IP Addressing

IP Addresses

• Structure of an IP address
• Classful IP addresses
• Limitations and problems with classful IP addresses
• Subnetting
• CIDR
• IP Version 6 addresses
Definition of the Internet (1995)

- On October 24, 1995, the FNC unanimously passed a resolution defining the term Internet.
- **RESOLUTION:** The Federal Networking Council (FNC) agrees that the following language reflects our definition of the term "Internet". "Internet" refers to the global information system that:
  1. Is logically linked together by a globally unique address space based on the Internet Protocol (IP) or its subsequent extensions/follow-ons;
  2. Is able to support communications using the Transmission Control Protocol/Internet Protocol (TCP/IP) suite or its subsequent extensions/follow-ons, and/or other IP-compatible protocols; and
  3. Provides, uses or makes accessible, either publicly or privately, high level services layered on the communications and related infrastructure described herein.

Time Line of the Internet

- Source: Internet Society
History of the Internet

Mid 1960: Papers on “Packet Switching” emerge.
End 1969s: ARPA sponsors the development of a packet-switching network, called the ARPANET. First four nodes are UCLA, SRI, U. Utah, UCSB.
1974: The TCP/IP protocols and model are being proposed by Cerf/Kahn.
1983: ARPANET adopts TCP/IP. At this time, the ARPANET has 200 routers.
1984: NSF funds a TCP/IP based backbone network. This backbone grows into the NSFNET, which becomes the successor of the ARPANET.
1995: NSF stops funding of NSFNET. The Internet is completely commercial.

Growth of the Internet: Number of Hosts

Source: Internet Software Consortium
Applications of the Internet

- Traditional core applications:
  - Email
  - News
  - Remote Login (Telnet)
  - File Transfer
- The killer application:
  - World-Wide Web (WWW)
- Future applications:
  - Peer-to-Peer applications
  - videoconferencing
  - Internet Broadcast

The Internet - A Network of Networks

- The Internet is a collection of networks
- Networks are organized in a (loose) multilayer hierarchy
Internet Service Provider

- An **ISP (Internet Service Provider)** or **IAP (Internet Access Provider)** provides access to the Internet
- The location where an ISP or corporate network obtains access to the Internet is called a **POP (point-of-presence)**.
- **Network Access Point (NAPs)** are network exchange facility where ISPs connect (“peer”) with one another

Addresses on the Internet

- Hostname: Argon.cerf.edu
- Port number: 80
- IP address: 128.143.137.144
- MAC address: 00:a0:24:71:e4:44
What is an IP Address?

- An IP address is a unique global address for a network interface

- An IP address:
  - is a 32 bit long identifier
  - encodes a network number (network prefix) and a host number

Dotted Decimal Notation

- IP addresses are written in a so-called *dotted decimal notation*

- Each byte is identified by a decimal number in the range [0..255]:

  - Example:
    
    $\begin{array}{cccc}
    10000000 & 10001111 & 10001001 & 10010000 \\
    \text{1st Byte} & \text{2nd Byte} & \text{3rd Byte} & \text{4th Byte} \\
    = 128 & = 143 & = 137 & = 144 \\
    \end{array}$

    $128.143.137.144$
Network prefix and Host number

- The network prefix identifies a network and the host number identifies a specific host (actually, interface on the network).

  network prefix  host number

- **How do we know how long the network prefix is?**
  - The network prefix is implicitly defined (see class-based addressing)
  - The network prefix is indicated by a netmask.

Example

- **Example**: argon.cerf.edu

  128.143  137.144

- Network id is:  **128.143.0.0**
- Host number is:  **137.144**
- Network mask is: **255.255.0.0**  or  **ffff0000**

- Prefix notation:  **128.143.137.144/16**
  - Network prefix is 16 bits long
**Classful IP Adresses**

- When Internet addresses were standardized (early 1980s), the Internet address space was divided up into classes:
  - **Class A**: Network prefix is 8 bits long
  - **Class B**: Network prefix is 16 bits long
  - **Class C**: Network prefix is 24 bits long

- Each IP address contained a key which identifies the class:
  - **Class A**: IP address starts with “0”
  - **Class B**: IP address starts with “10”
  - **Class C**: IP address starts with “110”

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**Internet Address Classes**

- **Class A**
  - Network Prefix: 8 bits
  - Host Number: 24 bits

- **Class B**
  - Network Prefix: 16 bits
  - Host Number: 16 bits

- **Class C**
  - Network Prefix: 24 bits
  - Host Number: 8 bits
More Internet Address Classes

Class D

<table>
<thead>
<tr>
<th>bit #</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>31</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class D</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

multicast group id

Class E

<table>
<thead>
<tr>
<th>bit #</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>31</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class E</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(reserved for future use)

- We will learn about multicast addresses later in this course.

IP Addresses

- These are the address ranges:

<table>
<thead>
<tr>
<th>Class</th>
<th>From</th>
<th>To</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.0.0.0 / 8</td>
<td>127.255.255.255 / 8</td>
</tr>
<tr>
<td>B</td>
<td>128.0.0.0 / 16</td>
<td>191.255.255.255 / 16</td>
</tr>
<tr>
<td>C</td>
<td>192.0.0.0 / 24</td>
<td>223.255.255.255 / 24</td>
</tr>
<tr>
<td>D</td>
<td>224.0.0.0</td>
<td>239.255.255.255</td>
</tr>
<tr>
<td>E</td>
<td>240.0.0.0</td>
<td>247.255.255.255</td>
</tr>
</tbody>
</table>

Note: Host Id’s with all 0’s and all 1’s are not allowed. Host id = 0….0 means “this host”, host id = “1….1” indicates a broadcast.
Special IP Addresses

- **Reserved or (by convention) special addresses:**
  
  - **127.0.0.1** loopback interface
  - **hostid is all “0…0”** name of the network e.g., 128.143.0.0
  - **hostid is all “1…1”** broadcast on the network e.g., 128.143.255.255
  - **hostid = 1** address of default gateway e.g., 192.0.1.1

- **Test / Experimental addresses**
  (packets should get dropped if they contain this destination address, see RFC 1918):

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

Trade-off of Address Classes

- **There are a total of** \(2^{32} = 4,294,967,296\) **IP addresses.**

  - **Class A (prefix /8):** 7 bits to identify a network
    - only 128 Class A networks
    - each network can have 16 million \(2^{24}\) hosts.

  - **Class B (prefix /16):** 14 bits to identify a network
    - about 16,000 networks
    - about 65,000 \(2^{16}\) hosts per network

  - **Class C (prefix /24):** 21 bits to identify a network
    - about 2 million networks
    - only 255 networks per network
Problems with Classful IP Addresses

- The original classful address scheme had a number of problems

**Problem 1. Too few network addresses for large networks**
  - Class A and Class B addresses are gone

**Problem 2. Two-layer hierarchy is not appropriate for large networks with Class A and Class B addresses.**
  - **Fix #1:** Subnetting
Problems with Classful IP Addresses

**Problem 3. Inflexible.** Assume a company requires 2,000 addresses
- Class A and B addresses are overkill
- Class C address is insufficient (requires 40 Class C addresses)

- **Fix #2:** Classless Interdomain Routing (CIDR)

Problems with Classful IP Addresses

**Problem 4: Exploding Routing Tables:** Routing on the backbone Internet needs to have an entry for each network address. In 1993, the size of the routing tables started to outgrow the capacity of routers.

- **Fix #2:** Classless Interdomain Routing (CIDR)
Problems with Classful IP Addresses

**Problem 5.** The Internet is going to outgrow the 32-bit addresses

– **Fix #3:** IP Version 6

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**Subnetting**

- **Problem:** Organizations have multiple networks which are independently managed
  - **Solution 1:** Allocate one or more Class C address for each network
    - Difficult to manage
    - From the outside of the organization, each network must be addressable.
  - **Solution 2:** Add another level of hierarchy to the IP addressing structure

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Basic Idea of Subnetting

• Split the host number portion of an IP address into a subnet number and a (smaller) host number.
• Result is a 3-layer hierarchy

Then:
• Subnets can be freely assigned within the organization
• Internally, subnets are treated as separate networks
• Subnet structure is not visible outside the organization

Subnet Masks

• Routers and hosts use an extended network prefix (subnet mask) to identify the start of the host numbers

Class B with subnetting

Subnet mask (255.255.255.0)

* There are different ways of subnetting. Subnetting with mask 255.255.255.0 is quite common. UVA uses 255.255.255.0 and 255.255.0.0
Typical Addressing Plan for an Organization

- Each layer-2 network (Ethernet segment, FDDI segment) is allocated a subnet address.

CIDR - Classless Interdomain Routing

- IP backbone routers have one routing table entry for each network address:
  - With subnetting, a backbone router only needs to know one entry for each Class A, B, or C networks
  - This is acceptable for Class A and Class B networks
    - $2^7 = 128$ Class A networks
    - $2^{14} = 16,384$ Class B networks
  - But this is not acceptable for Class C networks
    - $2^{21} = 2,097,152$ Class C networks
- In 1993, the size of the routing tables started to outgrow the capacity of routers
- Consequence: The Class-based assignment of IP addresses had to be abandoned
CIDR - Classless Interdomain Routing

• Goals:
  – Restructure IP address assignments to increase efficiency
  – Hierarchical routing aggregation to minimize route table entries

• CIDR (Classless Interdomain routing) abandons the notion of classes:
  Key Concept: The length of the network id (prefix) in the IP addresses is kept arbitrary

• Consequence: Routers advertise the IP address and the length of the prefix (Prefix replaces subnetmask !)

CIDR Example

• CIDR notation of a network address:
  192.0.2.00/18
  • "18" says that the first 18 bits are the network part of the address (and 14 bits are available for specific host addresses)
  • The network part is called the prefix

• Assume that a site requires a network address with 1000 addresses
• With CIDR, the network is assigned a continuous block of 1024 addresses with a 22-bit long prefix
CIDR: Prefix Size vs. Network Size

<table>
<thead>
<tr>
<th>CIDR Block Prefix</th>
<th># of Host Addresses</th>
</tr>
</thead>
<tbody>
<tr>
<td>/27</td>
<td>32 hosts</td>
</tr>
<tr>
<td>/26</td>
<td>64 hosts</td>
</tr>
<tr>
<td>/25</td>
<td>128 hosts</td>
</tr>
<tr>
<td>/24</td>
<td>256 hosts</td>
</tr>
<tr>
<td>/23</td>
<td>512 hosts</td>
</tr>
<tr>
<td>/22</td>
<td>1,024 hosts</td>
</tr>
<tr>
<td>/21</td>
<td>2,048 hosts</td>
</tr>
<tr>
<td>/20</td>
<td>4,096 hosts</td>
</tr>
<tr>
<td>/19</td>
<td>8,192 hosts</td>
</tr>
<tr>
<td>/18</td>
<td>16,384 hosts</td>
</tr>
<tr>
<td>/17</td>
<td>32,768 hosts</td>
</tr>
<tr>
<td>/16</td>
<td>65,536 hosts</td>
</tr>
<tr>
<td>/15</td>
<td>131,072 hosts</td>
</tr>
<tr>
<td>/14</td>
<td>262,144 hosts</td>
</tr>
<tr>
<td>/13</td>
<td>524,288 hosts</td>
</tr>
</tbody>
</table>

CIDR and Address assignments

- Backbone ISPs obtain large block of IP addresses space and then reallocate portions of their address blocks to their customers.

Example:
- Assume that an ISP owns the address block 206.0.64.0/18, which represents 16,384 (2^{14}) IP addresses
- Suppose a client requires 800 host addresses
- With classful addresses: need to assign a class B address (and waste ~64,700 addresses) or four individual Class Cs (and introducing 4 new routes into the global Internet routing tables)
- With CIDR: Assign a /22 block, e.g., 206.0.68.0/22, and allocated a block of 1,024 (2^{10}) IP addresses.
CIDR and Routing Information

Dest: 209.88.237.205

Internet Backbone

ISP X owns:
- 206.0.64.0/18
- 204.188.0.0/15
- 209.88.232.0/21

ISP Y:
- 209.88.237.0/24

Organization z1:
- 209.88.237.192/26

Organization z2:
- 209.88.237.0/26

Backbone sends everything which matches the prefixes 206.0.64.0/18, 204.188.0.0/15, 209.88.232.0/21 to ISP X.

ISP X sends everything which matches the prefix:
- 206.0.68.0/22 to Company X
- 209.88.237.0/24 to ISP Y

ISP Y sends everything which matches the prefix:
- 209.88.237.192/26 to Organizations z1
- 209.88.237.0/26 to Organizations z2

Dest: 209.88.237.205

ISP X does not know about Organizations z1, z2.

ISP Y sends everything which matches the prefix:
- 209.88.237.192/26 to Organizations z1
- 209.88.237.0/26 to Organizations z2

Backbone routers do not know anything about Company X, ISP Y, or Organizations z1, z2.
Example

- The IP Address: 207.2.88.170

```
207  2  88  170
11001111  0000010  01011000  10101010
```

Belongs to:
City of Charlottesville, VA: 207.2.88.0 – 207.2.92.255
```
11001111  0000010  01011000  00000000
```

Belongs to:
Cable & Wireless USA  207.0.0.0 – 207.3.255.255
```
11001111  00000000  00000000  00000000
```

You can find about ownership of IP addresses via http://www.arin.net/whois/

CIDR and Routing

- CIDR addressing enables a hierarchical routing scheme

- Note the similarity to the telephone system:

```
+1  904  982  2200
```

- Backbone routers can treat all addresses with the same prefix in the same way

- Routing table lookup: Lookup the entry with the longest prefix
IPv6 - IP Version 6

- **IP Version 6**
  - Is the successor to the currently used IPv4
  - Specification completed in 1994
  - Makes improvements to IPv4 (no revolutionary changes)

- One (not the only !) feature of IPv6 is a significant increase in of the IP address to **128 bits (16 bytes)**
  - IPv6 will solve – for the foreseeable future – the problems with IP addressing

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**IPv6 Header**

```
+-----------------------------------------------+
| 32 bits                                      |
| version (4 bits)  | Traffic Class (8 bits) | Flow Label (24 bits) |
| Payload Length (16 bits) | Next Header (8 bits) | Hop Limits (8 bits) |
+-----------------------------------------------+

Source IP address (128 bits)

Destination IP address (128 bits)
```

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IPv6 vs. IPv4: Address Comparison

- **IPv4** has a maximum of 
  \[ 2^{32} = 4 \text{ billion addresses} \]
- **IPv6** has a maximum of 
  \[ 2^{128} = (2^{32})^4 = 4 \text{ billion x 4 billion x 4 billion x 4 billion addresses} \]

Notation of IPv6 addresses

- **Convention**: The 128-bit IPv6 address is written as eight 16-bit integers (using hexadecimal digits for each integer)
  \[ \text{CEDF:BP76:3245:4464:FACE:2E50:3025:DF12} \]

- **Short notation**:
  - Abbreviations of leading zeroes:
    \[ \text{CEDF:BP76:0000:0000:0000:0000:3025:DF12} \rightarrow \text{CEDF:BP76:0:0:0:0:3025:DF12} \]
  - “::0000:0000:0000” can be written as “::” 
    \[ \text{CEDF:BP76:0:0:FACE:0:3025:DF12} \rightarrow \text{CEDF:BP76::FACE:0:3025:DF12} \]
  - IPv6 addresses derived from IPv4 addresses have 96 leading zero bits. Convention allows to use IPv4 notation for the last 32 bits.
    \[ ::80:8F:89:90 \rightarrow ::128.143.137.144 \]
IPv6 Provider-Based Addresses

• The first IPv6 addresses will be allocated to a provider-based plan

<table>
<thead>
<tr>
<th>Type</th>
<th>Registry ID</th>
<th>Provider ID</th>
<th>Subscriber ID</th>
<th>Subnetwork ID</th>
<th>Interface ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

• **Type**: Set to “010” for provider-based addresses
• **Registry**: identifies the agency that registered the address

*The following fields have a variable length (recommended length in “()”)*
• **Provider**: Id of Internet access provider *(16 bits)*
• **Subscriber**: Id of the organization at provider *(24 bits)*
• **Subnetwork**: Id of subnet within organization *(32 bits)*
• **Interface**: identifies an interface at a node *(48 bits)*

More on IPv6 Addresses

• The provider-based addresses have a similar flavor as CIDR addresses

• IPv6 provides address formats for:
  – **Unicast** – identifies a single interface
  – **Multicast** – identifies a group. Datagrams sent to a multicast address are sent to all members of the group
  – **Anycast** – identifies a group. Datagrams sent to an anycast address are sent to one of the members in the group.
Summary

- IP addresses have two parts: a network prefix, and a host number
- Classful IP addresses: the size of the network prefix is 8 (Class A), 16 (Class B), or 24 (Class C) bits.
- With **subnetting**, part of the host number can be used to identify a (sub)network:
  - IP address space has a 3-level hierarchy
  - Hosts and routers need to know the subnetmask
- With **CIDR**, the network prefix can have any size
  - IP addressing and routing hierarchy can be general
  - Hosts and routers need to know the size of the prefix
- **IPv6** has a very large (128 bits) address space.
  - Provider based addresses are similar to CIDR
  - Supports multicast and anycast addresses