

The Internet

ITS323: Introduction to Data Communications
CSS331: Fundamentals of Data Communications

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Application Layer Protocols

LANs and WANs

LANs

- ▶ Different types: different topologies, different technologies, different purposes
- ▶ Many LANs operate at layers 1 and 2 (Physical and Data Link Layer) using switches and hubs
- ▶ Bridges can connect LANs of similar technologies together

WANs

- ▶ Can interconnect LANs over a larger distance
- ▶ Point-to-point link (e.g. ADSL, PDH) or a network (e.g. ATM, SDH, telephone) using packet or circuit switching
- ▶ Device that interconnects the WAN to LAN must support both technologies
- ▶ WANs typically operate at Layers 1 and 2

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Connect Multiple LANs and WANs

- ▶ Organisations have different requirements of their network, and therefore may choose different technologies for their LANs/WANs
- ▶ Aim: allow any computer to communicate with any other computer, independent of what LAN/WAN they are connected to
- ▶ Internetworking involves connecting the many different types of LANs/WANs together to achieve this aim
- ▶ An internetworking protocol supports data delivery across different types of LANs/WANs
- ▶ E.g. the Internet Protocol (IP)

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Internetworking with Routers

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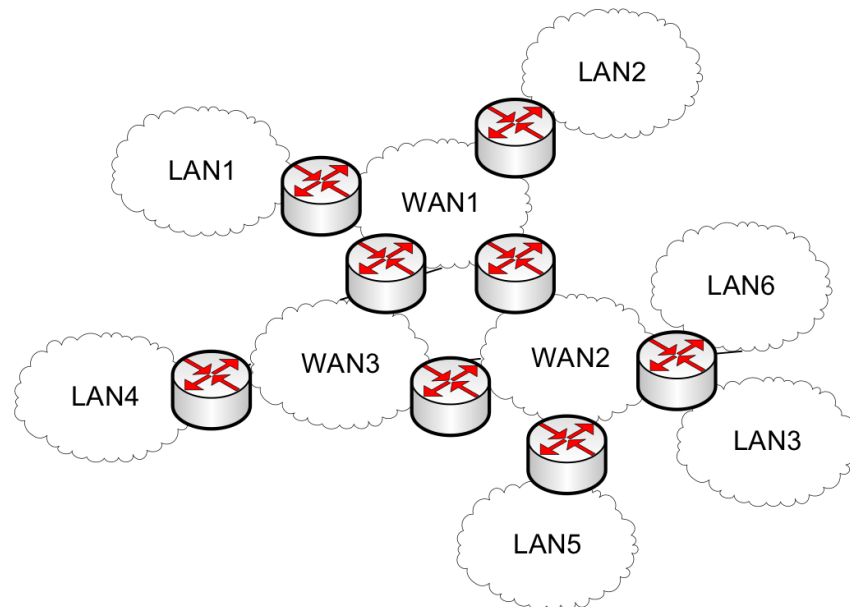
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- ▶ Internetworking is performed using routers
- ▶ Routers connect two or more LANs or WANs together
- ▶ Routers are packet switches that operate at network layer



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The Internet Protocol

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- ▶ IP is the internetworking protocol used in the Internet
- ▶ Implemented in hosts and routers
- ▶ Features:
 - ▶ Datagram packet switching
 - ▶ Network layer
 - ▶ Connection-less
 - ▶ Addressing
 - ▶ Fragmentation-and-reassembly
- ▶ IP version 4 most widely used; IPv6 is available
- ▶ Features IP does NOT provide:
 - ▶ Connection control, error control, flow control (TCP)
 - ▶ Status reporting (ICMP)
 - ▶ Priority, quality of service (DiffServ, IntServ)
 - ▶ Security (IPsec)

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Terminology

- ▶ Routers: nodes that connect networks (LANs/WANs) together; operate at network layer
- ▶ Subnetworks: individual networks (LANs and WANs)
- ▶ Internetworking: connect two or more subnets together using routers
- ▶ An internetwork or an internet: the resulting network from internetworking
- ▶ The Internet: an internet that uses the Internet Protocol (IP) and used today to connect networks across the globe
- ▶ Routing: process of discovering a path from source to destination through a network
- ▶ Forwarding: process of sending data along a path through a network
- ▶ Packet Switch: a generic device that performs switching in a Packet Switching network. May operate at data link or network layer. A packet switch at network layer is called a router
- ▶ Circuit Switch: a generic device that performs circuit switching in a Circuit Switching network
- ▶ Ethernet switch: an IEEE 802.3 switch (either Ethernet, Fast Ethernet or Gigabit Ethernet). Operates at data link layer

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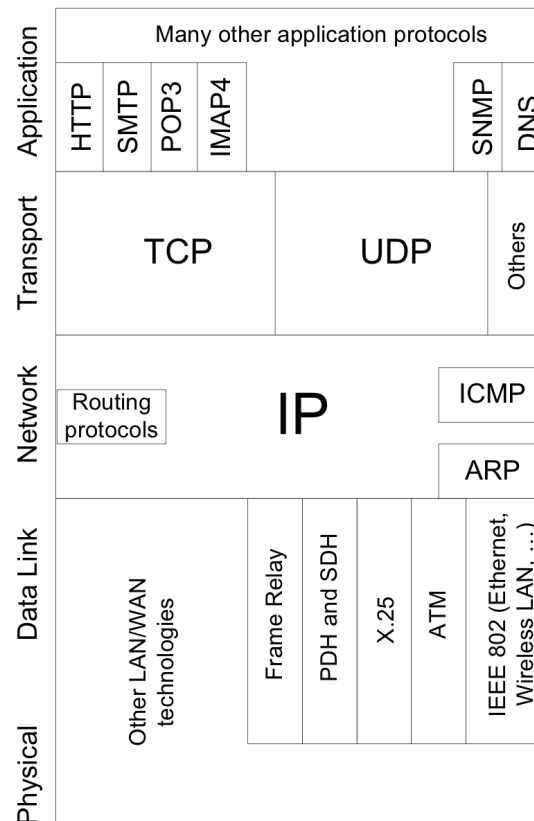
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IP in the TCP/IP Stack

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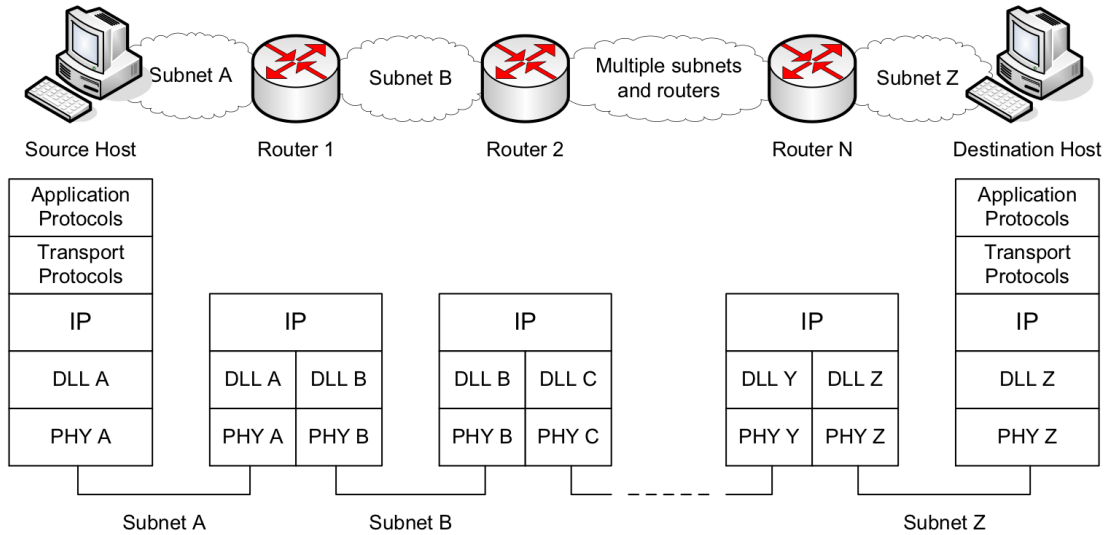
IP Hosts and Routers

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- ▶ Hosts are the end-devices (stations)
 - ▶ Usually only use single network interface at a time
 - ▶ Hosts do not forward IP datagrams
 - ▶ Either source or destination
- ▶ Routers are the datagram packet switches
 - ▶ Routers have two or more interfaces (since they connect LANs/WANs together)
 - ▶ Routers forward datagrams
 - ▶ Routers can act as a source or destination of datagrams (however this is mainly for management purposes)
- ▶ IP routing is the process of discovering the best path between source and destination; store destination and next router in routing table
 - ▶ E.g. RIP, EIGRP, OSPF, BGP
- ▶ IP forwarding is the process of delivering an IP datagram from source to destination; read next router from routing table

IP Hosts and Routers

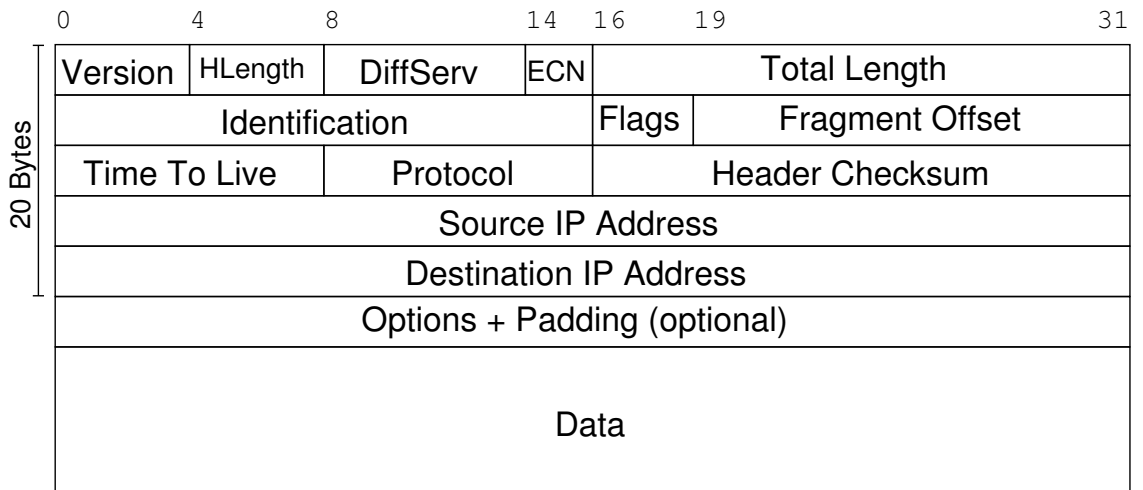
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IP Datagram

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- ▶ Variable length header and variable length data
- ▶ Header: 20 Bytes of required fields; optional fields may bring header size to 60 Bytes
- ▶ Data: length must be integer multiple of 8 bits; maximum size of header + data is 65,656 Bytes



IP Datagram Fields

- ▶ Version [4 bits]: version number of IP; current value is 4 (IPv4)
- ▶ Header Length [4 bits]: length of header, measured in 4 byte words
- ▶ DiffServ [6 bits]: Used for quality of service control
- ▶ ECN [2 bits]: Used for notifying nodes about congestion
- ▶ Total Length [16 bits]: total length of the datagram, including header, measured in bytes
- ▶ Identification: sequence number for datagram
- ▶ Flags: 2 bits are used for Fragmentation and Re-assembly, the third bit is not used
- ▶ Fragment Offset [13 bits]: See Fragmentation and Re-assembly
- ▶ Time To Live [8 bits]: datagram lifetime
- ▶ Protocol [8 bits]: indicates the next higher layer protocol
- ▶ Header Checksum [16 bits]: error-detecting code applied to header only; recomputed at each router
- ▶ Source Address [32 bits]: IP address of source host
- ▶ Destination Address [32 bits]: IP address of destination host
- ▶ Options: variable length fields to include options
- ▶ Padding: used to ensure datagram is multiple of 4 bytes in length
- ▶ Data: variable length of the data

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IP Routing and Forwarding

Routing Tables

- ▶ Store address of destination and next node
- ▶ Created manually or by routing protocols

Routing Protocols in the Internet

- ▶ Collect network status information, calculate least cost paths and update routing tables
- ▶ Adaptive routing protocols: OSPF, RIP, EIGRP, BGP

Forwarding

- ▶ Routers forward IP datagrams from source host to destination host
- ▶ Destination host address in IP datagram header
- ▶ Lookup destination address in routing table

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Other Features

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- ▶ IP includes:
 - ▶ Fragmentation and reassembly: source host and routers may divide datagrams into smaller fragments; destination host reassembles fragments into full datagram
 - ▶ Time To Live (TTL): source sends “lifetime” of datagram in header; decremented by each router; if 0, datagram is discarded
- ▶ Other network layer features:
 - ▶ ICMP: error reporting, ping
 - ▶ ARP: map IP addresses to Ethernet addresses
 - ▶ IPv6
 - ▶ Multicasting
 - ▶ Quality of Service (DiffServ)
 - ▶ Mobility (Mobile IP)
 - ▶ Security (IPsec)

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- ▶ IPv4 addresses are 32 bits in length
- ▶ Split into network portion and host portion: first N bits identify a subnet in the Internet; last H bits identify an IP device (host/router) in that subnet
- ▶ All subnets in the Internet have unique network portion
- ▶ All IP devices in a subnet have same network portion, but unique host portions
- ▶ Where/how to split has changed over time: Classful, Subnet addressing, Classless addressing
- ▶ Focus on classless addressing
- ▶ Why split? Allows hierarchical addressing, makes routing in Internet scalable

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Representing IPv4 Addresses

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- ▶ Writing and remembering 32 bits is difficult for humans
- ▶ IP addresses usually written in dotted decimal notation
- ▶ Decimal number represents the bytes of the 32 bit address
- ▶ Decimal numbers are separated by dots

IP: 11000000111001000001000100111001

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Classless IP Addressing

- ▶ Subnet mask or address mask identifies where the IP address is split between network and host portion
- ▶ Mask is 32 bits: a bit 1 indicates the corresponding bit in the IP address is the network portion; a bit 0 indicates the corresponding bit in the IP address is the host portion
- ▶ The mask can be given in dotted decimal form or a shortened form, which counts the number of bit 1's from left

IP: 10000010000100010010100110000001

Mask: 1111111111111111111111110000000000

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Special Case IP Addresses

Selected IP addresses are used for special purposes; they cannot be used to identify a host

Network Address identifies a subnet in the internet; all bits in host portion are 0

Directed Broadcast Address identifies all hosts on a specific subnet; all bits in host portion are 1

Local Broadcast Address identifies all hosts on the current subnet; all bits are 1

Loopback Address identifies current host; first 8 bits are 01111111; also called localhost

Startup Source Address identifies host if currently it has no address; all bits are 0

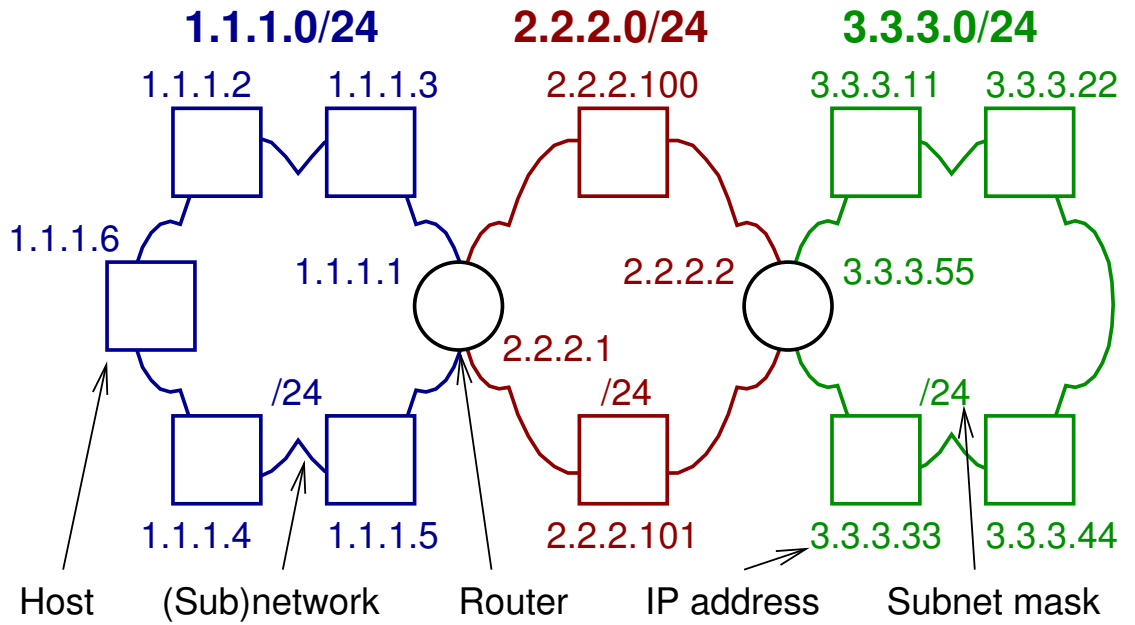
Selected addresses reserved for private networks (e.g. not connected to Internet; behind NAT)

- ▶ 10.0.0.0—10.255.255.255
- ▶ 172.16.0.0—172.31.255.255
- ▶ 192.168.0.0—192.168.255.255

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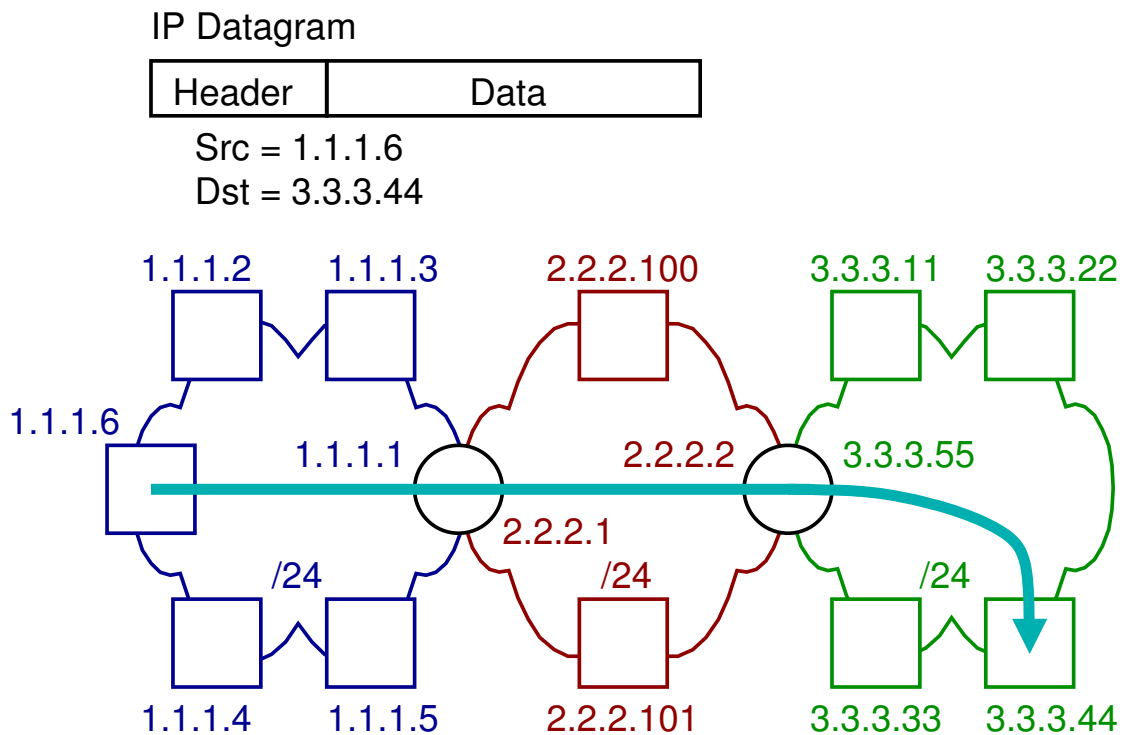
Example of IP Addressing

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Example of Unicast

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Example of Directed Broadcast

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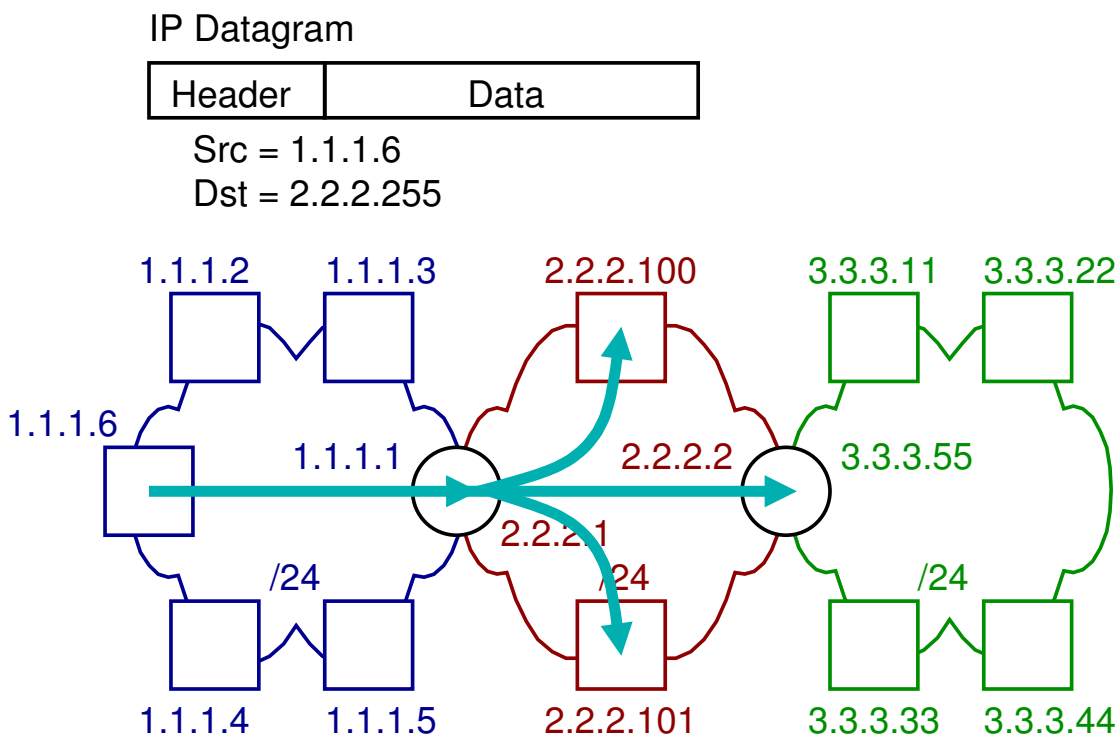
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Example of Startup Source and Local Broadcast

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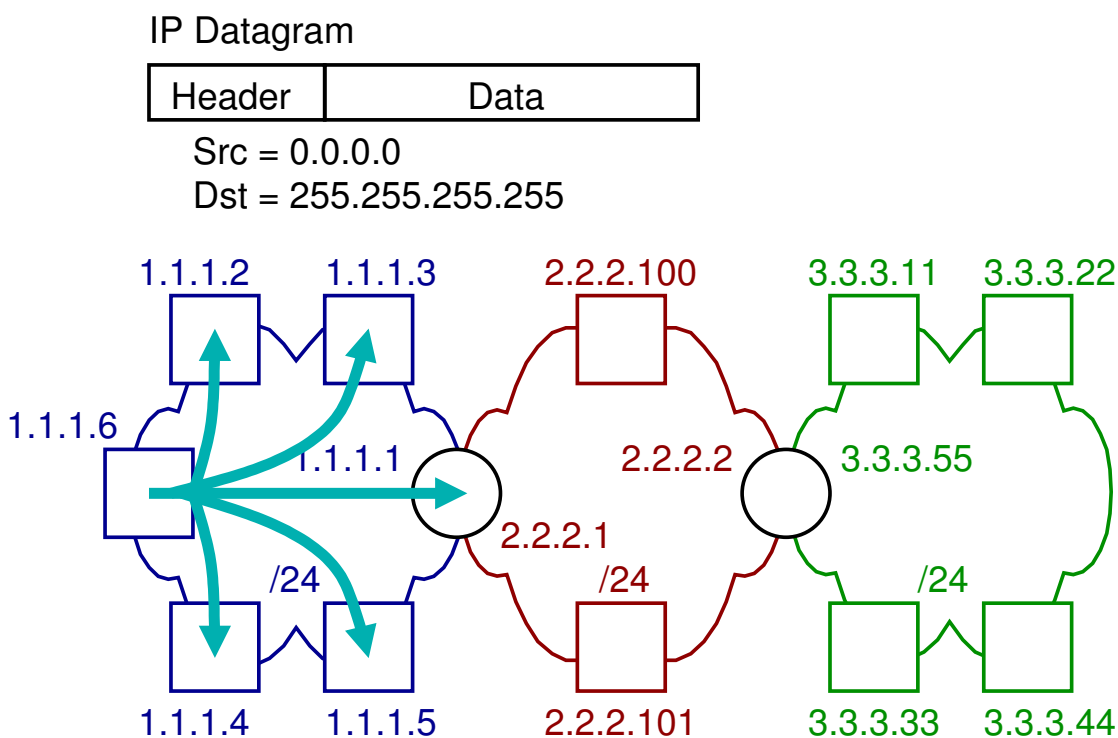
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Example of Loopback Address

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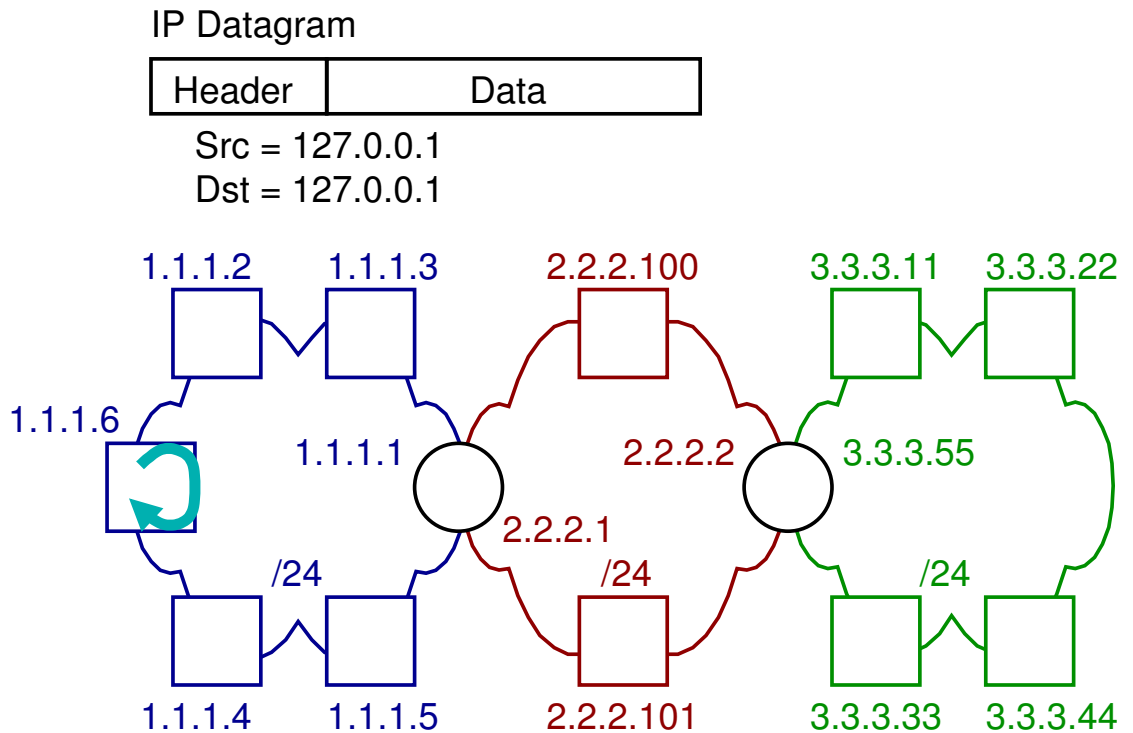
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IP Addressing Example

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My office computer has address 104.209.61.169/18. What is the network address and directed broadcast address for my network? How many IP devices can be attached to my network?

Obtaining an IP Address

- ▶ Internet Assigned Numbers Authority (IANA) manages the assignment of IP addresses
- ▶ IANA delegates IP network ranges to regional authorities (e.g. APNIC), delegated further to national registries (e.g. THNIC)
- ▶ Organisations obtain network addresses from national/local registries
- ▶ Organisations are free to assign addresses as they wish from assigned network address
 - ▶ Manually set IP address on each computer
 - ▶ Protocol to automatically configure IP addresses in computers on network: Dynamic Host Configuration Protocol

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- ▶ Most Internet applications follow a client/server model of initiating communication:
 1. Server waits for client to initiate communication
 2. Client initiates communication
 3. Once the communication is initiated, data can flow in both directions (client to server and server to client)
- ▶ Examples:
 - ▶ Web browser (Firefox, Safari) and web server (Apache, IIS)
 - ▶ Email client (Thunderbird, Outlook) and email server (MS Exchange, Postfix)
 - ▶ Instant messaging client and server (LINE, MSN, TextSecure)
 - ▶ Bittorrent (uTorrent, Transmission) and tracker (Opentracker, VUZE)

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Issues with Client/Server Applications

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- ▶ How to make it easy for programmers to create applications without knowing details of communications?
 - ▶ Transport protocols implement features common to many apps, e.g. TCP, UDP
- ▶ How to allow applications implemented in different languages/OS by different people to communicate?
 - ▶ Application layer protocols, e.g. HTTP, SMTP, FTP
 - ▶ Use a common API: Sockets
- ▶ How to identify different applications on same computer?
 - ▶ Addresses to identify applications: Ports

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Transport Protocols

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- ▶ Send data between application processes on source and destination hosts
- ▶ End-to-end (or host-to-host) communications
- ▶ Transmission Control Protocol
 - ▶ Most widely used transport protocol
 - ▶ Connection-oriented, error control, flow control, congestion control
- ▶ Others: User Datagram Protocol (UDP), SCTP, DCCP, old and domain-specific protocols
- ▶ Protocol number: identifies transport protocol used by both hosts
 - ▶ 8-bit number; e.g. 6 = TCP, 17 = UDP; 1 = ICMP
 - ▶ Included in IP header

<http://www.iana.org/assignments/protocol-numbers/>

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How does a client identify a server application?

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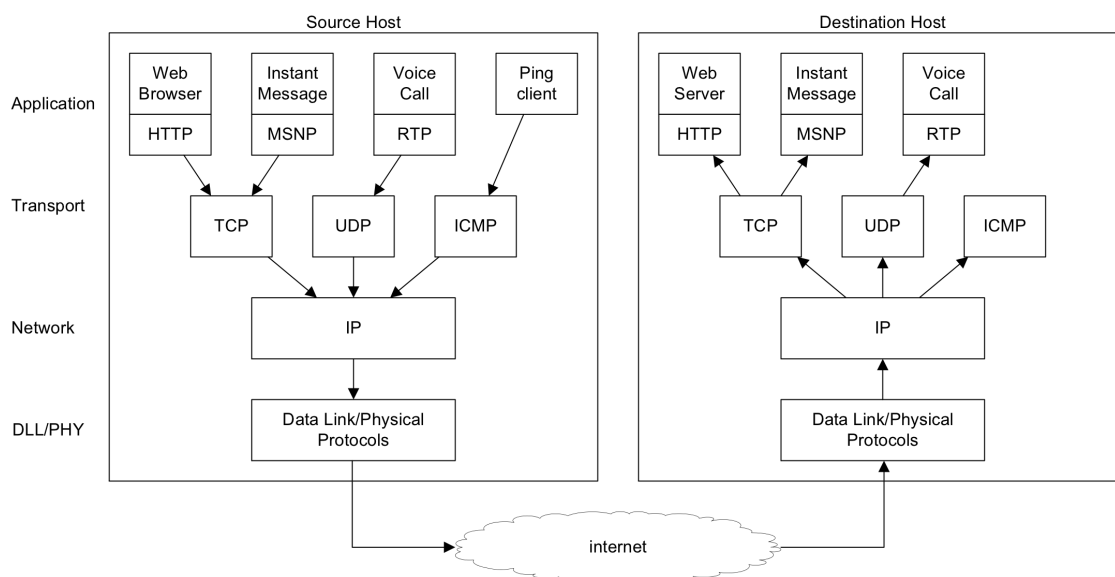
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- ▶ Internet contains multiple hosts
 - ▶ Host (interface) identified by IP address
- ▶ A host may implement multiple transport protocols
 - ▶ Transport protocol identified by protocol number
- ▶ Multiple applications may use same transport protocol
 - ▶ Ports identify application processes on a host
- ▶ Five addresses uniquely identify end-to-end communications
 1. Source IP
 2. Destination IP
 3. Protocol number
 4. Source port
 5. Destination port

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Multiple Applications, Multiple Transport Protocols



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Port Numbers

- ▶ Ports are 16-bit numbers
- ▶ Source port, destination port in transport protocol header
- ▶ On a host, ports are managed by operating system
 - ▶ Unique port assigned to processes for Internet communications
 - ▶ Ports are local to a host
- ▶ Well-known ports: 0–1023
 - ▶ Common servers use well-known ports by default
 - ▶ http = 80, https = 443, ssh = 22, ftp = 20/21, smtp = 25, dns = 53, dhcp = 67, ipp = 631
- ▶ Registered ports: 0–49151
 - ▶ Servers use registered ports by default
 - ▶ openvpn = 1094, mysql = 3306, steam = 27015, ...
- ▶ Dynamic ports: 49152–65535
 - ▶ Clients use dynamic ports, assigned by OS

<http://www.iana.org/assignments/port-numbers/>

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Transmission Control Protocol

- ▶ Most commonly used transport protocol today
 - ▶ Web browsing, email, file sharing, instant messaging, file transfer, database access, proprietary business applications, some multimedia applications (at least for control purposes), . . .
- ▶ Services provided by TCP:
 - ▶ Stream-oriented: TCP treats data from application as continuous stream of bytes, sequence numbers count bytes
 - ▶ Connection-oriented: setup connection before data transfer
 - ▶ Full duplex connection: send data in either direction
 - ▶ Flow and error control: Go-Back-N style
 - ▶ Congestion control: if network congestion, source slows down

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TCP Segment

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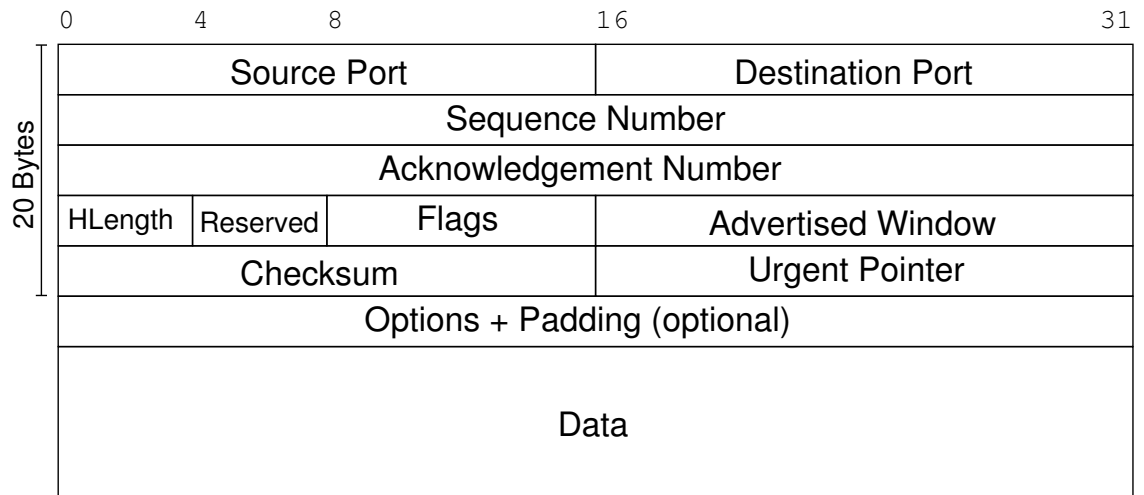
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- ▶ Header contains 20 bytes, plus optional fields
- ▶ Optional fields must be padded out to multiple of 4 bytes

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TCP Segment Fields

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- ▶ Source/Destination port
- ▶ Sequence number of the first data byte in this segment (or ISN)
- ▶ Acknowledgement number: sequence number of the next data byte TCP expects to receive
- ▶ Header Length: Size of header (measured in 4 bytes)
- ▶ Window: number of bytes the receiver is willing to accept (for flow control)
- ▶ Checksum: error detection on TCP segment
- ▶ Urgent pointer points to the sequence number of the last byte of urgent data in the segment
- ▶ Options: such as maximum segment size, window scaling, selective acknowledgement, ...

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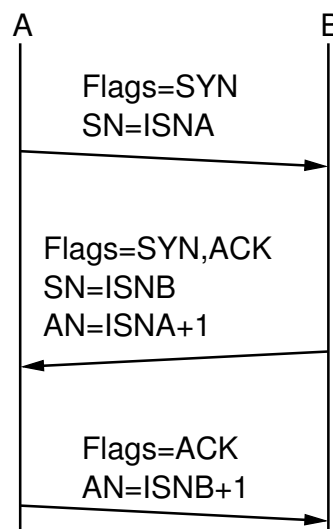
TCP Segment Flags

- ▶ Flags (1 bit each, if 1 the flag is true or on):
- ▶ CWR: Congestion Window Reduced
- ▶ ECE: Explicit Congestion Notification Echo
- ▶ URG: segment carries urgent data, use the urgent pointer field; receiver should notify application program of urgent data as soon as possible
- ▶ ACK: segment carries ACK, use the ACK field
- ▶ PSH: push function
- ▶ RST: reset the connection
- ▶ SYN: synchronise the sequence numbers
- ▶ FIN: no more data from sender

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TCP Connection Establishment: Three-Way Handshake

Agree upon initial sequence numbers, prepare buffer for data



- ▶ Initiator A selects an Initial Sequence Number, *ISNA*
- ▶ B acknowledges *ISNA* and also chooses its own *ISNB*
- ▶ Data transfer can start after *ISNB* is ACKed
- ▶ Optionally, 3rd segment can contain data

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TCP Data Transfer

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- ▶ Segments can contain varying amount of data
- ▶ Set ACK flag to indicate an acknowledgement, piggybacking is common
- ▶ Speed of data transfer depends on:
 - ▶ Flow control: sliding-window
 - ▶ Error control: Go-Back-N style
 - ▶ Congestion control: loss of segments indicates congestion, sender slows down

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- ▶ Many different protocols to support types of applications
 - ▶ HTTP, FTP, SMTP, SSH, Telnet, BitTorrent, SIP, IMAP, RDP, SMB, ...
- ▶ Other protocols to support network operation
 - ▶ DNS, DHCP/BOOTP, NTP, SNMP, ...