Internet and Transport Protocols

CS461: Computer Networks

HiLCoE

School of Computer Science and Technology

Contents

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

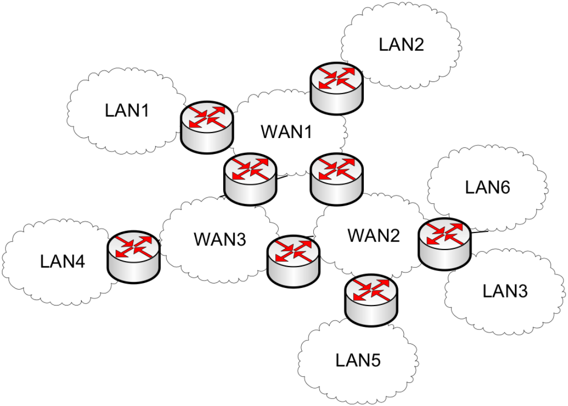
- Can interconnect LANs over a larger distance
- Point-to-point link (e.g. ADSL, PDH) or a network (e.g. ATM, SDH, telephone) using packet or circuit switching
- Device that interconnects the WAN to LAN must support both technologies
- WANs typically operate at Layers 1 and 2

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)

Internetworking with Routers

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



The Internet Protocol

- IP is the internetworking protocol used in the Internet
- Implemented in hosts and routers
- Features:
  - Datagram packet switching
  - Network layer
  - Connnection-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)

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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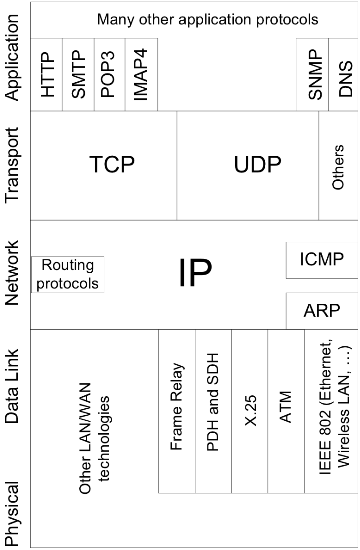
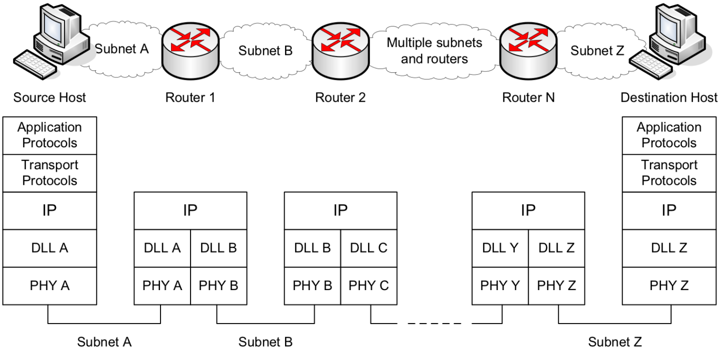
IP in the TCP/IP Stack



IP Hosts and Routers

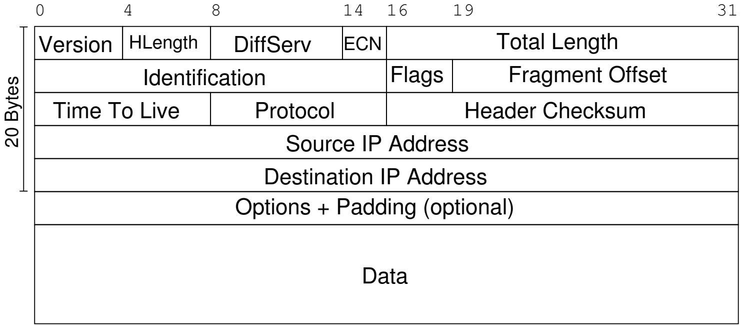
- Hosts are the end-devices (stations)
  - Usually only use single network interface at a time
  - Hosts do not forward IP datagrams
  - Either source or destination
- Routers are the datagram packet switches
  - Routers have two or more interfaces (since they connect LANs/WANs together)
  - Routers 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



IP Datagram

- 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

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

Other Features

- 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 sents "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

- IPv4 addressess 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

Representing IPv4 Addresses

- 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
```

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:   10000010000100010100110000001
Mask: 11111111111111111111100000000000
```

Special Case IP Addresses

Selected IP addressess 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

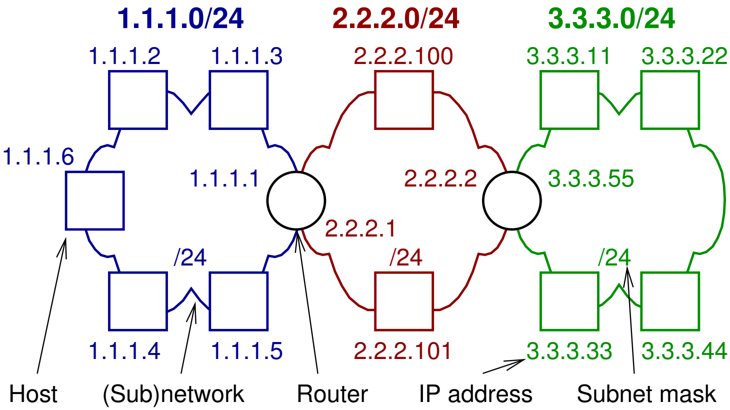
Loopback Address identifies current host; first 8 bits are 01111111; also called localhost

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

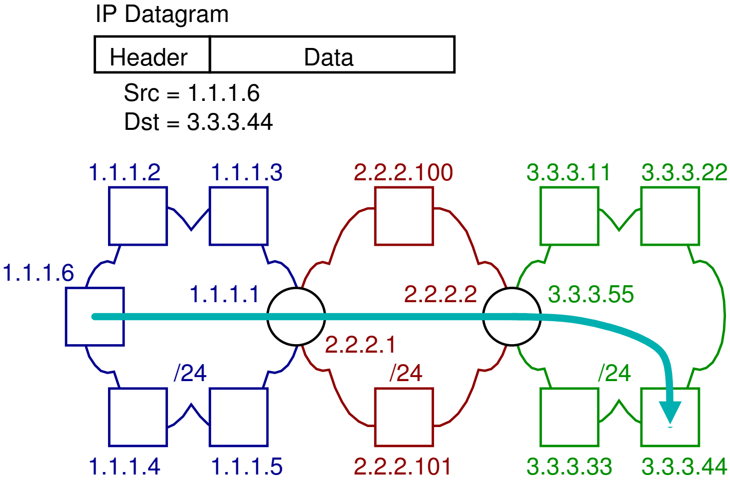
Selected addresses reserved for private networks (e.g. not connected to Internet; behind NAT)

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

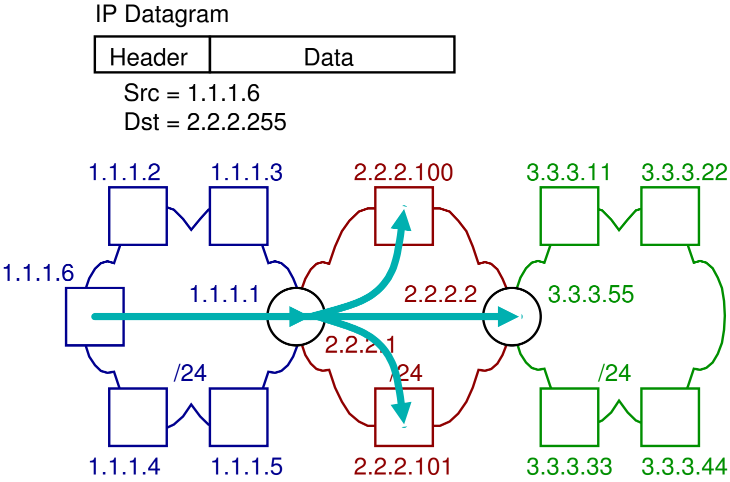
Example of IP Addressing



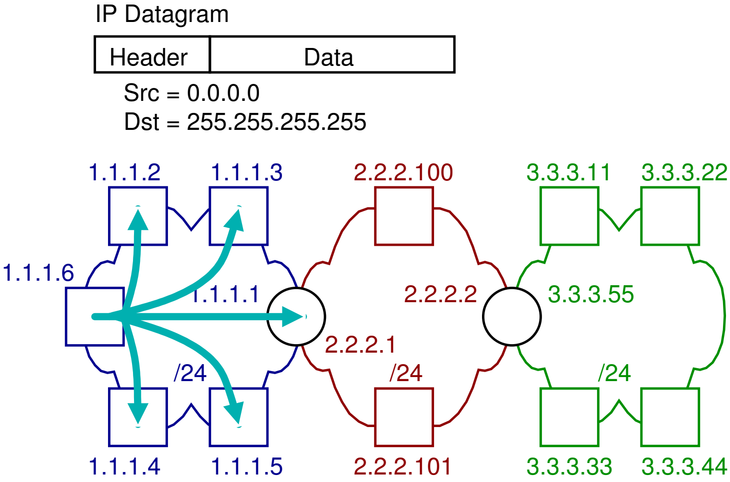
Example of Unicast



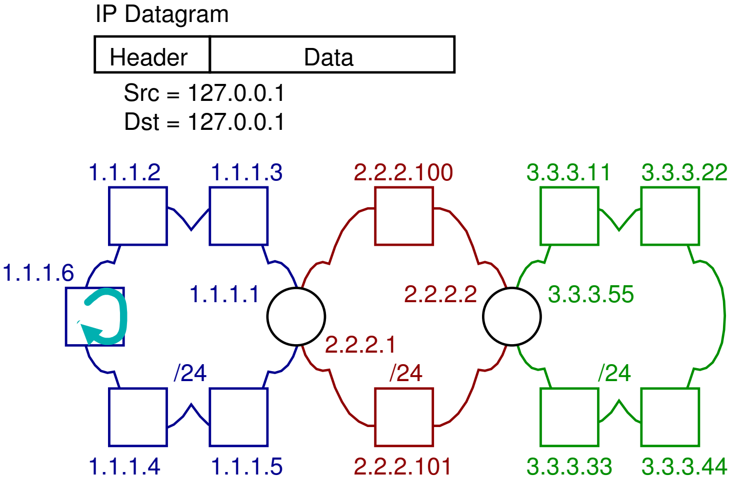
Example of Directed Broadcast



Example of Startup Source and Local Broadcast



Example of Loopback Address



IP Addressing Example

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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Internet Applications

- 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)

Issues with Client/Server Applications

- 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

Transport Protocols

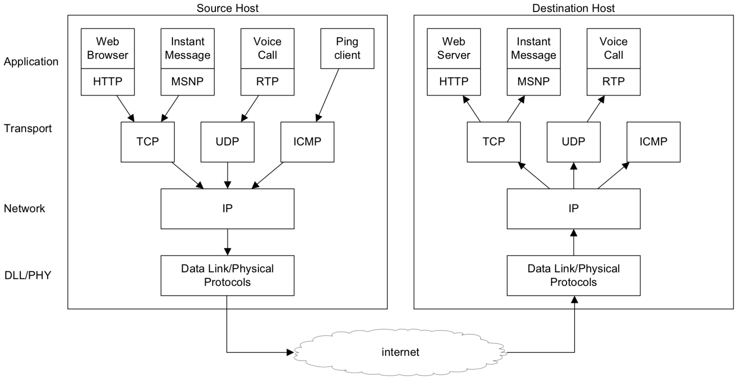
- Send data between application processes on source and destination hosts
- End-to-end (or host-to-host) communications
- Transmission Control Protocol
  - Most widely used transport protocol
  - Connection-oriented, error control, flow control, congestion control
- Others: User Datagram Protocol (UDP), 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/`

How does a client identify a server application?

- 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

Multiple Applications, Multiple Transport Protocols



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
- Registed ports: 0–49151
  - Servers use registed ports by default
  - openvpn = 1094, mysql = 3306, steam = 27015, . . .
- Dynamic ports: 49152–65535
  - Clients use dynamic ports, assigned by OS

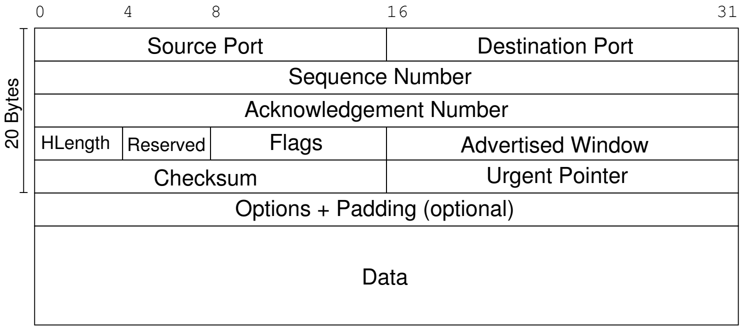
`http://www.iana.org/assignments/port-numbers/`

Contents

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

TCP Segment



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

TCP Segment Fields

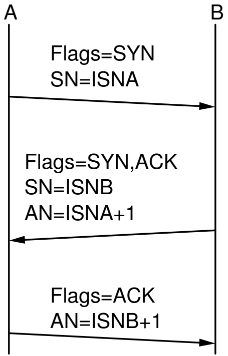
- Source/Destination port
- Sequence number of the first data byte in this segment (or ISN)
- Acknowledgement number: sequence number of the next data byte TCP expects to receive
- Header Length: Size of header (measured in 4 bytes)
- Window: number of bytes the receiver is willing to accept (for flow 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, . . .

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

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 *ISNAB*
- Data transfer can start after *ISNB* is ACKed
- Optionally, 3rd segment can contain data

TCP Data Transfer

- 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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Application Layer Protocols

- 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, . . .