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
IP Addresses

<table>
<thead>
<tr>
<th>32 bits</th>
</tr>
</thead>
<tbody>
<tr>
<td>version (4 bits)</td>
</tr>
<tr>
<td>Identification (16 bits)</td>
</tr>
<tr>
<td>TTL Time-to-Live (8 bits)</td>
</tr>
<tr>
<td>Source IP address (32 bits)</td>
</tr>
<tr>
<td>Destination IP address (32 bits)</td>
</tr>
</tbody>
</table>

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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:

  \[
  \begin{array}{cccc}
  10000000 & 10001111 & 10001001 & 10010000 \\
  1^{st} \text{ Byte} & 2^{nd} \text{ Byte} & 3^{rd} \text{ Byte} & 4^{th} \text{ Byte} \\
  = 128 & = 143 & = 137 & = 144 \\
  \end{array}
  \]

  \[128.143.137.144\]
Network prefix and Host number

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

- **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**: ellington.cs.virginia.edu

  - 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
Learning about the length of the prefix

• On Unix: **ifconfig -a**

```
fxp0: flags=8943<UP,BROADCAST,RUNNING,PROMISC,SIMPLEX,MULTICAST>
     mtu 1500
     inet 128.143.137.201 netmask 0xffff0000 broadcast 128.143.255.255
```

• On Windows: **ipconfig**

```
Windows NT IP Configuration
Ethernet adapter elnk31:
     IP Address. . . . . . . . . : 128.143.137.144
     Subnet Mask . . . . . . . . : 255.255.0.0
     Default Gateway . . . . . . : 128.143.137.1
```

Classful IP Addresses

• 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”
Internet Address Classes

Class A

<table>
<thead>
<tr>
<th>bit #</th>
<th>0</th>
<th>1</th>
<th>7</th>
<th>8</th>
<th>31</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Network Prefix</td>
<td>8 bits</td>
<td>Host Number</td>
<td>24 bits</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Class B

<table>
<thead>
<tr>
<th>bit #</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>15</th>
<th>16</th>
<th>31</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td></td>
<td></td>
<td>15</td>
<td>16</td>
<td>host</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Network Prefix</td>
<td>16 bits</td>
<td>Host Number</td>
<td>16 bits</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Class C

<table>
<thead>
<tr>
<th>bit #</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>23</th>
<th>24</th>
<th>31</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td></td>
<td></td>
<td>23</td>
<td>24</td>
<td>host</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Network Prefix</td>
<td>24 bits</td>
<td>Host Number</td>
<td>8 bits</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>multicast group id</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(reserved for future use)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

More Internet Address Classes

- 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

Allocation of Classful Addresses
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

**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
**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

**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

```
+----------------+ +----------------+ +----------------+
| network prefix | | host number     |
+----------------+ +----------------+
| network prefix | | subnet number   |
| extended network prefix |
| host number     |
```
- 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

<table>
<thead>
<tr>
<th>Subnet mask (255.255.255.0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>111111111111111111111111111100000000</td>
</tr>
</tbody>
</table>

* 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.

```
128.143.0.0/16
<table>
<thead>
<tr>
<th>128.143.7.0 / 24</th>
</tr>
</thead>
<tbody>
<tr>
<td>128.143.71.0 / 24</td>
</tr>
<tr>
<td>128.143.16.0 / 24</td>
</tr>
<tr>
<td>128.143.17.0 / 24</td>
</tr>
<tr>
<td>128.143.32.0 / 24</td>
</tr>
<tr>
<td>128.143.136.0 / 24</td>
</tr>
</tbody>
</table>
```
Advantages of Subnetting

• With subnetting, IP addresses use a 3-layer hierarchy:
  » Network
  » Subnet
  » Host
• Improves efficiency of IP addresses by not consuming an entire Class B or Class C address for each physical network/
• Reduces router complexity. Since external routers do not know about subnetting, the complexity of routing tables at external routers is reduced.

• Note: Length of the subnet mask need not be identical at all subnetworks.

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

Internet Backbone

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

Company X:
- 206.0.68.0/22

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

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

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

• The IP Address: 207.2.88.170

207 2 88 170

11001111 00000010 01011000 10101010

Belongs to:
City of Charlottesville, VA: 207.2.88.0 – 207.2.92.255

11001111 00000010 01011000 00000000

Belongs to:
Cable & Wireless USA 207.0.0.0 – 207.3.255.255

11001111 00000000 00000000 00000000

CIDR and Routing

• CIDR addressing enables a hierarchical routing scheme

• Note the similarity to the telephone system:

+1 804 982 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**

- **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 $2^{32} = 4$ billion addresses
- **IPv6** has a maximum of $2^{128} = (2^{32})^4 = 4$ 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)
  

- **Short notation**:
  - Abbreviations of leading zeroes:
    
    CEDF:BP76:0000:0000:009E:0000:3025:DF12
    
    → CEDF:BP76:0:0:9E:0:3025:DF12
  
  - "::0000:0000:0000" can be written as "::"
    
    CEDF:BP76:0:0:FACE:0:3025:DF12
    
    → 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
    
    → ::128.143.137.144
### IPv6 Provider-Based Addresses

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

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