TCP/IP

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The Internet

- The Internet is the largest and most popular global network.
- It is a network of networks.
- 1996: over 9 million networks.
- 150,000 users join the network every month

Internet is an Information Highway

The Internet (cont.)

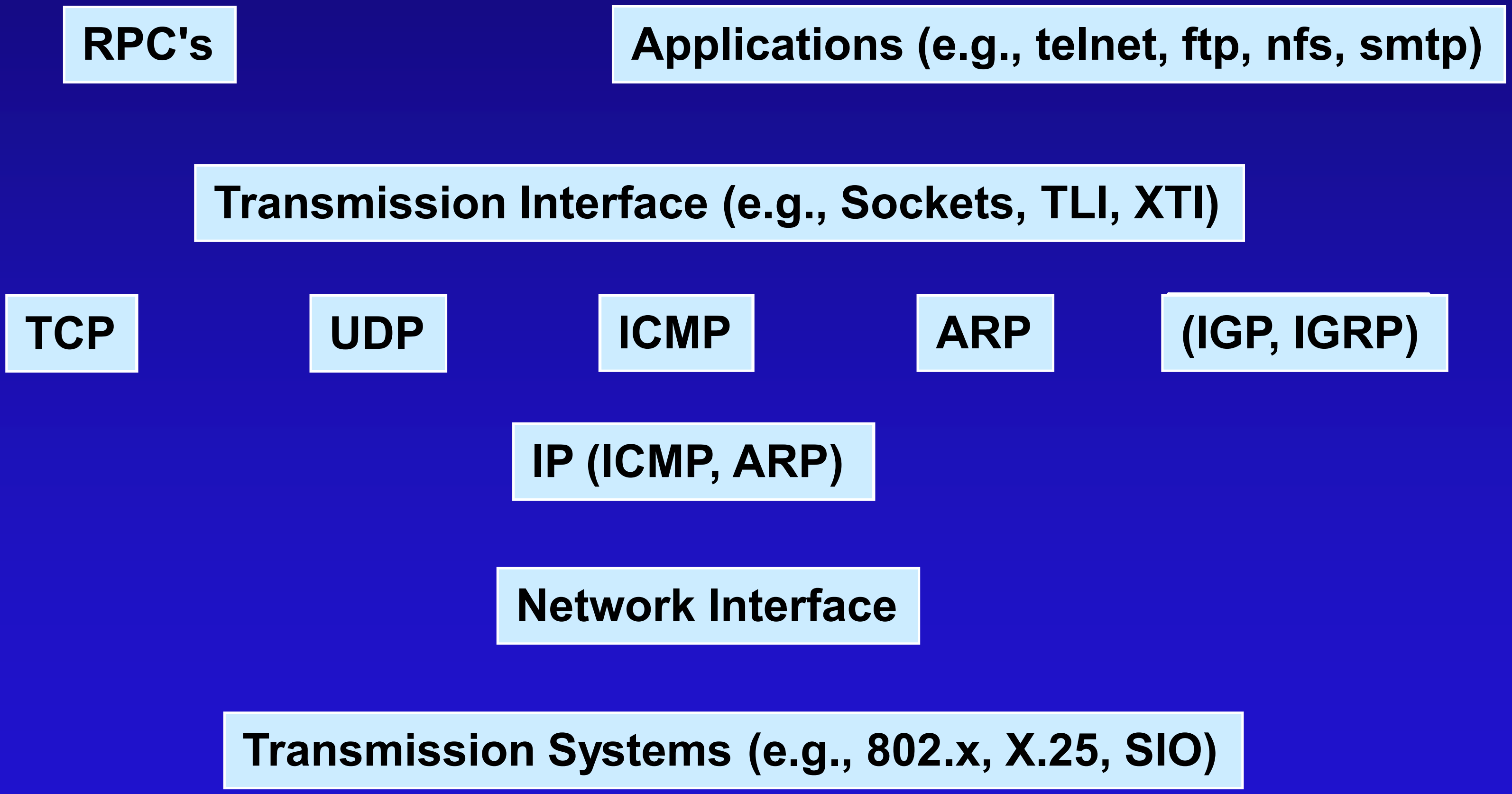
- The Internet is connected using dedicated communication links (copper, fiber, satellite)
- Almost all hosts connected to the Internet speak TCP/IP.

TCP/IP

- TCP/IP is an entire set of data communications protocols
- TCP and IP are two of these protocols
- IP: Internet Protocol.
- TCP: Transmission Control Protocol.

There are many other protocols in this suite

ome Protocols in the TCP/IP Suite



RPC's

Applications (e.g., telnet, ftp, nfs, smtp)

Transmission Interface (e.g., Sockets, TLI, XTI)

TCP

UDP

ICMP

ARP

(IGP, IGRP)

IP (ICMP, ARP)

Network Interface

Transmission Systems (e.g., 802.x, X.25, SIO)

TCP/IP Features

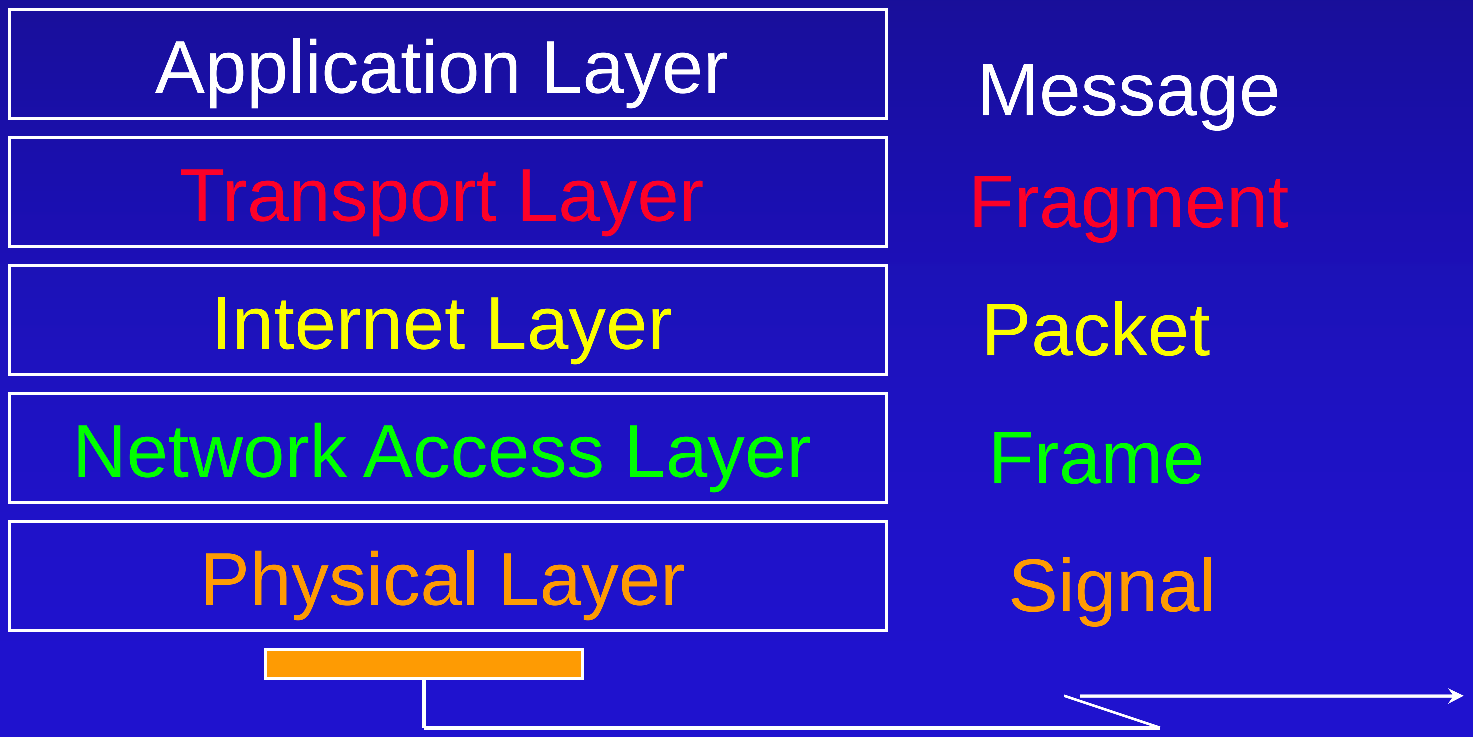
- Popularity of TCP/IP
  - » provides an elegant solution to world wide data communication.
  - » DARPA funding of ARPANET to provide robust communications resulted in TCP/IP
  - » TCP/IP became a defacto standard
- TCP/IP has Open Protocol Standards: freely available, and independent from any hardware platform.

TCP/IP Features (cont.)

- **Independence from specific network hardware**
  - » TCP/IP allows many types of networks to be integrated (Ethernet, Token Ring, X.25)
  - » TCP/IP is used in both LANs/ and WANs
  - » Supports dial-up connectivity
- Common addressing scheme
  - » Every TCP/IP host has a unique address
- Standardized high-level protocols for world wide available network services

TCP/IP Protocol Architecture

- Layered architecture



Application Layer	Message
Transport Layer	Fragment
Internet Layer	Packet
Network Access Layer	Frame
Physical Layer	Signal

Application Layer

- Includes all software programs that use the Transport Layer protocols to deliver data messages
- Examples of protocols:
  - » Telnet: Network Terminal Protocol
  - » FTP: File Transfer Protocol
  - » SMTP: Simple Mail Transfer Protocol
  - » DNS: Domain Name Service
  - » HTTP: World Wide Web (WWW)

Transport Layer

- Interface between the Application and Internet layers
- Two main protocols
  - » Transmission Control Protocol (TCP)
    - ï Provides reliable end-to-end data delivery service, connection-oriented
  - » User Datagram Protocol (UDP)
    - ï Provides low overhead connection-less datagram delivery service

Internet Layer

- Heart of TCP/IP
  - » Provides basic packet delivery service on which TCP/IP networks are built
- Main functions
  - » Defines datagram, basic unit of transmission in the Internet
  - » Provides Internet addressing
  - » Routing of datagrams

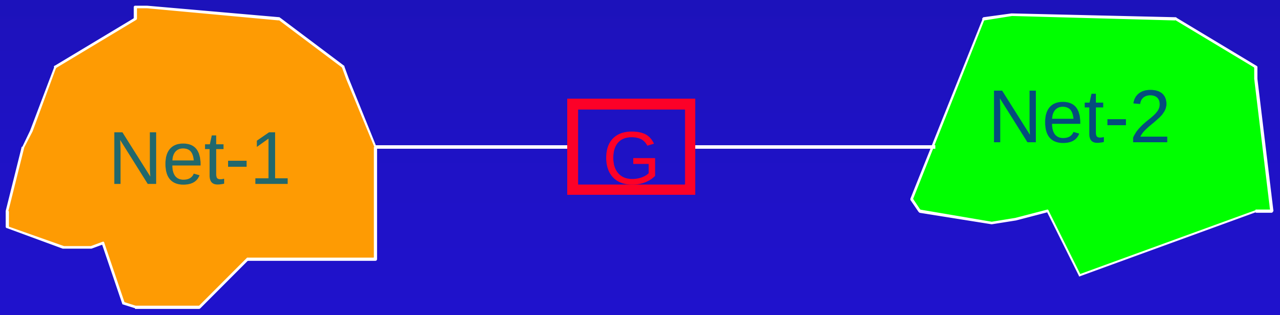
Internet Layer (cont.)

- » Interfaces the Transport layer and Network Access layer
- » Performs fragmentation and re-assembly of datagrams

- ● IP is an unreliable protocol
  - » no error control

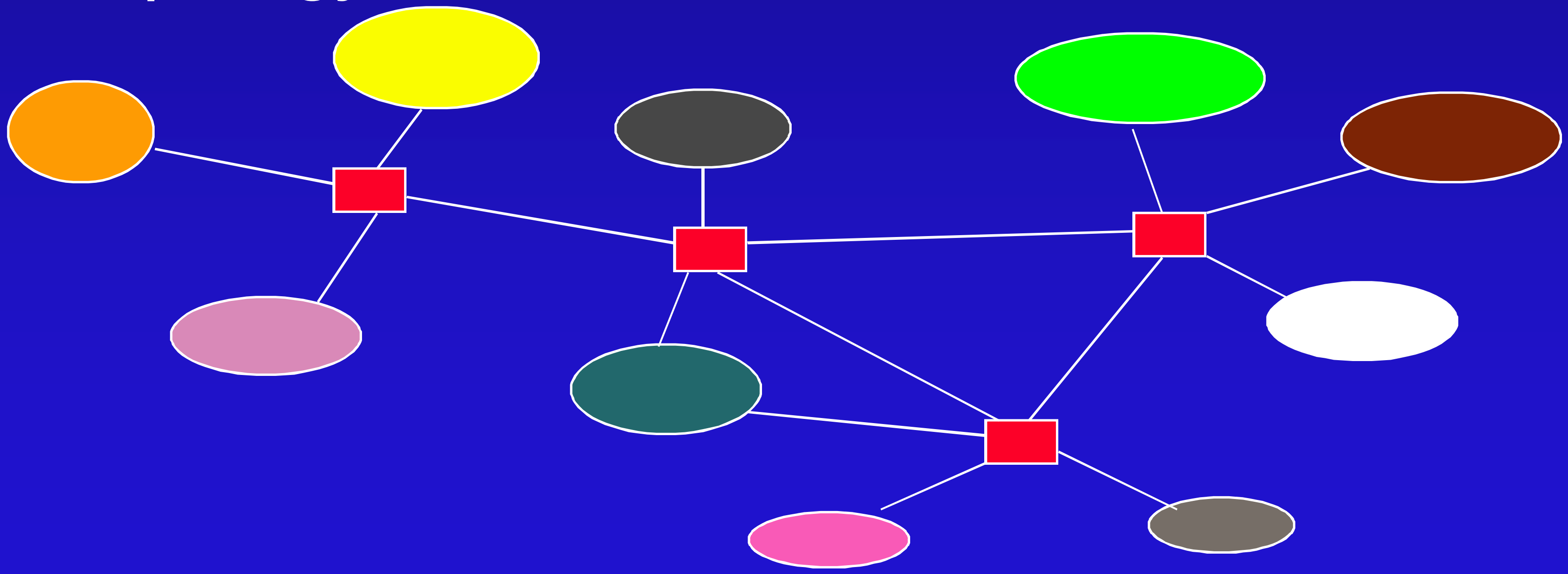
Internetworking

- Network: Any communication system capable of transferring packets
- Internet Gateways/Routers are used to connect networks together.



Internetworking (cont.)

- For complex interconnections, gateways must have knowledge of internet topology



Internetworking (cont.)

- Gateways route packets based on destination network not on destination host
- Besides the gateways, internet access software is needed on each host to allow application programs to see the internet as a single virtual network
- Application software remains unaffected by changes to the internet

Important questions

- How are the machines addressed?
- How do internet (IP) addresses relate to physical addresses?
- How do internet gateways learn about routes?

Internet addresses

- Internet is a universal communication system that uses a globally accepted addressing scheme to identify hosts connected to it.
- IP addresses uniquely identify each host
- Internet addressing helps TCP/IP software hide physical network details

Internet addresses (cont.)

- Names, addresses, and routes refer to successively lower level representations of host identifiers
  - » A name identifies what an object is,
  - » its address identifies where it is, and
  - » a route indicates how to get to it
- TCP/IP addressing scheme is analogous to physical network addressing

Internet addresses (cont.)

- Each Internet host is assigned a 32-bit integer address called its Internet address or IP address
- The integers are carefully structured for efficient routing
- IP address = {Net-ID, Host-ID}
- Gateways base routing on Net-ID

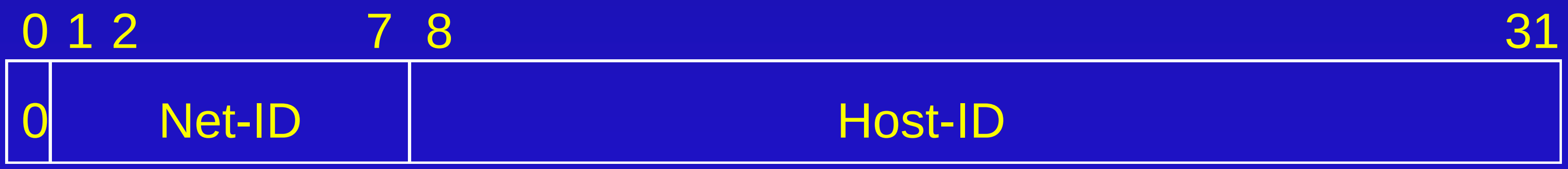
Internet addresses (cont.)

- 32-bit address number specified in each IP datagram
  - » Written as 4 decimal numbers separated by dots (dotted quad notation)
  - » Each number is from 0-255
  - » Example: razi 196.1.64.2
- Number of bits used for Net-Id and for Host-Id depends on class of IP address

Classes of IP addresses

- Class A: Used for very few, large networks with more than 2^{16} hosts.

  First byte < 128



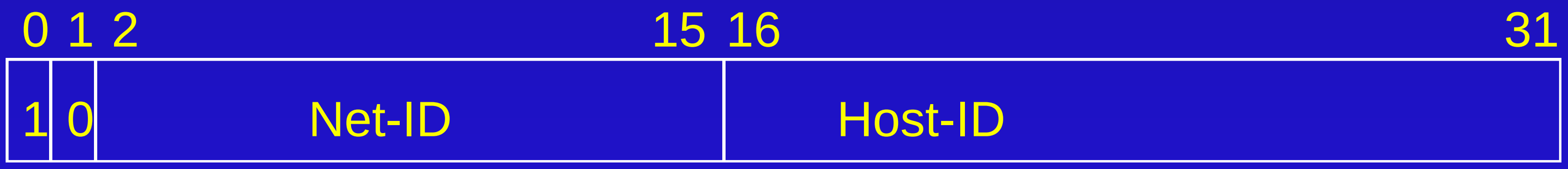
0 1 2 7 8 31

0 | Net-ID | Host-ID

lasses of IP addresses (cont.)

- Class B: For medium size networks that have between 2^8 and 2^{16} hosts

First byte is from 128 to 191



0 1 2 15 16 31

1 0 Net-ID Host-ID

lasses of IP addresses (cont.)

- Class C: Small network < 2^8 hosts

First byte is from 192 to 223

0	1	2	3 23	24 31
1	1	0	Net-ID	Host-ID

Internet addresses (cont.)

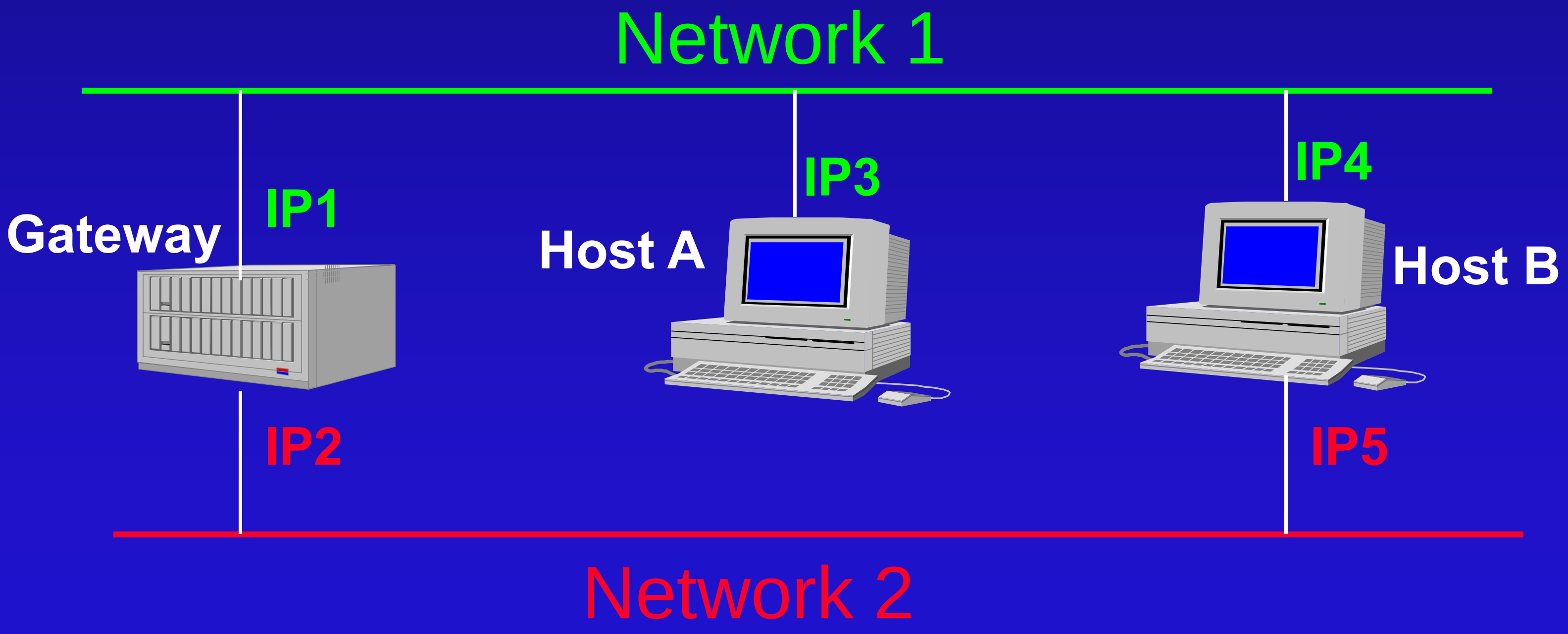
- IP address
  - » Not a host address
  - » Each network interface has an IP address
  - » Each IP address specifies a connection to a network not an individual machine
- A gateway connecting N networks has N distinct IP addresses, one for each physical network connection

Special Addresses

- Net-Id = 0, Host-Id = 0
  - » Designates this host, Allowed only at startup
- Net-Id = 0
  - » Host on this net, Allowed only at startup
- Host-Id = all 1ôs
  - » Broadcast address
  - » Never a valid source address

Weaknesses of IP addressing

If connection of Host B to Network 1 fails, users on Host A who specify IP4 can no longer reach B, where as those that specify IP1 can still reach Host B



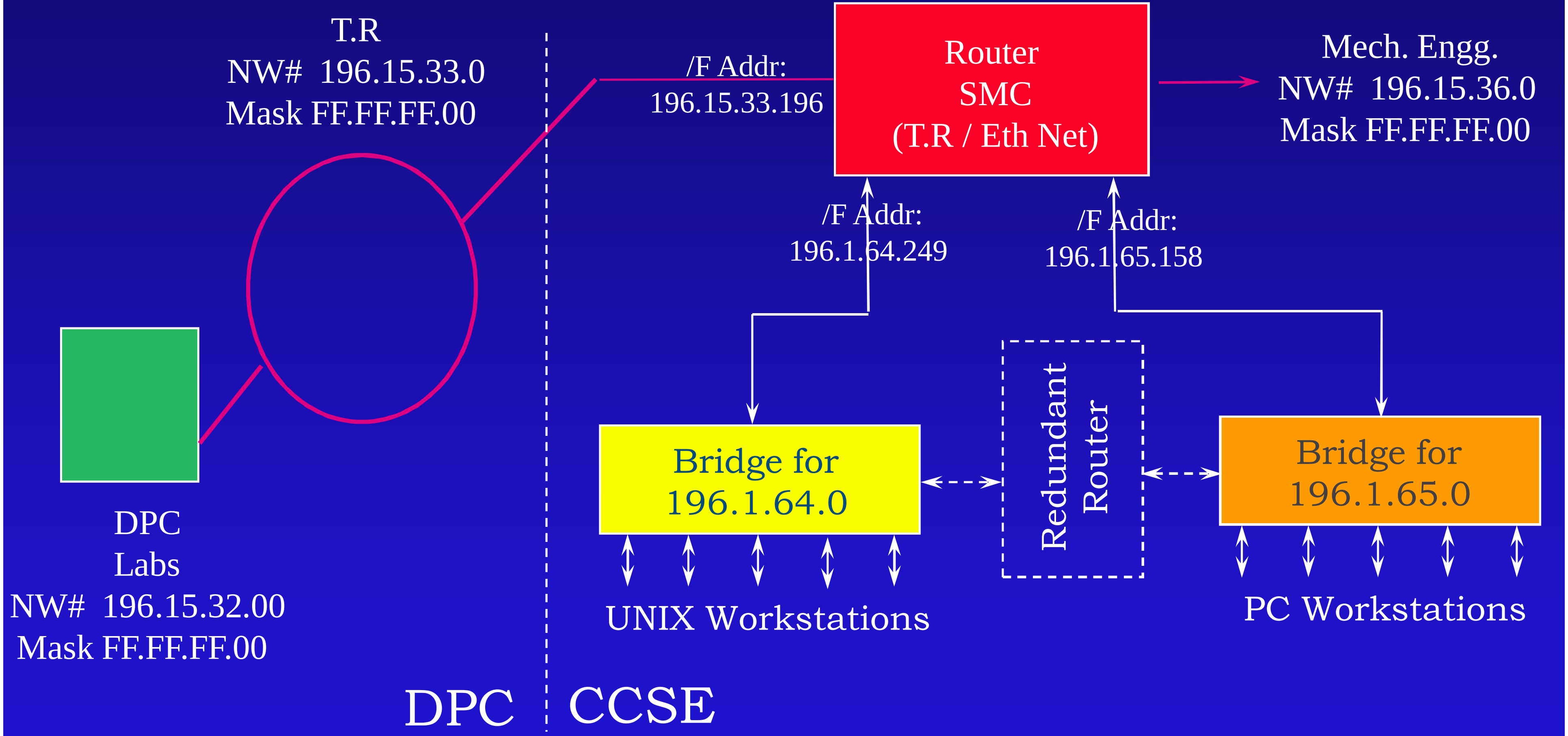
Internet Addressing Authority

- All internet addresses are assigned by a central authority:

  The network Information Center (NIC)

- The NIC assigns the Net-Id portion
  - » Small networks (< 255 hosts) are assigned Class C addresses, since many LANs are expected
  - » Large networks are assigned Class A addresses since only few such networks are expected

CCSE Network IP Addresses



T.R
NW# 196.15.33.0
Mask FF.FF.FF.00

/F Addr:
196.15.33.196

Router
SMC
(T.R / Eth Net)

Mech. Engg.
NW# 196.15.36.0
Mask FF.FF.FF.00

/F Addr:
196.1.64.249

/F Addr:
196.1.65.158

Redundant
Router

Bridge for
196.1.64.0

Bridge for
196.1.65.0

UNIX Workstations

PC Workstations

DPC
Labs
NW# 196.15.32.00
Mask FF.FF.FF.00

DPC

CCSE

Mapping IP Address to Physical Address

- How does a machine map its IP address to its physical network address?
  - » Example:
    - ï Machines A and B connected to the same network, with IP addresses IA and IB and physical addresses PA and PB.
    - ï Suppose A has has only Bâs IP address, then how does A map IB to PB?

Address Resolution

- Some protocol suites adopt one of the following:
  - » Keep mapping tables in each machine
  - » Hardware (physical) addresses are encoded in the high level addresses
- Both are ad-hoc, awkward solutions

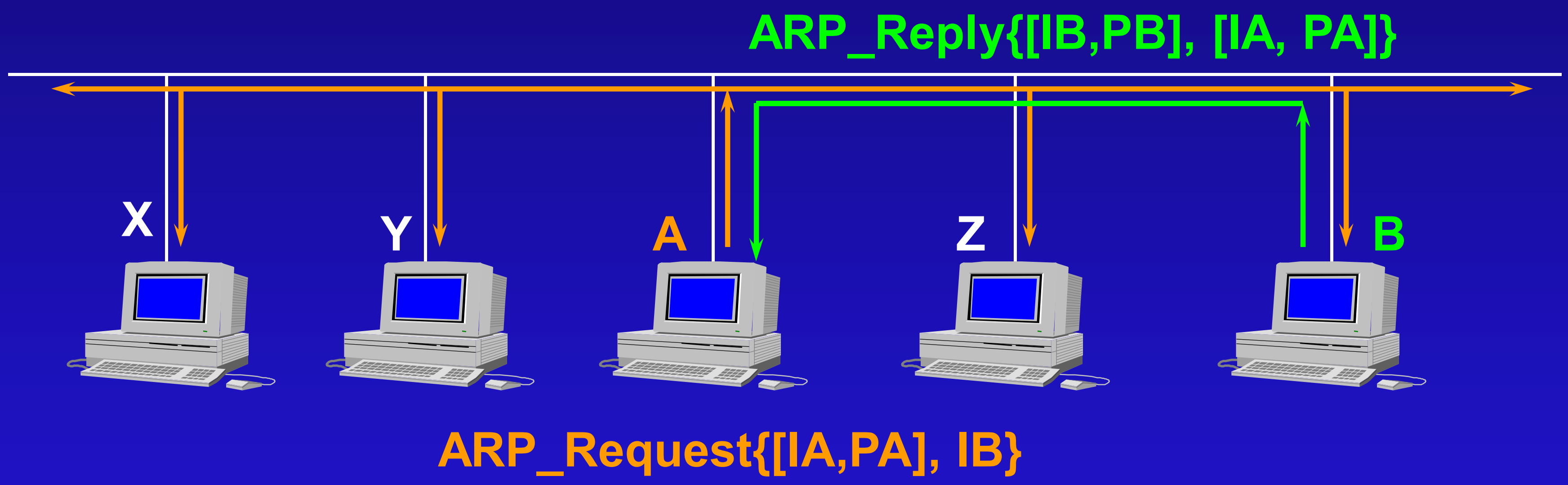
Resolution Through Dynamic Binding (ARP)

- Ethernet uses 48-bit physical addresses
  - » Addresses assigned by manufacturers
  - » Replacing a faulty interface card meant a change to the machine physical address
- Canôt encode 48-bit long address into a 32-bit long IP address
- TCP/IP solution: Address Resolution Protocol (ARP)

ARP

- Exploits broadcast capability of Ethernet
- Allows a host to find the Ethernet address of a target host on the same network, given the targetôs IP address
- Allows new machines to be added with no code recompilation
- Builds and maintains dynamically a table to translate IP addresses into Ethernet physical addresses

ARP (cont.)



ARP (cont.)

- Hosts that use ARP maintain a small cache of recently acquired (IP,P) address bindings
- Cache is updated dynamically
  - » Timer for each entry
  - » Whenever a new binding is received, update the corresponding table entry and reset the associated timer

ARP (cont.)

- ARP is a low level protocol that hides the underlying network physical addressing, permitting us to assign IP addresses of our choosing to every machine
- We think of it as part of the physical network and not as part of the internet protocols

Determining an IP Address at Startup

- Diskless machines use IP addresses to communicate with the file server
- Also, many diskless machines use TCP/IP TFTP protocols to obtain their initial boot image, thus requiring that they obtain and use IP addresses
- Designers keep both the bootstrap code and initial OS images free from specific IP addresses for portability

termining an IP Address at Startup (cont.)

- How does a diskless machine determine its IP address?
- When bootsrap code starts execution on a diskless machine, it uses the network to contact a RARP server to obtain the machineôs IP address
- Usually, a machineôs IP address is kept in a database where the OS finds it at startup

R e Resolution Protocol

- RARP is the protocol used to solve the reverse problem solved by ARP
  - » Given a physical address, get the corresponding IP address
- RARP uses the same message format as ARP
- RARP messages are sent encapsulated in Ethernet frames

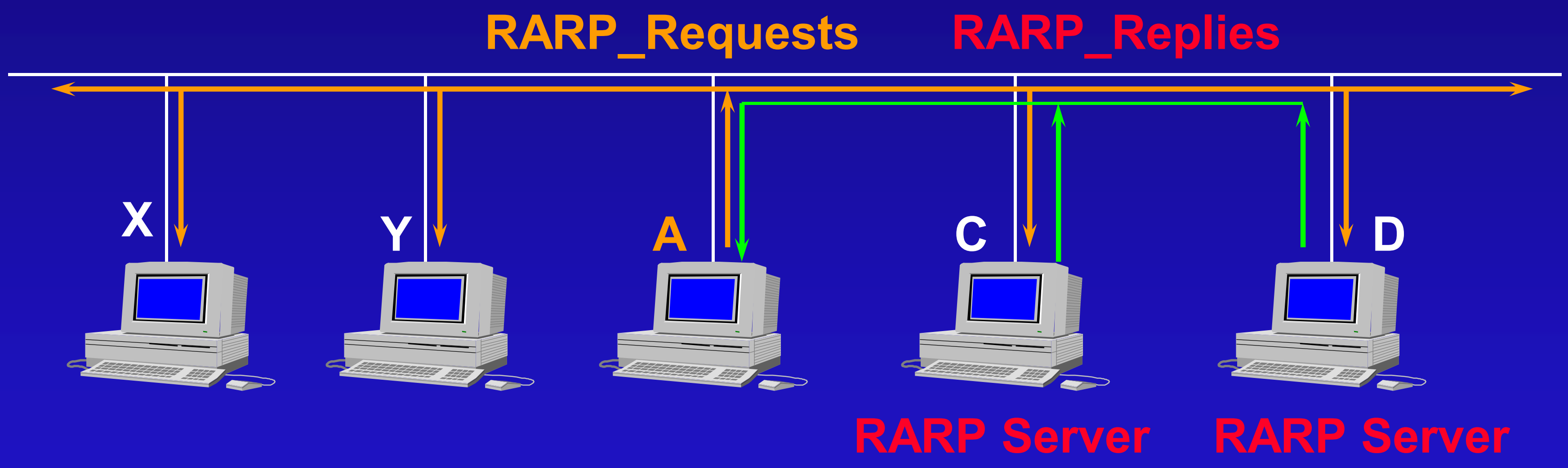
RARP (cont.)

- » The frame type field contains the value &8035 to identify the contents of the frame as a RARP message
- » The data portion of the frame contains the 28-octet RARP message

● RARP allows a host to ask about an arbitrary target

- ï The sender supplies its HA separate from the target HA, and the server is careful to reply to the senderôs HA

RARP (cont.)



Internet Protocol (IP)

- Connectionless Protocol
  - » does **not** exchange control information to establish end-to-end connection before exchanging data
  - » no **handshaking**
  - » contrast with connection-oriented protocols
- IP relies on protocols in other layers to establish a connection if they require connection oriented service
- IP is an **unreliable** protocol
  - » no error detection and recovery code
  - » protocols in other layers provide this checking when required

Routing Datagrams

- Header contains destination address
  - » 32 bit IP address identifies destination network and specific host on it
  - » If destination addr is that of a host on the local network
    - ï packet is delivered directly
  - » If destination addr is not on the local network
    - ï packet is passed to a gateway for delivery
- Gateways are devices that switch packets between the different physical networks
  - » IP makes the **routing** decision for each packet

Routing Datagrams

- Internet gateways are called IP routers
- Two types of network devices
  - » Hosts
  - » Gateways
- Multi-homed hosts act as gateways
- Hosts (end-systems) process packets through all four TCP/IP protocol layers
- Gateways (intermediate systems) process the packets only up to the Internet layer where routing decisions are made
- Routing is done at IP level
  - » a datagram may travel through several different types of physical networks

Fragmenting Datagrams

- Each network type has an **MTU**
  - » Maximum Transmission Unit
  - » largest packet that network can transfer
- If gateway connects dissimilar networks
  - » MTU may be different
  - » if datagram recvôd from one network is longer than other networkôs MTU divide datagram into smaller fragments for transmission
    - ï **fragmentation**
- Re-assembly of datagram occurs at internet layer of final destination
- Information about fragmentation is kept in the datagram header

Passing Datagrams Up

- If datagram is for local host
  - » IP strips header and passes data portion to the correct Transport Layer protocol
- Which protocol to pass up to?
  - » each Transport Layer protocol has a unique protocol number
  - » Information is kept in Protocol field of datagram header

Delivering the Data

- To deliver data
  - » get it to correct host
  - » within the host get it to the correct user or application
- Addressing
  - » IP addresses uniquely identify each host
- Routing
  - » Gateways deliver data to correct network
- Multiplexing
  - » Protocol and port numbers deliver data to correct software module within the host

Internet Routing Architecture

- Core Gateways
  - » backbone of the Internet
  - » Exchange routing information using GGP
    - ï Gateway to Gateway Protocol
- Autonomous Systems
  - » groups of networks outside core
  - » Reachability information using EGP
    - ï Exterior Gateway Protocol
- Routing Domains
  - » Border gateway Protocol (BGP)

Routing

- Both hosts and gateways make routing decisions
- For most hosts
  - » if dest host is on local network
    - ï direct delivery
  - » if dest host is on a remote network
    - ï forward to local gateway
- Routing is network oriented
  - » IP computes network portion of IP address
  - » Network is looked up in local routing table

Routing Tables

- Pairs of Destination & Gateway
  - » Specify gateways for particular destination networks
  - » e.g. for net 196.1.67 use gateway 196.1.65.250
- Default Route
  - » default gateway
- Loopback route for local host
- All gateways in routing table are on networks directly connected to local system
- Routing table does not contain end-to-end routes it only points to the next hop

ICMP

- Internet Control Message Protocol
  - » part of Internet Layer
- Flow Control
- Detecting unreachable destinations
- Redirecting routes
- Checking remote hosts

Transport Layer

Between Application and Internet Layers

Two important protocols :

- Transmission Control Protocol (TCP)
  - » provides reliable data delivery service with end-to-end error detection and correction
- User Datagram Protocol (UDP)
  - » provides low-overhead connectionless datagram delivery service

Application programs can choose appropriate service

ser Datagram Protocol (UDP)

- Gives application programs direct access to a datagram delivery service
- Unreliable, connectionless protocol
- UDP uses 16-bit port number to deliver data to the correct application process
  - » Source Port
  - » Destination Port

UDP

- Why use UDP?
  - » low overhead
  - » if amount of data is small
  - » query-response model
  - » application provides own technique for reliable data delivery

Transmission Control Protocol (TCP)

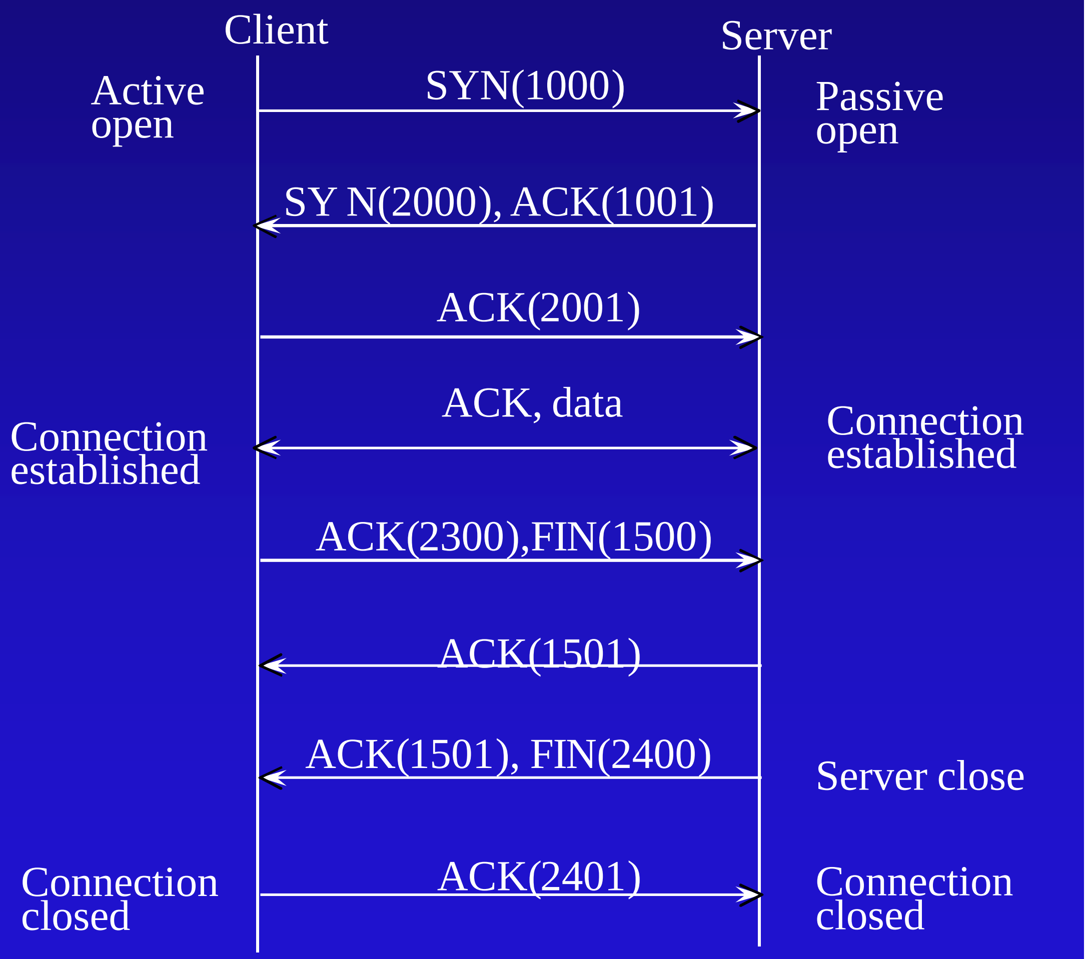
- TCP verifies data is delivered accurately and in sequence
- TCP is a reliable, connection-oriented, byte-stream protocol

TCP’s Virtual Circuit

- Uses a sliding window protocol
- Reliability
  - » positive acknowledgment with re-transmission (PAR)
  - » each TCP segment has checksum
  - » if received undamaged, receiver sends positive acknowledgment
  - » after appropriate time-out sender will re-transmit packets for which no positive ack has been received

CP Connection Estab. and Term.

- Connection-Oriented
  - » TCP establishes logical end-to-end connection between two hosts
- 3-way handshake
- At end of xfer another 3-way handshake
  - » FIN (no more data)



Client

Server

Active open

SYN(1000)

Passive open

SY N(2000), ACK(1001)

ACK(2001)

ACK, data

Connection established

Connection established

ACK(2300),FIN(1500)

ACK(1501)

ACK(1501), FIN(2400)

Server close

Connection closed

ACK(2401)

Connection closed

TCP : Data Flow

- TCP views data as a stream of bytes, not as independent packets
  - » maintains sequence of bytes
  - » Sequence Number and Acknowledgment Number fields in TCP header keep track of bytes
- Acknowledgment Segment
  - » positive acknowledgment - tells sender how much data has been recvôd
  - » flow control - **window** field tells sender how much more data the remote end is willing to accept
    - ï sliding window
- TCP xfers data to correct application
  - » uses port numbers

TCP Segment

<table>
<tr><th>0</th><th colspan="2">8</th><th>16</th><th>31</th></tr>
<tr><td colspan="3">SOURCE PORT</td><td colspan="2">DESTINATION PORT</td></tr>
<tr><td colspan="5">SEQUENCE NUMBER</td></tr>
<tr><td colspan="5">ACKNOWLEDGMENT NUMBER</td></tr>
<tr><td>OFF.</td><td>RES.</td><td>CODE</td><td colspan="2">WINDOW</td></tr>
<tr><td colspan="3">CHECKSUM</td><td colspan="2">URGENT POINTER</td></tr>
<tr><td colspan="4">OPTIONS</td><td>PADDING</td></tr>
<tr><td colspan="5">DATA</td></tr>
<tr><td colspan="5">* * *</td></tr>
</table>

Client Server Model

- Client-Server paradigm is the primary pattern of interactions among cooperating applications.
- This model constitutes the foundation on which distributed algorithms are built.

Client Server Model (cont.)

- Server: Any program that offers a service reachable over the network
  - If a machineôs primary purpose is to support a particular server program, the term server is usually applied to both, the machine and the server program
- Client: An executing program becomes a client when it sends a request to a server and waits for a response

Client Server Model (cont.)

- Servers accept requests arriving over the network, perform the requested services, and return the results to the requesters
- Simplest service
  - » Request arrives in a single IP datagram
  - » Server responds in another IP datagram

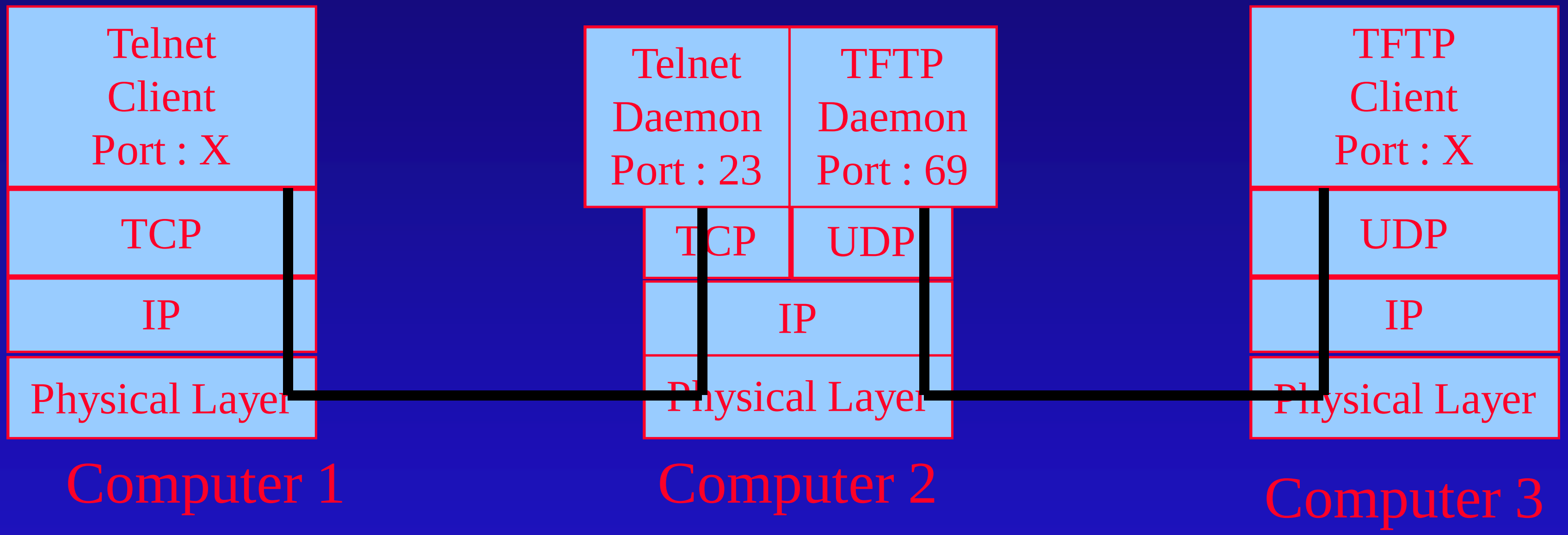
Multiplexing

- Data on destination must be delivered to the correct user or process or server
- Data moves up and down TCP/IP layers
  - » mechanism to deliver it to correct protocols in each layer
- Multiplexing
  - » System combines data from several applications into a few transport protocols
- Data arriving from network must be **demultiplexed**
  - » TCP/IP uses protocol numbers and port numbers for this

Demultiplexing

- Protocol Numbers
  - » byte in datagram header
  - » when datagram arrives at dest., IP layer has to forward it to one of the transport protocols above it
  - » decided using datagramâs protocol number
    - ï e.g. 6 (TCP), 17 (UDP)
- Port Numbers
  - » helps transport protocol determine which application layer protocol to forward data to
  - » Source and Destination Port Numbers
  - » Defined numbers for well-known services
  - » Dynamically assigned ports

Multiplexing and Demultiplexing



- TCP : Connection oriented service

A connection is defined by the four tuple:

(Src IP Addr, Src Port #) (Dest IP Addr, Dest Port #)

- UDP : Datagram service

Name Service Concepts

- A name defines what we seek
- An address indicates where it is
- A route indicates how to get there

Names & Addresses

- Names are there because they are easier for humans to remember
  - » telnet ccse   OR   telnet 196.1.64.1
- Hostname can be assigned to any device that has an IP address
- Underlying software uses IP addresses
- Conversion from name to IP address
  - » Host Table
  - » Domain Name System (DNS)

Host Table

- Simple text file that associates IP addresses with host names
  - » aliases of names can also be given
- Commonly used in LANs
- Major Problems with this approach in a huge Internet
  - » Large size
    - ï inefficient lookup
  - » Frequency of updates
    - ï no technique for automatically distributing information about newly registered hosts

Domain Name System

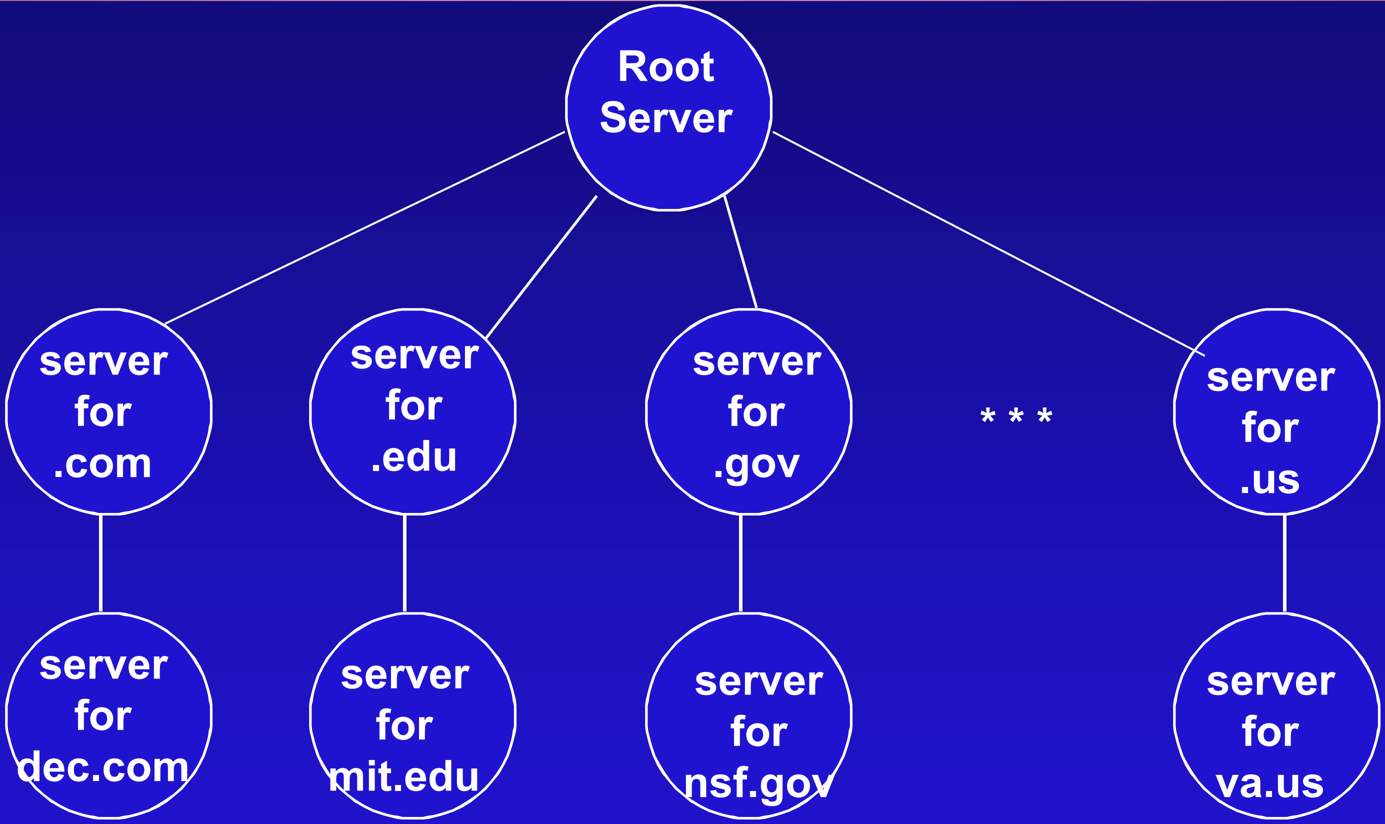
- Designed to overcome both major weaknesses of host table approach
- DNS scales well
  - » No single large table
  - » Distributed database system
- DNS guarantees that new host information will be disseminated to the rest of the network as needed
  - » actually it is only sent to those who are interested

Domain Hierarchy

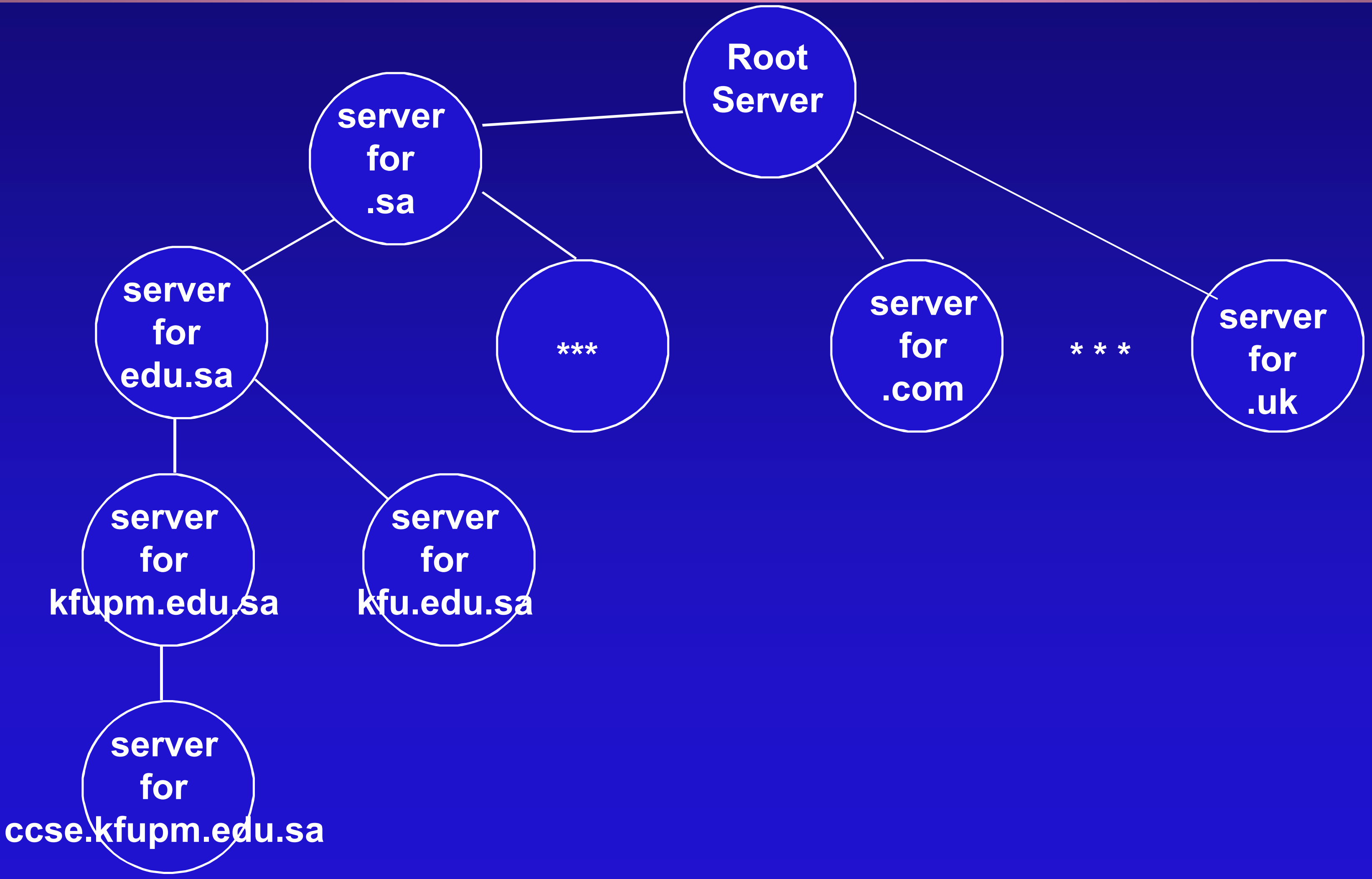
- DNS has no central database with all host information
- Thousands of name servers organized in an hierarchy
- Root Domain
  - Root Servers
- Top Level Domains
  - Organizational
  - Geographic

com	Commercial
edu	Educational
gov	Governmental
mil	Military
org	Other Organizations
XX	two letter country code e.g. sa for Saudi Arabia

DNS Hierarchy



DNS Resolution



Domain Names

- Domains and Subdomains
  - » once domain is registered in parent domain, decision to create sub-domains is decentralized
- Domain names reflect the domain hierarchy
  - » most specific to least specific
    - ï razi.kfupm.edu.sa
    - ï hpkhan.fc.hp.com
    - ï nic.ddn.mil
- Name Lookup
  - » recursive query
  - » non-recursive query

Application Level Protocols

Internet services are provided through application level programs

- ***Telnet*** is a terminal emulation application program.
  - » Allows a user to remote-login on to another computer.
- ***FTP*** is the major TCP/IP file transfer protocol
  - » A facility to access files on remote machines
  - » File transfer is among the most frequently used TCP/IP applications
  - » Anonymous downloading of files.

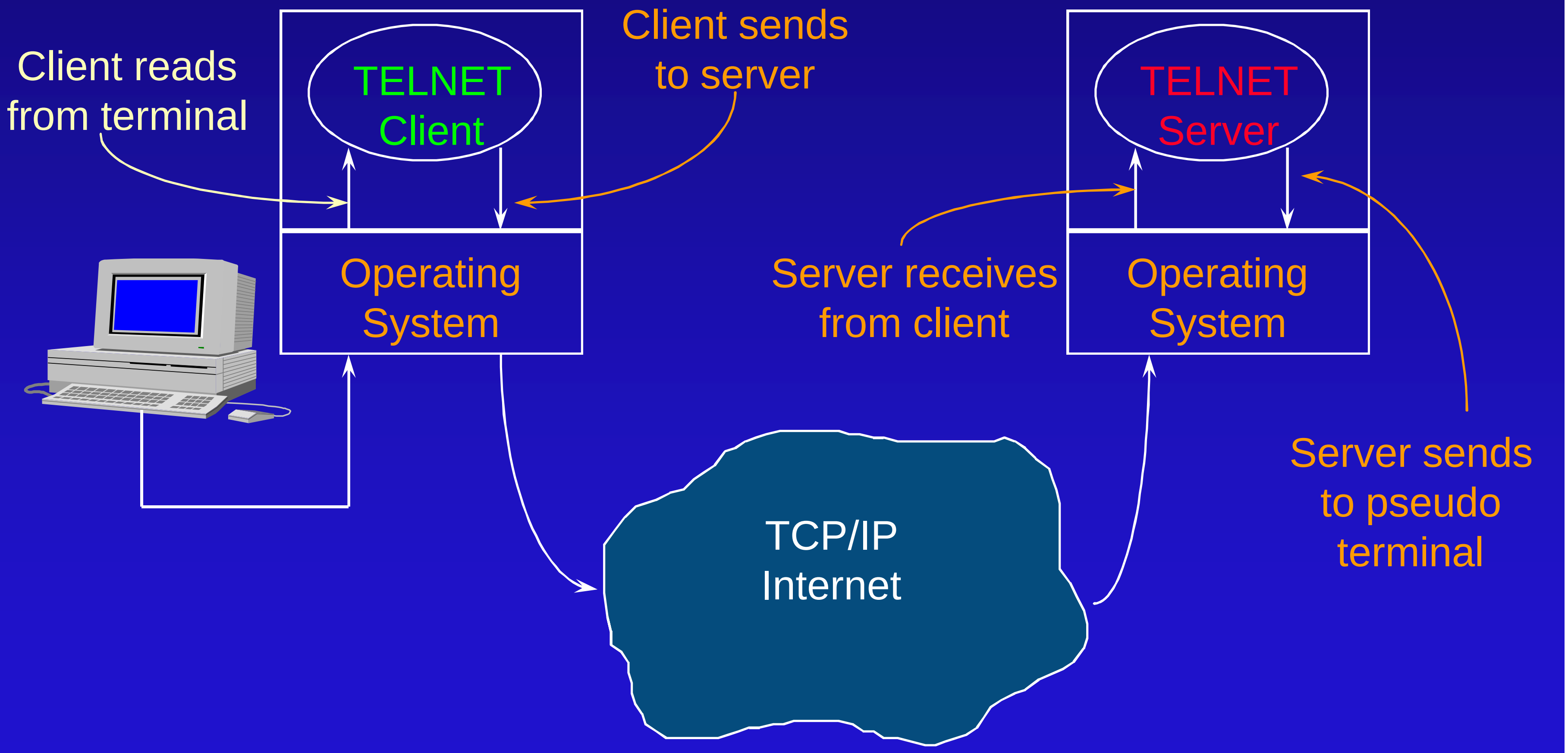
TELNET (cont.)

- **TELNET**
  - » Allows a user at one site to establish a TCP connection to a login server at another
    - TELNET client software allows the user to specify a remote machine by giving its domain name or IP address
  - » Passes keystrokes from the user terminal (client site) to the remote machine (server)
  - » Carries output from the remote machine back to the userôs terminal

TELNET (cont.)

- TELNET offers three basic services
  - » It defines a Network Virtual Terminal (NVT) that provides a standard interface to remote systems
  - » It includes a mechanism that allows the client and server to negotiate options, and it provides a set of standard options
  - » It treats both ends symmetrically (either end can negotiate options)

TELNET (cont.)


Client reads from terminal
TELNET Client
Client sends to server
TELNET Server
Operating System
Server receives from client
Operating System
TCP/IP Internet
Server sends to pseudo terminal

File Transfer Protocol

- Clients use TCP to connect to the server
- FTP uses two different connections for file transfer. One for data and one for control information

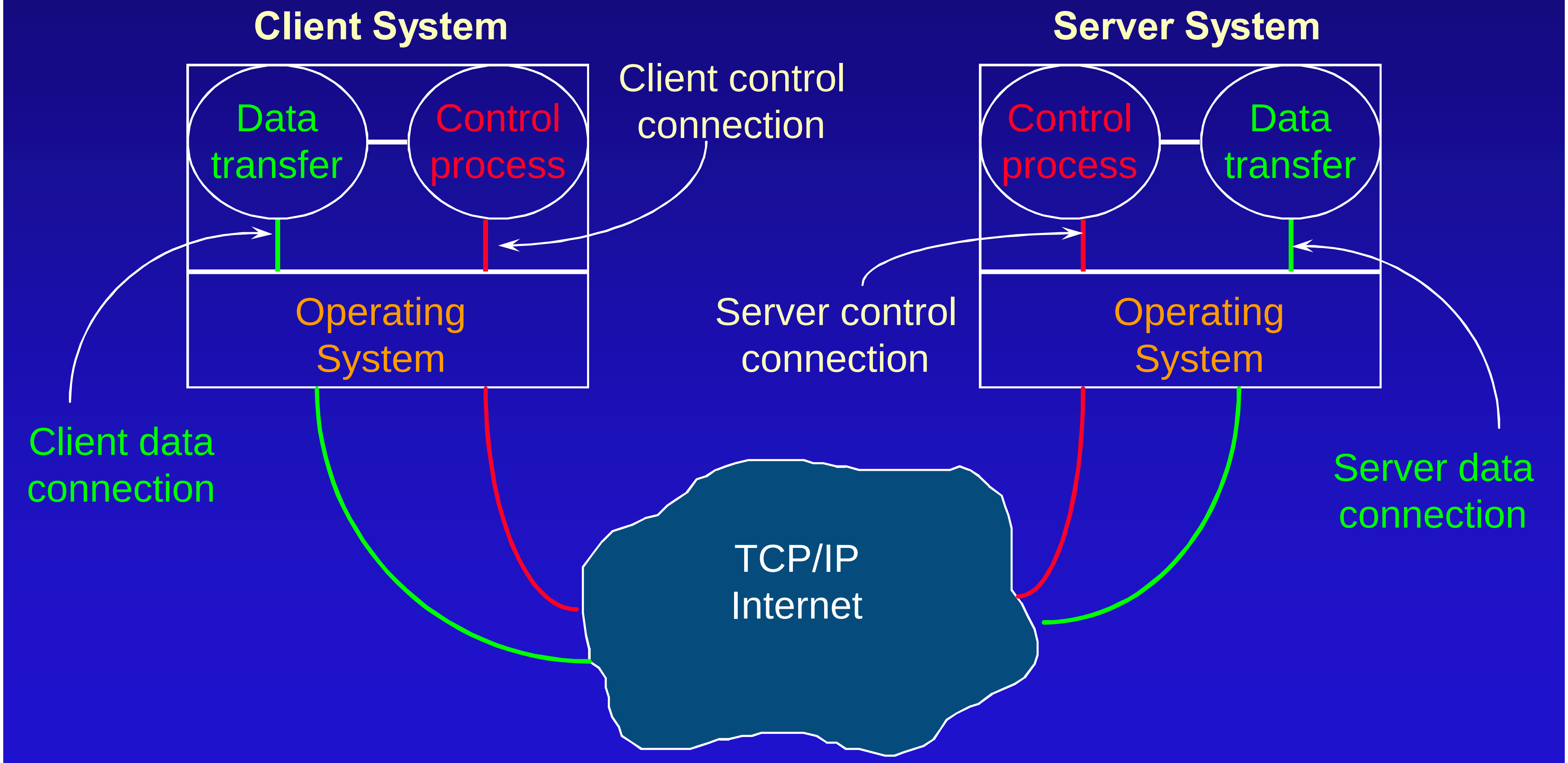
  ï Control connection carries commands telling the server which file to transfer

  ï Data transfer connection carries data transfers
- A single master server process awaits connections and creates a slave process to handle each connection

File Access Model

- Control connection is used to
  - » pass user commands to the server
  - » allow client and server control processes to coordinate their use of dynamically assigned TCP ports and the creation of data transfer processes that use those ports
- The format used by FTP for passing data across the control connection is the NVT format

File Access Model (cont.)



File Access Model (cont.)

- Data transfer connections and the data transfer processes that use them are created dynamically, but the control connection persists throughout a session
- Once the control connection disappears, the session is terminated, and software at both ends terminates all data transfer processes

Email

- Email is the first encounter of users with computer networks
- Millions connected to the Internet use it.
- Low cost and fast communication.
- Encourages collaboration.
- "A person ... can say HELP to 10,000 people ... The next morning he may have 15 answers to his problem."

Email (cont.)

- E-mail is delivered in few minutes.
- E-mail costs half that of regular postal mail (SNAIL MAIL) and ONLY 15% that of Fax.
- In 1992, responsible for 20% of traffic.

Email (cont.)

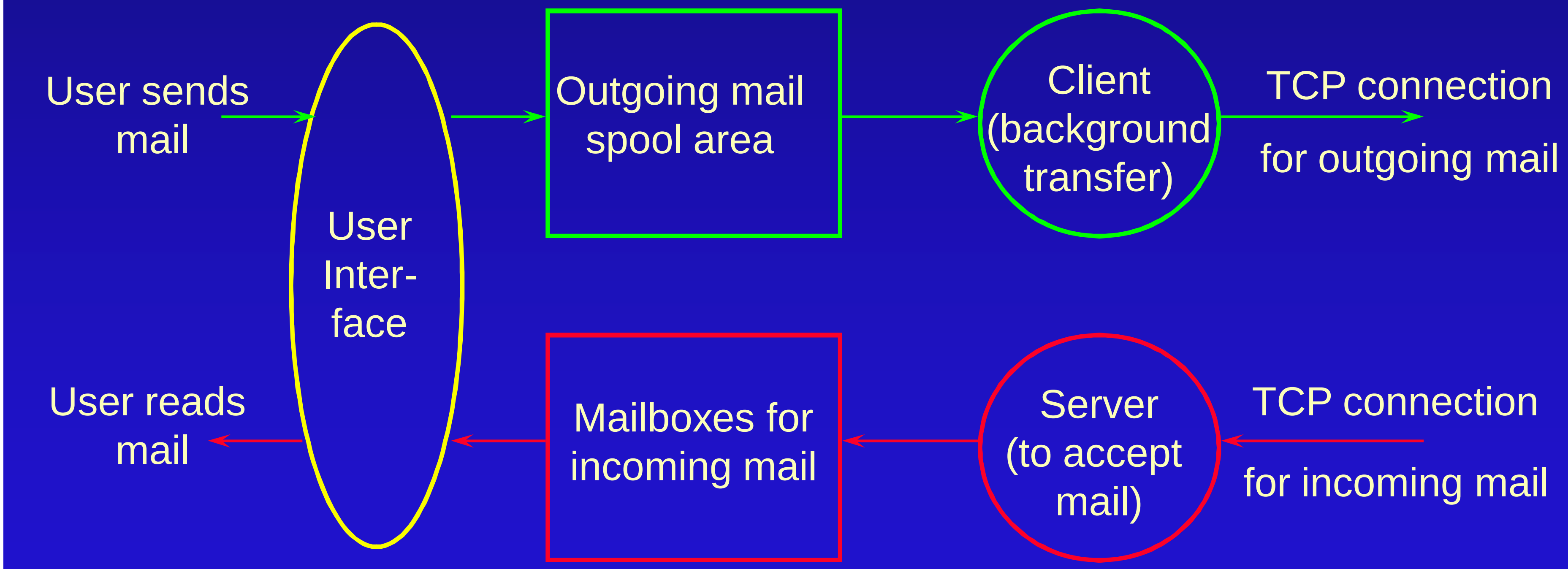
aakhan@ccse.kfupm.edu.sa

aakhan	: User name
@	: Connects the who to where
ccse	: subdomain name
kfupm	: domain
edu	: segment type
sa	: final where segment (sa= Saudi Arabia, tn= Tunisia, ca: Canada)

Email (cont.)

- Mail systems use Spooling technique to handle delayed delivery
  - » When a user sends a message, the system places a copy in its private storage (spool) area along with the identification of sender, recipient, dest machine, and time of deposit
  - » The transfer is initiated in the background, allowing the sender to proceed with other activities

onceptual Components of an Email System


User sends mail
User reads mail
User Inter- face
Outgoing mail spool area
Mailboxes for incoming mail
Client (background transfer)
Server (to accept mail)
TCP connection for outgoing mail
TCP connection for incoming mail

Email concepts (cont.)

- The background mail transfer process becomes a client
  - » It maps the dest machine name to an IP address
  - » It forms a TCP connection to the mail server on dest machine
  - » It passes a copy of the message to the remote server, which stores a copy in the remoteôs system spool area

Email concepts (cont.)

» Once the client and server agree that the copy has been accepted and stored, the client removes the local copy

» If TCP connection fails, the transfer process records the time it tried delivery and terminates

Email concepts (cont.)

» The background transfer process sweeps through the spool area periodically

For each undelivered or new outgoing mail

- ï It attempts delivery again
- ï If a mail message cannot be delivered after an extended time (3 days), it returns the mail message to the sender

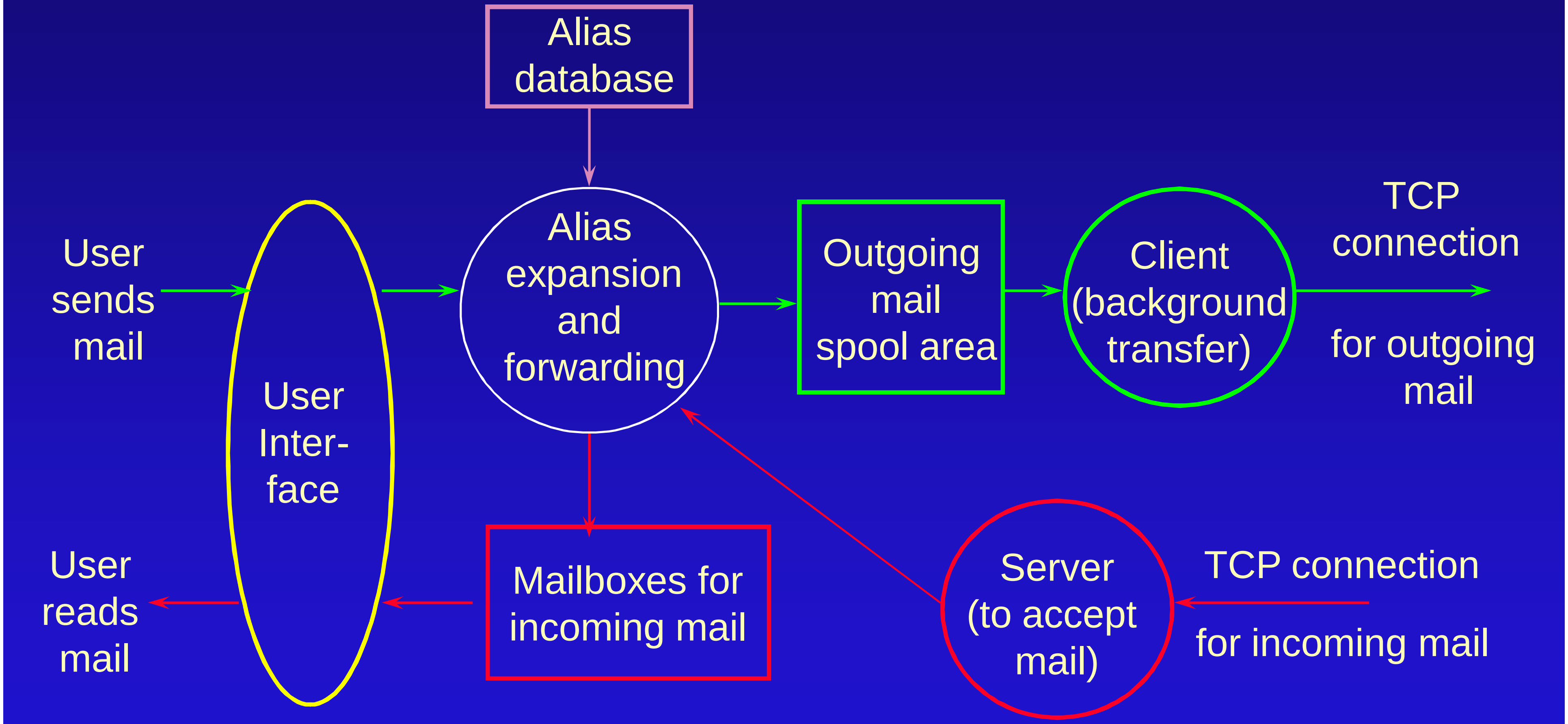
Mailbox names and Aliases

- Users specify
  - » the mail destination machine (usually the machineôs domain name)
  - » a mailbox at that machine (usually the userôs login Id)
- Most systems provide mail forwarding software that includes alias expansion mechanism

ias Expansion and Mail Forwarding

- A mail forwarder allows the local site to map Ids used in mail addresses to a set of one or more new mail addresses
- After a user composes a message and names a recipient
  - the mail interface consults the local aliases to perform necessary mappings before passing the message to the delivery system

onceptual Model of a Mail System



CP/IP Standard for Email Service

- TCP/IP divides its mail standard into two sets
  - » One standard specifies the format for mail messages (RFC 822)
  - » The other specifies the details of electronic mail exchange between two computers
- This division makes it possible to build mail gateways to non TCP/IP networks while still using the same format

Standard Format

- Headers contain readable text, divided into lines that consist of
  - » a keyword
  - » a colon ñò
  - » a value
- Some keywords are required, others are optional, and the rest are un-interpreted

Electronic Mail Addresses

- Email addresses have a simple, easy to remember form

  local-part@domain-name

  domain-name: mail exchanger of the mail destination

  local-part: address of a mailbox on that machine

  aakhan@ccse.kfupm.edu.sa

Protocol (SMTP)

- SMTP is the standard mail transfer protocol of TCP/IP
- SMTP focuses on how the underlying mail delivery system passes messages across a link from one machine to another
- SMTP is simple.

SMTP (cont.)

- Communication between a client and a server consists of readable text
- Initially, the client establishes a reliable stream connection to the server
- It then waits for the server to send the message ñ220 READY FOR MAILò
- Upon receipt of the 220 message, the client sends a ñHELLOò command

(End of line marks the end of a command)

SMTP (cont.)

- The server responds by identifying itself
- Then the sender can transmit one or more mail messages, terminate the connection or request the server to exchange the roles of sender & receiver
- The receiver must ACK each message. It can also abort the entire connection or abort the current message transfer

End of this part