IP Addressing

Introductory material.
An entire module devoted to IP addresses.

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>version (4 bits)</th>
<th>header length (8 bits)</th>
<th>Type of Service/TOS (8 bits)</th>
<th>Total Length (in bytes) (16 bits)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identification (16 bits)</td>
<td>Flags (3 bits)</td>
<td>Fragment Offset (13 bits)</td>
<td>Total Length (in bytes) (16 bits)</td>
</tr>
<tr>
<td>TTL Time-to-Live (8 bits)</td>
<td>Protocol (8 bits)</td>
<td>Header Checksum (16 bits)</td>
<td>Source IP address (32 bits)</td>
</tr>
<tr>
<td>Destination IP address (32 bits)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Ethernet Header | IP Header | TCP Header | Application data | Ethernet Trailer

Ethernet frame

IP Addresses

<table>
<thead>
<tr>
<th>0x4</th>
<th>0x5</th>
<th>0x00</th>
<th>44</th>
</tr>
</thead>
<tbody>
<tr>
<td>9d08</td>
<td>010</td>
<td>000000000000</td>
<td></td>
</tr>
<tr>
<td>128</td>
<td>0x06</td>
<td>0bff</td>
<td></td>
</tr>
<tr>
<td>128.143.137.144</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>128.143.71.21</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Ethernet Header | IP Header | TCP Header | Application data | Ethernet Trailer

Ethernet frame
What is an IP Address?

- An IP address is a unique global address for a network interface
- Exceptions:
  - IP addresses are dynamically assigned (→ DHCP, Lab 7)
  - IP addresses in private networks (→ NAT, Lab 7)
- An IP address:
  - is a **32 bit long** identifier
  - encodes a network number (**network prefix**) and a **host number**

Network prefix and Host number

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

<table>
<thead>
<tr>
<th>network prefix</th>
<th>host number</th>
</tr>
</thead>
</table>

- **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**.
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:**

    
    | 1st Byte | 2nd Byte | 3rd Byte | 4th Byte |
    |----------|----------|----------|----------|
    | 10000000 | 10001111 | 10001001 | 10010000 |
    | 128      | 143      | 137      | 144      |
    
    - 128.143.137.144

Example

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

  
<table>
<thead>
<tr>
<th>128.143</th>
<th>137.144</th>
</tr>
</thead>
<tbody>
<tr>
<td>128.143</td>
<td>137.144</td>
</tr>
</tbody>
</table>

  - Network address is: 128.143.0.0 (or 128.143)
  - Host number is: 137.144
  - Netmask is: 255.255.0.0 (or ffff0000)

  - Prefix or CIDR notation: 128.143.137.144/16
    - Network prefix is 16 bits long
Special IP Addresses

- **Reserved or (by convention) special addresses:**
  
  **Loopback interfaces**
  - all addresses 127.0.0.1-127.0.0.255 are reserved for loopback interfaces
  - Most systems use 127.0.0.1 as loopback address
  - loopback interface is associated with name "localhost"

  **IP address of a network**
  - Host number is set to all zeros, e.g., 128.143.0.0

  **Broadcast address**
  - Host number is all ones, e.g., 128.143.255.255
  - Broadcast goes to all hosts on the network
  - Often ignored due to security concerns

- **Test / Experimental addresses**
  Certain address ranges are reserved for "experimental use". 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

- **Convention (but not a reserved address)**
  Default gateway has host number set to ‘1’, e.g., e.g., 192.0.1.1

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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
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

```
<table>
<thead>
<tr>
<th>network prefix</th>
<th>host number</th>
</tr>
</thead>
</table>
```

```
<table>
<thead>
<tr>
<th>network prefix</th>
<th>subnet number</th>
<th>host number</th>
</tr>
</thead>
</table>
```

```
| extended network prefix |
```

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

Typical Addressing Plan for an Organization that uses subnetting

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

```
128.143.0.0/16
```

```
128.143.7.0 / 24
```

```
128.143.8.0 / 24
```

```
128.143.17.0 / 24
```

```
128.143.22.0 / 24
```

```
128.143.136.0 / 24
```
**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.

**Subnetmask**

- Routers and hosts use an extended network prefix (subnetmask) to identify the start of the host numbers

```
<table>
<thead>
<tr>
<th>128.143</th>
<th>137.144</th>
</tr>
</thead>
<tbody>
<tr>
<td>network prefix</td>
<td>host number</td>
</tr>
</tbody>
</table>
```

```
<table>
<thead>
<tr>
<th>128.143</th>
<th>137</th>
<th>144</th>
</tr>
</thead>
<tbody>
<tr>
<td>network prefix</td>
<td>subnet number</td>
<td>host number</td>
</tr>
</tbody>
</table>
```

```
11111111 11111111 11111111 11111111 10000000 00000000 00000000 00000000
```

subnetmask
Example: Subnetmask

- 128.143.0.0/16 is the IP address of the network
- 128.143.137.0/24 is the IP address of the subnet

- 128.143.137.144 is the IP address of the host
- 255.255.255.0 (or ffffff00) is the subnetmask of the host

- When subnetting is used, one generally speaks of a “subnetmask” (instead of a netmask) and a “subnet” (instead of a network)
- Use of subnetting or length of the subnetmask if decided by the network administrator
- Consistency of subnetmasks is responsibility of administrator

No Subnetting

- All hosts think that the other hosts are on the same network
With Subnetting

- Hosts with same extended network prefix belong to the same network

With Subnetting

- Different subnetmasks lead to different views of the size of the scope of the network
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"

The old way: Internet Address Classes
The old way: Internet Address Classes

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

<table>
<thead>
<tr>
<th>Class E</th>
<th>bit # 0 1 2 3 4 5</th>
<th>31</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 1 1 1 0</td>
<td></td>
</tr>
<tr>
<td>(reserved for future use)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

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 10,000 addresses
  - Class A and B addresses are overkill (>64,000 addresses)
  - Class C address is insufficient (requires 40 Class C addresses)

- **Problem 4: Flat address space.** 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
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:**
  – New interpretation of the IP address space
  – 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 prefix in the IP addresses is kept arbitrary
  – Consequence: Size of the network prefix must be provided with an IP address
CIDR Notation

- CIDR notation of an IP address:
  
  \[192.0.2.0/18\]
  
  - "18" is the prefix length. It states that the first 18 bits are the network prefix of the address (and 14 bits are available for specific host addresses)

- CIDR notation can replace the use of subnetmasks (but is more general)
  - IP address 128.143.137.144 and subnetmask 255.255.255.0 becomes 128.143.137.144/24

- CIDR notation allows to drop trailing zeros of network addresses:
  \[192.0.2.0/18\] can be written as \[192.0.2/18\]

CIDR address blocks

- CIDR notation can nicely express blocks of addresses
- Blocks are used when allocating IP addresses for a company and for routing tables (route aggregation)

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

- Aggregation of routing table entries:
  - 128.143.0.0/16 and 128.144.0.0/16 are represented as 128.142.0.0/15
- Longest prefix match: Routing table lookup finds the routing entry that matches the the longest prefix

<table>
<thead>
<tr>
<th>Prefix</th>
<th>Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>128.0.0.0/4</td>
<td>interface #5</td>
</tr>
<tr>
<td>128.128.0.0/9</td>
<td>interface #2</td>
</tr>
<tr>
<td>128.143.128.0/17</td>
<td>interface #1</td>
</tr>
</tbody>
</table>

What is the outgoing interface for 128.143.137.0/24?

Route aggregation can be exploited when IP address blocks are assigned in an hierarchical fashion.
CIDR and Routing Information

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

Company X:
- 206.0.68.0/22

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

ISP X does not know about Organizations z1, 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 in North America via [http://www.arin.net/whois/](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

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 the IP address to **128 bits (16 bytes)**
  - IPv6 will solve – for the foreseeable future – the problems with IP addressing
  - $10^{24}$ addresses per square inch on the surface of the Earth.
IPv6 vs. IPv4: Address Comparison

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

• **Convention**: The 128-bit IPv6 address is written as **eight 16-bit integers** (using hexadecimal digits for each integer)


• **Short notation**:  
  • Abbreviations of leading zeroes:
    CEDF:BP76:0000:009E:0000:3025:DF12  
    → CEDF:BP76:0:0:9E:0:3025:DF12
  • “:0000:0000:0000” can be written as “::”
    CEDF:BP76::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)