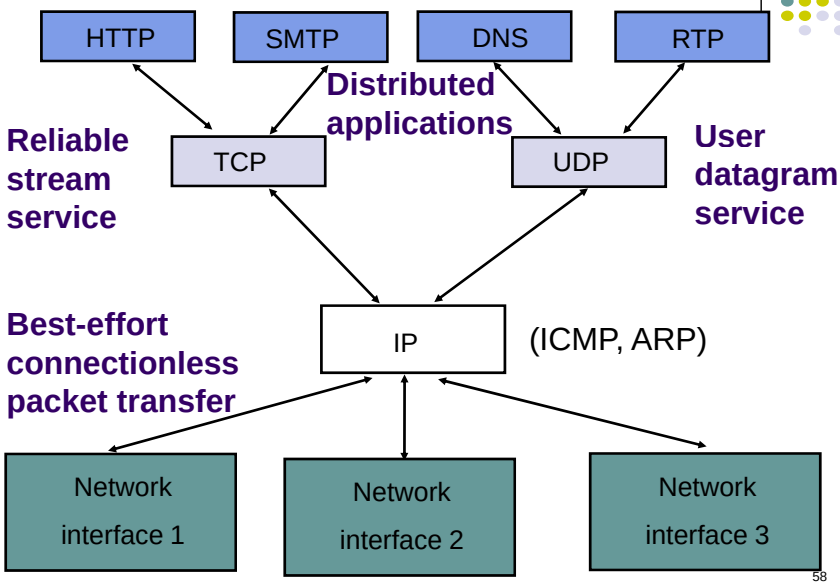
TCP/IP Protocol Suite



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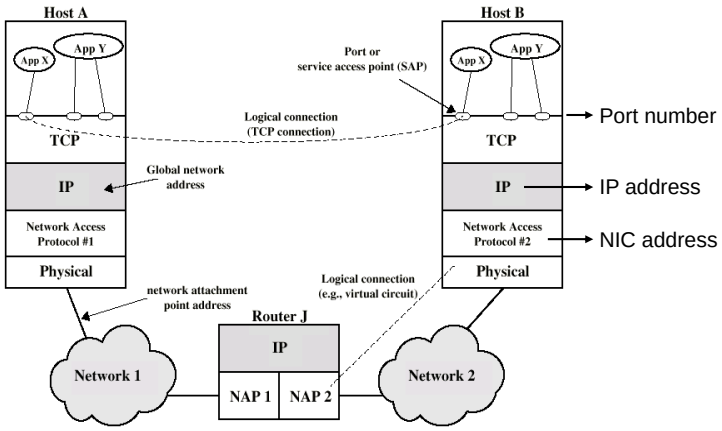
TCP/IP Addressing

- Port (or SAP) numbers of processes at source and destination
- IP addresses of source and destination
- Network interface card (NIC) addresses defined by the NIC



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IP Addresses

- Each host in the Internet is identified by a globally unique IP address
- The IP address identifies the host's network interface rather than the host itself (usually the host is identified by its physical address within a network).
- An IP address consists of two parts: network ID and host ID (more on formats of IP addresses later).
- IP addresses on the Internet are distributed in a hierarchical way. At the top of the hierarchy is ICANN (Internet Corporation for Assigned Names and Numbers). ICANN allocates blocks of IP addresses to regional Internet registries. There are currently three regional Internet registries that cover the Americas, Europe, and Asia. The regional registries then further allocate blocks of IP addresses to local Internet registries within their geographic region. Finally, the local Internet registries assign addresses to end users.
- Router: a node that is attached to two or more physical networks. Each network interface has its own IP address.

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Physical Addresses

- On a physical network, the attachment of a device to the network is often identified by a physical address.
- The format of the physical address depends on the particular type of network.
- Example: Ethernet LANs use 48-bit addresses.
  - Ethernet: protocol for bus LANs, originally designed by Xerox, later developed into IEEE 802.3 standard.
  - Every machine in a LAN comes with a NIC that is assigned a physical address.

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Physical Addresses (2)

- LANs (and other networks) assign physical addresses to the physical attachment to the network
- The network uses its own address to transfer packets or frames to the appropriate destination
- IP address needs to be resolved to physical address at each IP network interface
- Example: Ethernet uses 48-bit addresses
  - Each Ethernet network interface card (NIC) has globally unique Medium Access Control (MAC) or physical address
  - First 24 bits identify NIC manufacturer; second 24 bits are serial number
  - 00:90:27:96:68:07 12 hex numbers

Intel

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Network Interface Cards (NICs)

- NICs are adapters installed in a computer that provide the connection point to a network.
- Each NIC is designed for a specific type of LAN, such as Ethernet, token ring, FDDI.
- A NIC provides an attachment point for a specific type of cable, such as coaxial cable, twisted-pair cable, or fiber-optic cable.
- Every NIC has a **globally unique** identifying node address (globally unique physical address).
- Token ring and Ethernet card addresses are hardwired on the card.
- The IEEE (Institute of Electrical and Electronic Engineers) is in charge of assigning addresses to token ring and Ethernet cards. Each manufacturer is given a unique code and a block of addresses.

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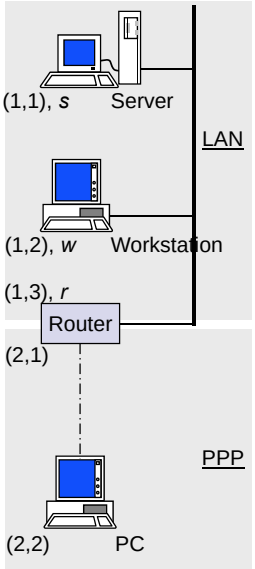
Example: HTTP and Web Browsing



Infrastructure:

1. A LAN comprising of a server and a workstation is connected via a router to a PC. The connection between the router and PC is a point-to-point (PPP) connection.
2. Each machine on the LAN typically have two addresses:
   - An IP address known globally
   - An Ethernet address determined by its network interface card (NIC)
3. The router has as many IP addresses as the number of networks connected to it.

	Server	Work station	Router	PC	Router
IP	(1,1)	(1,2)	(1,3)	(2,2)	(2,1)
Ethernet	*s*	*w*	*r*		*r*

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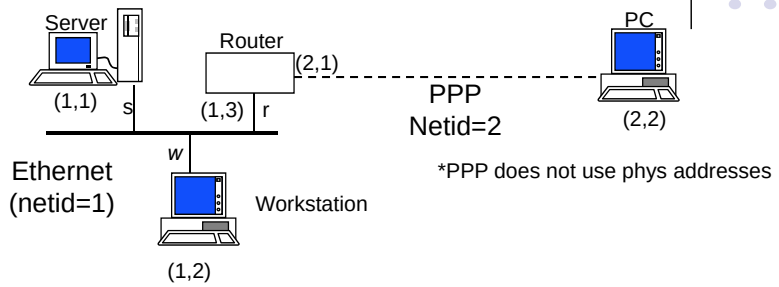
Example



	netid	hostid	Physical address
server	1	1	s
workstation	1	2	w
router	1	3	r
router	2	1	-
PC	2	2	-

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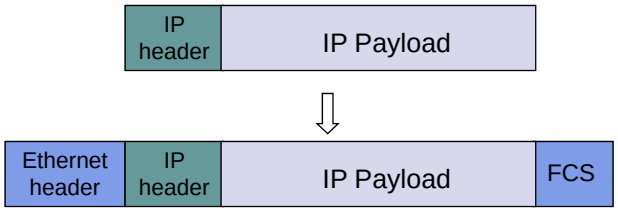
Encapsulation



- Ethernet header contains:
  - source and destination physical addresses
  - network protocol type (e.g. IP)

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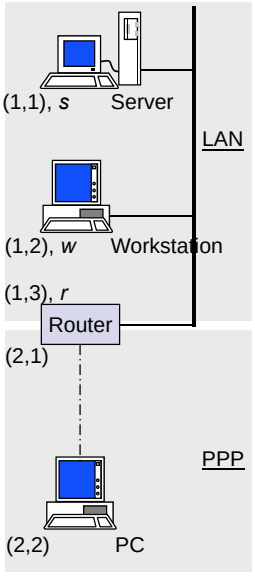
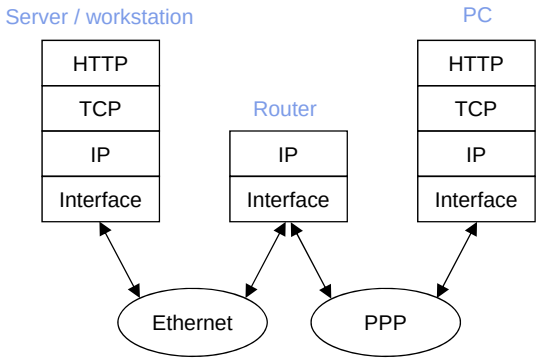
Example: HTTP and Web Browsing (2)



Protocols: used for an HTTP request made by PC to server



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Example: HTTP and Web Browsing (3)

Instruction: http://www.tesla.comm.utoronto.ca/infocomm/index.html

Hypertext transfer protocol: Specifies rules by which client / server interact.

Uniform Resource locator (URL) of the server: 1st part typically translated to an address by Domain Name Server (DNS), 2nd part specifies document

- HTTP is only concerned with the interaction of the client with the server, not with the actual setting up of connection.
- A connection is first set up between the client and the server. For connection-oriented services, this implies setting up of a physical connection.
- HTTP requires the service of TCP to provide a reliable service between the two machines. TCP itself requires the service of IP and so on. This leads to a layered approach.

HTTP (application)
TCP (Transport)
IP (Internet)

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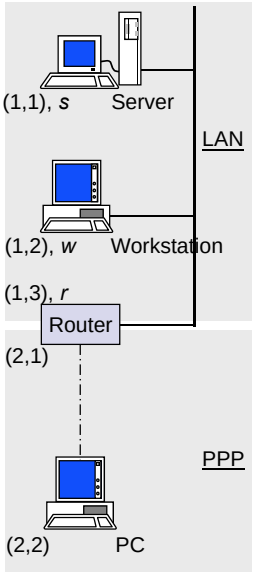
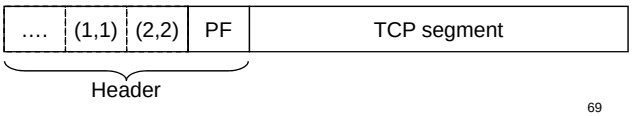
Example: HTTP and Web Browsing (4)



Task: Transfer of an HTTP request from PC to Server

1. For simplicity, assume a TCP connection is established between the server and PC (more on connections later).
2. HTTP request is passed on to the TCP layer of PC that creates a TCP segment containing server port number (SP#) and client port number (CP#)

3. TCP segment is passed to IP layer that creates an IP datagram where protocol field (PF) shows that upper layer has asked for the information. IP datagram is passed on to interface layer.



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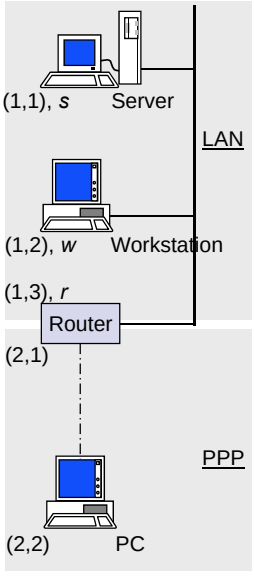
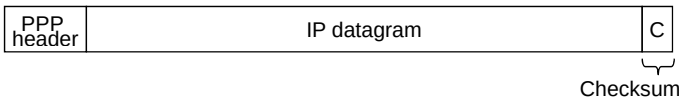
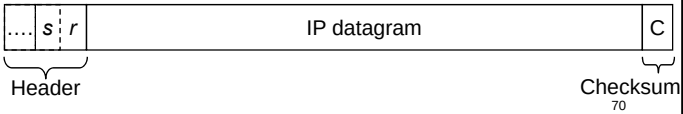
Example: HTTP and Web Browsing (5)



4. Interface layer encapsulates the IP datagram into a PPP frame, and sends the PPP frame to the router.



5. The IP datagram is extracted by the interface layer of the router and passed on to the Internet layer. The Internet layer extracts the destination address (1,1) and checks the routing table for a match.
6. Since a match exists, the Interface layer prepares an Ethernet frame encapsulating the IP datagram plus the Ethernet addresses in the header, and broadcasts the Ethernet frame on the LAN.



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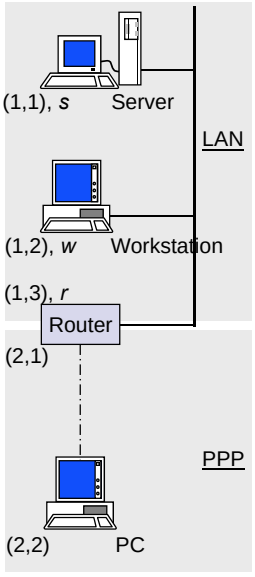
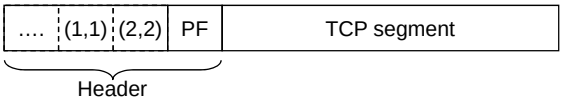
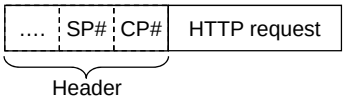
Example: HTTP and Web Browsing (6)



4. Interface layer of the Server compares the Ethernet address with the address on its network interface card (NIC). The address matches so the Ethernet frame is accepted.
5. A Checksum is performed to check for errors. In case of no errors, the IP datagram is extracted and passed on to the Internet layer.



6. The Internet layer maps the IP address and sees that the IP datagram is meant for it. It extracts the TCP segment and passes it on to the TCP layer



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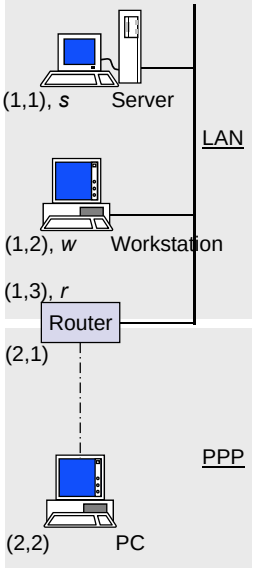
Example: HTTP and Web Browsing (7)



7. HTTP request is extracted by TCP layer and passed on to specified port number.
8. Recall that the protocol used by the Transport layer is TCP, which is a reliable connection-oriented protocol. An acknowledgment is therefore sent to the PC in exactly the same manner as the request was received.

- The Application layer retrieves the HTML document and transmits it to the PC following steps (1-8) in reverse order.

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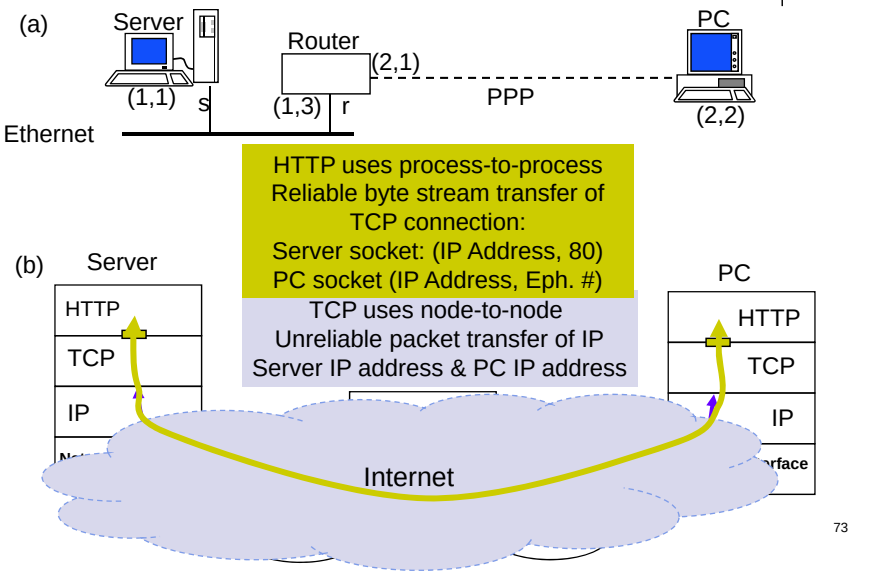
How the layers work together

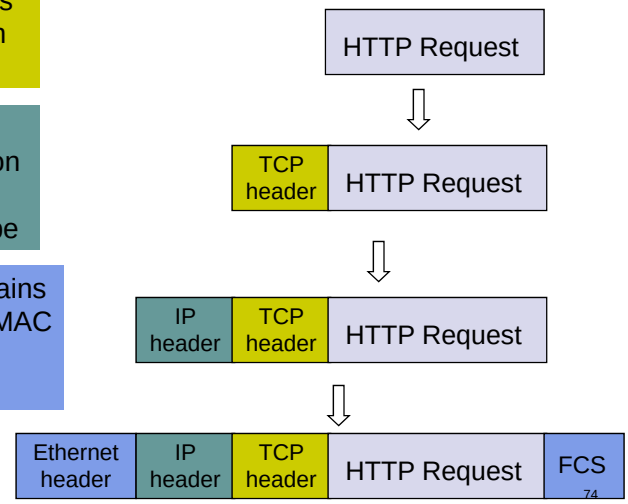


Encapsulation

TCP Header contains source & destination port numbers

IP Header contains source and destination IP addresses; transport protocol type

Ethernet Header contains source & destination MAC addresses; network protocol type



Summary

- Encapsulation is key to layering
- IP provides for transfer of packets across diverse networks
- TCP and UDP provide universal communications services across the Internet
- Distributed applications that use TCP and UDP can operate over the entire Internet
- Internet names, IP addresses, port numbers, sockets, connections, physical addresses

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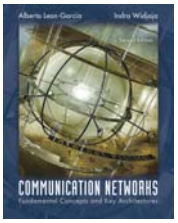
Chapter 2 Applications and Layered Architectures



More Application Layer Protocols & Utilities

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Domain Name System

- Domain Name System (Service)(DNS) links names to IP addresses in the Internet.
- The system uses a hierarchical tree topology to reflect different administrative levels.

  Example: www.cs.yorku.ca (130.63.96.20)
- DNS servers are distributed databases strategically located on the Internet.
- Most Internet service providers have DNS servers.
- Converting domain names to IP addresses & vice versa:

  www.whatismyipaddress.com

  www.hcidata.co.uk/host2ip.htm

  nslookup program (“man nslookup” on Unix for info)

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DNS Query

- In the previous HTTP example, the client first needs to perform a DNS query to obtain the IP address corresponding to the domain name.
- Send a message to a DNS server.
- DNS queries use UDP (why?)
- The following example assumes that the client and the DNS server are located on the same LAN.

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- Finding out the network address of "www.cs.fsu.edu"
  - netscape goes to a domain name server (DNS) to find out the IP address of "www.cs.fsu.edu"

    host = gethostbyname("www.cs.fsu.edu");
  - DNS server in our department:

    nu.cs.fsu.edu (128.186.121.10) at 8:0:20:7d:4f:49
  - How does netscape know the address of the DNS server?
    - Hard-coded at system (network) configuration. E.g. /etc/resolv.conf in my Linux system.

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- Getting the IP address from the DNS server
  - Netscape, using UDP transport sets up a dialogue with the DNS Server at 128.186.121.10/53 to get the desired address
    - TCP/IP protocol uses IP to send a datagram to 128.186.121.10.
      - Turns out that 128.186.121.10 and my IP address are on the same Ethernet domain; can send the DNS query directly via the Ethernet.
      - Needs to find out the Ethernet address of 128.186.121.10.
      - Uses ARP protocol, sends an ARP packet over the network

        What is the address of 128.186.121.10?

        Host 128.186.121.10 replies: result: 8:0:20:7d:4f:49.
      - IP asks Ethernet to send an Ethernet frame to 8:0:20:7d:4f:49.
      - Ethernet on nu.cs.fsu.edu (DNS server) receives a frame, turns out to be an IP packet destined for it, passes it to the IP module.
      - IP module finds out that it is a UDP packet and passes it to the UDP module.
      - UDP realizes that a process is listening to port 53, notifies the process.
      - Process handles the message and replies to Netscape host.
    - DNS client dialogue involves several message exchanges
  - The DNS server eventually sends a message back: 128.186.121.41 is the network address of www.cs.fsu.edu

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SMTP and E-mail

A sends an email to B ⇒ 3 transactions

1. A sends the message to the local SMTP server.
2. Local SMTP server transfers the message to the destination SMTP server.
3. Destination SMTP server delivers the message to B.

- SMTP works best when the receiver machine is always available.
- Users in a PC environment usually retrieve their email from a mail server using the Post Office Protocol (POP3) (working in conjunction with SMTP).

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More Protocols and Utilities

- Telnet
- FTP
- IP utilities
  - PING: determines if a host is online and available
    Example: ping –s gardiner.cs.utoronto.ca
  - Echo (port 7): echoes a character back to sender
  - Daytime (port 13): returns time and date
  - traceroute: returns the source-to-destination route
  - netstat: queries a host about its TCP/IP network status
- For more utilities: http://www.caida.org/tools/taxonomy/

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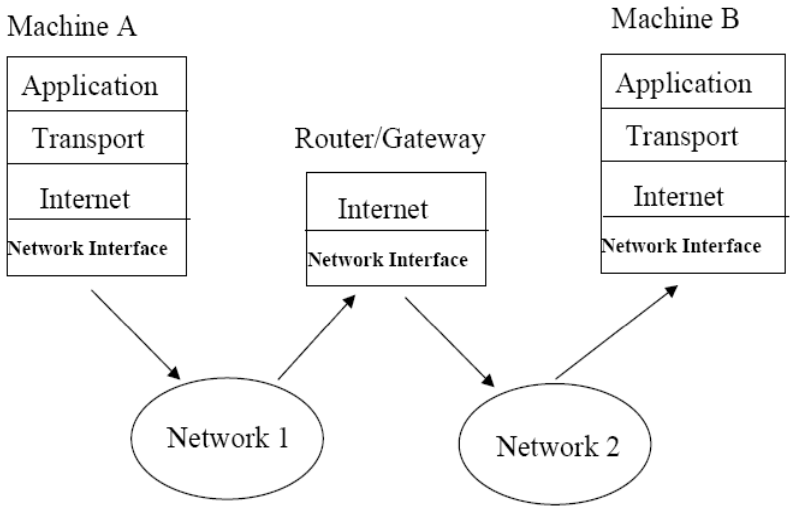
Summary of TCP/IP Model



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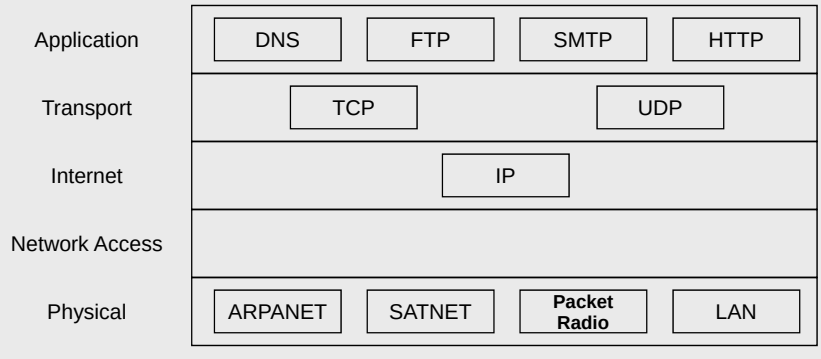
TCP/IP Model and Example Protocols

A list of protocols used in TCP/IP:



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Reading

- Chapters 1 and 2 from Stallings
- Reference:

  Chapters 1 and 2 from “Communication Networks: Fundamentals Concepts and Key Architectures,” 2nd edition by Alberto Leon-Garcia and Indra Widjaja, McGraw-Hill, 2004

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