Basic Network Organization

Portions Courtesy Ellen Liu

Outline

- Internet and Internet Standards
- Protocols and Protocol Layering
  - Packet-switching
  - Segment, packet, frame
  - TCP segment header and IP packet header
- Addressing in networks
- The IP protocol

Internet

- Internet started as a research network called ARPANET in 1969. It became commercial in late 1980s.
- Today’s Internet is a collection of networks owned by various levels of ISPs (Internet service providers).
- It has now evolved into a public utility.

A map of the Internet: http://www.opte.org/maps/

Internet Governance

No formal management. Policies established by professional and government organizations:

- **ICANN**: Internet Corporation for Assigned Names and Numbers. Allocation of IP addresses, domain names, protocol port numbers, autonomous system numbers.
- **ISOC**: Internet Society. Overlooking technical development
  - **IETF**: Internet Engineering Task Force. Produces Internet standards
  - **IAB**: Internet Architecture Board. Directly oversees IETF’s work
Internet Standards and Documents
- RFC (request for comment) - a memorandum published by IETF describing methods, behaviors, research, or innovations applicable to the working of the Internet and Internet-connected systems
- There are 6921 RFCs as of today. See the rfc index at http://www.ietf.org/download/rfc-index.txt
- RFCs started as Internet Drafts. Each went through an intensive review process.
- There are many IETF working groups. Each is busy on the Internet drafts under the group charter. Everybody who is interested can join these groups and get involved.

RFCs
- Not all RFCs are standards. RFC status include: proposed standard (STD), informational, experimental, best current practice (BCP), historic, unknown
- Once an RFC is distributed, its contents never change
- Updates can extend, clarify, or supersede old RFCs, are distributed with a new RFC number
- RFC2026 and RFC5540 describe this process

Protocols
- Protocols: define type, format, and order of messages sent and received among network entities, and actions taken on message transmission and receipt, or other events (e.g., timer expires)
- Computers talk to each other in a way that is really not much different from how we humans talk to each other

Protocol Layering
- Network protocols are arranged in a hierarchy or stack, with higher-level ones making use of the ones beneath them
- Five protocol layers in Internet Protocol Stack: Application, Transport, Network, Data Link, Physical layers
- There are other networking protocol stacks. E.g., ISO OSI 7-layer model, ATM, X.25, SNA
  - Not as widely used as Internet Protocol stack

Physical Layer
- Physical layer is the specification of low-level electrical signals (or waves or light beams) used to encode a message
  - Generally encapsulated from the administrator
    - Although there are some limits on signal length over a medium
Packets
- The basic unit of data transmission
- Most media specify a Maximum Transmission Unit (MTU)
  - Packets cannot be larger than the MTU
  - Higher-level protocol messages may have to be split across multiple packets

Internet Protocol Layering
- SSH, FTP, DNS, HTTP, skype...
- TCP, UDP
- IP, ICMP
- ARP, Ethernet, 802.11, ...
- Copper, Fiber optic, radio waves

Data Link Layer
- Software-level abstraction of the physical layer + some higher-level protocols
- Ethernet (most common wired network)
  - Older wired protocols include Token Ring
- Wireless (802.11)
  - 801.11a, b, g, n, etc all specify different radio wave specifications

Packet Switching
- Packets: method of slicing digital messages into parcels. Each packet contains a header and payload. The payload carries a parcel of message
- As packets become available, they are sent along paths between a sender/receiver pair, then reassembled at the destination (see next slide)
- Store-and-forward: entire packet must arrive at a router before it can be transmitted onto next link
  - This introduces L/R seconds delay. L: packet size, R: link capacity (also called bandwidth, transmission rate)

MAC Address
- Unique identifier for a network device
  - E.g., 0e:d1:c3:db:e7:b3
  - First few bytes encode manufacturer and model
  - Others are supposed to be unique
- Used at the Data Link Layer to specify the destination for a message (packet)
- Note: Many NICs allow you to change the MAC address

Fragmentation and Reassembly
- Message is fragmented into packets, which are transmitted independently over various paths and reassembled at their destination
Segment, Packet, and Frame

- The name of the primitive data unit depends on the layer of the protocol in question
  - At the network layer, it is called a packet or datagram
  - At the transport layer above, it is called a segment
  - At the data link layer below, it is called a frame
- As the unit travels down the protocol stack in preparation for being sent, each protocol adds some header for doing its job
  - Thus, e.g., a packet is a segment plus a packet header, i.e., the segment becomes the packet payload

IP (Internet Protocol)

- Most common Network Layer protocol
- Routing packets from source machine to destination machines
  - Across networks (i.e., the Internet)
  - Data Link Layer is sufficient within a local network
    - E.g., among computers connected via a single wireless access point

IP Packet Header

- E.g., source, destination address: IP addresses of the source and destination; version: v4 or v6; entire second row for fragmentation/reassembly

IPv4 packet header (20 bytes)

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>version</td>
<td>4 bits</td>
</tr>
<tr>
<td>IHL</td>
<td>4 bits</td>
</tr>
<tr>
<td>total length</td>
<td>2 bytes</td>
</tr>
<tr>
<td>identification</td>
<td>2 bytes</td>
</tr>
<tr>
<td>flags</td>
<td>3 bits</td>
</tr>
<tr>
<td>fragment offset</td>
<td>4 bits</td>
</tr>
<tr>
<td>ttl</td>
<td>8 bits</td>
</tr>
<tr>
<td>protocol</td>
<td>8 bits</td>
</tr>
<tr>
<td>header checksum</td>
<td>16 bits</td>
</tr>
<tr>
<td>source address</td>
<td>4 bytes</td>
</tr>
<tr>
<td>destination address</td>
<td>4 bytes</td>
</tr>
<tr>
<td>options</td>
<td>2 bytes</td>
</tr>
<tr>
<td>padding</td>
<td>1 byte</td>
</tr>
<tr>
<td>data</td>
<td></td>
</tr>
</tbody>
</table>

IP Addresses

- IP address: also called network address. Used by software called the TCP/IP stack. Per network interface. One machine can have multiple of them
  - NIC: network interface card
- Are 4 bytes (32 bits) long for IPv4, and 16 bytes (128 bits) long for IPv6. All modern OS and devices support both
  - IPv6 has built-in security/authentication, it addresses IPv4 address space shortage
  - Will focus on IPv4 here

IP Address Examples

- IPv4: 130.245.65.129
  - 4 8-bit values, each separated by a dot
  - If any number is >=2^256, it is wrong
    - Here’s looking at you, CSI
- IPv6: fe80::7ed1:c3ff:fed0:a7b3
  - One hexadecimal digit encodes 4 bits
  - 8 x 4 hex digits = 128 bits
  - A string of consecutive 0’s in the middle replaced with double colons (::)
How many IPv4 Addresses are there?
- \(2^{32} \approx 4.3\) billion
- How many computers in the world?
  - \(~2\) billion on the internet in 2010
- How many people in the world?
  - \(~7\) billion
- So IPv4 will eventually run out
  - And management issues have caused problems already

The IP Protocol
- Major job: routing packets from source machine to destination machines. Actually two tasks
- Forwarding vs. routing
  - Forwarding: move a packet from a router’s input to an output
  - Routing: determine a route taken by a packet from source to destination
- Routing is done in the background. It produces IP forwarding tables
  - Will focus on forwarding here

Another way to look at IP Addresses
Consists of a network portion and a host portion
- Network portion: high order bits, identifies a logical network
- Host portion: the rest bits, identifies a node on the network

Packet Delivery (within network)
- You can figure out if an IP is in the same network by looking at the Network ID portion of the address
- Use a Data Link Layer protocol called Address Resolution Protocol (ARP) to ask:
  - “Does anyone know the MAC address of IP x.x.x.x?”
  - Cache results in a local table
  - Usually only ask once

Local Packet Delivery
- Common case: look up ARP cache, send directly from one computer to another

Remote Packet Delivery
- Computers also include routing tables that map network names onto remote IP addresses
- Within a simple network (like campus), your routing table may simply send all remote packets to the edge router
Interplay between routing, forwarding

Subnet
- A subnet is made of those network interfaces that can reach each other without passing through a router. All of them have the same subnet (network) portion
- Subnet mask: specifies the length of the network portion. The 1’s must be leftmost and contiguous
  - E.g., /24 or 255.255.255.0
  - What’s equivalent of /26? Answer: 255.255.255.192
- How many hosts can be in a /26 network/subnet? Answer: 62
  - Host portion of all 0’s denotes this subnet, all 1’s is used as a multicast address. They cannot be assigned to hosts

Historical network types
- Class A: only first byte used for network address
  - Huge, hard to get
- Class B: second two bytes for network
  - Still pretty big, easier to get
- Class C: First three bytes identify network
  - Easy to get – Even I have one for my lab
- Netmasks give you finer-grained subdivision

CIDR
- Classless Inter-Domain Routing. A method to allocate IP addresses and routing IP packets. Allows arbitrary length of the network portion
  - The previous classful addressing uses fixed length
    - Class A: 8 bits in network portion
    - Class B: 16 bits in network portion
    - Class C: 24 bits in network portion
  - CIDR notation: 192.144.0.0/21
  - Assume a site is given the block 192.144.0.0/21. The site could use the block in various ways. For example:

Superneung
- 1 network /21 with 2,046 hosts
- 8 networks /24 with 254 hosts each
- 16 networks /25 with 126 hosts each
- 32 networks /26 with 62 hosts each
- Q: how many routing table entries for each case?
  - A:
    - From the perspective of Internet, no need to have 8, 16, 32 entries
    - All refer to the same organization, go to the same ISP
    - A single entry 192.144.0.0/21 suffices.
  - Superneung aggregates several networks for purposes of routing
IP Forwarding Table

<table>
<thead>
<tr>
<th>Destination IP address range</th>
<th>Link Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>11001000 00010111 00010*** 00000000 through 11001000 00010111 00011000 11111111</td>
<td>through</td>
</tr>
<tr>
<td>11001000 00010111 00010000 00000000 through 11001000 00010111 00011000 11111111</td>
<td>otherwise</td>
</tr>
</tbody>
</table>

 Otherwise 2

 200.23.16.0/21 0
 200.23.24.0/24 1
 Otherwise 2

Longest Prefix Match

- In the previous example, assume the site has 8 /24 networks with 254 hosts each
  - We only need one entry to route to these 8 networks
- If one of the 8 networks moves to a new ISP, can add a more specific entry 192.144.32.0/24
  - In addition to the single 192.144.0.0/24 entry
- Longest prefix match. When both entries apply, use the one with longest prefix
  - Thus /24 is used. This way the packet is routed correctly to the new ISP

Hierarchical addressing: route aggregation

Hierarchical addressing allows efficient advertisement of routing information:

- Organization 0
  - 192.144.0.0/24

- Organization 1
  - 192.144.16.0/24

- Organization 2
  - 192.144.32.0/24

- Organizations 3-7

  - 192.144.64.0/24

ISP-Rs-U's

  - Send me anything with addresses beginning 192.144.0.0/24

Internet

  - Send me anything with addresses beginning 199.31.0.0/16

Hierarchical addressing: more specific routes

ISP-Rs-U's has a more specific route to Organization 1

- Organization 0
  - 192.144.0.0/24

- Organization 2
  - 192.144.16.0/24

- Organization 3
  - 192.144.32.0/24

- Organizations 4-7

  - 192.144.64.0/24

ISP-Rs-U's

  - Send me anything with addresses beginning 199.31.0.0/16 or 192.144.0.0/24

Internet

  - Send me anything with addresses beginning 192.144.0.0/24

Datagram forwarding table

- Four billion IP addresses, so rather than list individual destination address list range of addresses (aggregate table entries)

- When looking for forwarding table entry for given destination address, use longest address prefix that matches destination address.
Human-Understandable Addressing

Hostname and Ports
- Hostname: IP addresses are hard to remember. Thus we name our machines
  - Hostnames generally managed by a transport layer protocol called Domain Name Service (DNS)
- DNS maps human-readable names to IP addresses

$ host www.cs.stonybrook.edu
www.cs.sunysb.edu has address 130.245.27.2

Ports:
- An IP address leads packets to a machine. A port number leads packets to a process or service.
  - Ports are a TCP/UDP abstraction for a specific application/protocol
  - Where are ports in packets? They are in the transport segment header.
  - 16 bits to encode ports. How many ports overall possible? $2^{16}$. Some are well-known. Some not. See http://iana.org/assignments/port-numbers

TCP Segment Header
- E.g., sequence no. tells which data is in payload; acknowledge no. tells which data is received so far

Minimum (20 bytes)

TCP/IP Protocols
- A suite of protocols. Each defined by one or more RFCs. Some major ones:
  - IP: Internet Protocol. RFC791
  - ICMP: Internet Control Message Protocol. RFC792
  - ARP: Address Resolution Protocol. RFC826
  - UDP: User Datagram Protocol. RFC768
  - TCP: Transmission Control Protocol. RFC793