Chapter 5

Classless Addressing
Outline

- Variable-Length Blocks
- Subnetting
- Address Allocation
Classless Addressing

- Classful addressing has created many problems

- Solution: *classless addressing*
  - Proposed in 1996 and will eventually render classful addressing obsolete

- Idea: *variable-length blocks*
5.1 Variable-Length Blocks
Variable-Length Blocks

- The whole address space ($2^{32}$ addresses) is divided into blocks of different sizes.
Restrictions

- **Number of Addresses in a Block**
  - The number of addresses in a block must be a power of 2 (2, 4, 8, ...)

- **Beginning Addresses**
  - The beginning address must be evenly divisible by the number of addresses.
    - Ex: if a block contains 4 addresses, the beginning address must be divisible by 4.
    - Make the rightmost number of bits in the beginning address are zero.
  - If the block has less than 256 addresses, we need to check only the rightmost byte.
  - If it has less than 65,536 addresses, we need to check only the two rightmost bytes, and so on.
Example 1

Which of the following can be the beginning address of a block that contains 16 addresses?

205.16.37.32
190.16.42.44
17.17.33.80
123.45.24.52

Solution

The address 205.16.37.32 is eligible because 32 is divisible by 16. The address 17.17.33.80 is eligible because 80 is divisible by 16.
Example 2

Which of the following can be the beginning address of a block that contains 256 addresses?

205.16.37.32  
190.16.42.0  
17.17.32.0  
123.45.24.52

Solution

When the right-most byte is 0, the total address is divisible by 256. Only two addresses are eligible (b and c).
Example 3

Which of the following can be the beginning address of a block that contains 1024 addresses?

205.16.37.32
190.16.42.0
17.17.32.0
123.45.24.52

Solution

To be divisible by 1024, the rightmost byte of an address should be 0 and the second rightmost byte must be divisible by 4. Only the address 17.17.32.0 meets this condition.
Mask

- In classful addressing, the mask is implicit
  - The mask for a class A block is 255.0.0.0 (/8)

- However, in classless addressing
  - When an address is given, we must also have its mask to know its belonging block
  - Thus, the address must be accompanied by the mask
  - Use the CIDR notation with the number of 1s in the mask
CIDR Notation

- CIDR (Classless InterDomain Routing)
- Attach the number of common bits in every address in the block to the end of a classless address
  - i.e., the number of 1s in a mask

\[ x.y.z.t/n \]
Prefix and Suffix

- **Prefix**
  - Another name for the common part of the address range
  - Similar to the *netid*

- **Prefix length: the length of the prefix**
  - Equal to $n$ in the slash notation
  - Similar to the *hostid*

- **Suffix**
  - The varying part of the address range

- **Suffix length: the length of the suffix**
  - Equal to $(32-n)$ in slash notation
Prefix Lengths

<table>
<thead>
<tr>
<th>/n</th>
<th>Mask</th>
<th>/n</th>
<th>Mask</th>
<th>/n</th>
<th>Mask</th>
<th>/n</th>
<th>Mask</th>
</tr>
</thead>
<tbody>
<tr>
<td>/1</td>
<td>128.0.0.0</td>
<td>/9</td>
<td>255.128.0.0</td>
<td>/17</td>
<td>255.255.128.0</td>
<td>/25</td>
<td>255.255.255.128</td>
</tr>
<tr>
<td>/2</td>
<td>192.0.0.0</td>
<td>/10</td>
<td>255.192.0.0</td>
<td>/18</td>
<td>255.255.192.0</td>
<td>/26</td>
<td>255.255.255.192</td>
</tr>
<tr>
<td>/3</td>
<td>224.0.0.0</td>
<td>/11</td>
<td>255.224.0.0</td>
<td>/19</td>
<td>255.255.224.0</td>
<td>/27</td>
<td>255.255.255.224</td>
</tr>
<tr>
<td>/4</td>
<td>240.0.0.0</td>
<td>/12</td>
<td>255.240.0.0</td>
<td>/20</td>
<td>255.255.240.0</td>
<td>/28</td>
<td>255.255.255.240</td>
</tr>
<tr>
<td>/5</td>
<td>248.0.0.0</td>
<td>/13</td>
<td>255.248.0.0</td>
<td>/21</td>
<td>255.255.248.0</td>
<td>/29</td>
<td>255.255.255.248</td>
</tr>
<tr>
<td>/6</td>
<td>252.0.0.0</td>
<td>/14</td>
<td>255.252.0.0</td>
<td>/22</td>
<td>255.255.252.0</td>
<td>/30</td>
<td>255.255.255.252</td>
</tr>
<tr>
<td>/7</td>
<td>254.0.0.0</td>
<td>/15</td>
<td>255.254.0.0</td>
<td>/23</td>
<td>255.255.254.0</td>
<td>/31</td>
<td>255.255.255.254</td>
</tr>
<tr>
<td>/8</td>
<td>255.0.0.0</td>
<td>/16</td>
<td>255.255.0.0</td>
<td>/24</td>
<td>255.255.255.0</td>
<td>/32</td>
<td>255.255.255.255</td>
</tr>
</tbody>
</table>

Classful addressing is a special case of classless addressing.
Finding the Block

- When a classless address is given, we can find the block
  - The first address in the block
  - The number of addressed in the block
  - The last address in the block
Finding the First Address

- We can derive the first address if we know
  - One of the address in the block
  - The *prefix length*, or a *mask*, or the *suffix length*

- Solution 1
  - AND the mask and the address to find the first address, i.e., network address

- Solution 2
  - Just keep the first $n$ bits and change the rest to 0s
Example 4

What is the network address if one of the addresses is 167.199.170.82/27?
Solution

- The prefix length is 27
  - We must keep the first 27 bits as it is and change the remaining bits (5) to 0s.
- The 5 bits affect only the last byte.
- The last byte is 01010010.
- Changing the last 5 bits to 0s, we get 01000000 or 64.
- The network address is 167.199.170.64/27.
First Short Cut to Find the First Address

- Divide the prefix length into four groups and find the number of 1s in each group
- If the number of 1s in a group is 8
  - The corresponding byte in the first address is the same
- If the number of 1s in a group is zero
  - The corresponding byte in the first address is 0
- If the number of 1s in a group is between zero and eight
  - Keep the corresponding bits in that group
Example 5

- What is the first address in the block if one of the addresses is 140.120.84.24/20?

- Solution
  - The first, second, and fourth bytes are easy;
  - for the third byte we keep the bits corresponding to the number of 1s in that group.
  - The first address is 140.120.80.0/20.
  - See next slide
Example 5

IP Address

140  •  120  •  84  •  24

/n

8  8  4  0

First Address

84  0  1  0  1  0  1  0  0
Keep left 4 bits  0  1  0  1  0  0  0  0

Result in decimal: 80
Second Short Cut to Find the First Address

- To avoid using binary numbers

- Write the byte in the address as a sum of powers of 2
  - If a power is missing, insert 0

- Then choose the $m$ highest powers
  - $m = \text{corresponding number in the prefix length}$
Example 6

Find the first address in the block if one of the addresses is 140.120.84.24/20.

Solution

- The first, second, and fourth bytes are as defined in the previous example.

- To find the third byte,
  - Write 84 as the sum of powers of 2
  - Select only the leftmost 4 (m is 4)
  - The first address is 140.120.80.0/20
  - See next slide
### Example 6

Write 84 as sum of:

<table>
<thead>
<tr>
<th>128</th>
<th>64</th>
<th>32</th>
<th>16</th>
<th>8</th>
<th>4</th>
<th>2</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>64</td>
<td>0</td>
<td>16</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Select only leftmost 4:

| 0   | 64  | 0   | 16  |

Add to find the result: 80
Finding the Number of Addresses in the Block

- The total number of addresses in the block is $2^{32-n}$
Example 7

- Find the number of addresses in the block if one of the addresses is 140.120.84.24/20

- **Solution**
  - The prefix length is 20.
  - The number of addresses in the block is $2^{32} - 20$ or 212 or 4096.
Finding the Last Address in the Block

- Two methods
  - First method
    - Add the number of addresses in the block minus 1 to the first address
  - Second method
    - Add the first address to the complement of the mask
Example 8

- Using the first method, find the last address in the block if one of the addresses is 140.120.84.24/20.

- Solution
  - We found in the example 7
    - The first address is 140.120.80.0/20
    - The number of addresses is 4096.
  - To find the last address
    - Add 4095 (4096 – 1) to the first address.
  - See next slide
Example 8 (Cont.)

- To keep the format in dotted-decimal notation,
  - Represent 4095 in base 256
  - Write 4095 as 15.255.
  - We then add the first address to this number to obtain the last address

<table>
<thead>
<tr>
<th>140 . 120 . 80 . 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 . 255</td>
</tr>
<tr>
<td>---------------------</td>
</tr>
<tr>
<td>140 . 120 . 95 . 255</td>
</tr>
</tbody>
</table>

The last address is **140.120.95.255/20**.
Example 9

- Using the second method, find the last address in the block if one of the addresses is 140.120.84.24/20.

- Solution
  
  - The mask has twenty 1s and twelve 0s.
  
  - The complement of the mask has twenty 0s and twelve 1s. In other words, the mask complement is

    \[
    00000000 00000000 00001111 11111111
    \]

    or 0.0.15.255
Example 9 (Cont.)

- We add the mask complement to the beginning address to find the last address

\[
\begin{align*}
140 &. 120 &. 80 &. 0 \\
0 &. 0 &. 15 &. 255 \\
\hline
140 &. 120 &. 95 &. 255
\end{align*}
\]

*The last address is* 140.120.95.255/20. 
Example 10

- Find the block if one of the addresses is 190.87.140.202/29

- Solution: follow the procedure in the previous examples to find
  - The first address
    - The first address is 190.87.140.200/29
  - The number of addresses
    - The number of addresses is \(2^{(32-29)}\) or 8
  - The last address
    - The last address is 190.87.140.207/20
Example 11

- Show a network configuration for the block in the previous example
- Solution
  - The organization can assign the addresses in the block to the hosts in its network.
  - However, the first address needs to be used as the network address and the last address is kept as a special address (limited broadcast address).
  - Following figure shows how the block can be used by an organization.
  - Note that the last address ends with 207, which is different from the 255 seen in classful addressing.
Example 11

Network Organization

190.87.140.201/29
190.87.140.202/29
190.87.140.203/29
190.87.140.204/29
190.87.140.205/29
190.87.140.206/29
190.87.140.207/29 (Special Address)

Block: 8 Addresses

190.87.140.200/29

...
A granted block to an ISP is defined by:

- The first address
- The prefix length

CIDR notation totally determines the block:
- E.g., the block in previous example is defined as 190.87.140.200/29
Note

In classless addressing, the last address in the block does not necessarily end in 255.

In CIDR notation, the block granted is defined by the first address and the prefix length.
Subnetting
Subnetting

- We can also use subnetting with classless addressing
  - Just increase the prefix length to derive the subnet prefix length

- See the following example.
Finding the Subnet Mask

- **Subnet prefix**
  - Defined by the number of desired subnets
- If the number of subnets is $s$
  - The number of extra 1s in the prefix length is $\log_2 s$
- If we want **fixed-length subnets**
  - Each subnet has the same number of addresses
  - The number of subnets needs to be a power of 2

**In fixed-length subnetting, the number of subnets is a power of 2.**
Example 12

- An organization is granted the block 130.34.12.64/26.
- The organization needs 4 subnets.
- What is the subnet prefix length?

Solution

- We need 4 subnets
  - We need to add two more 1s \(\log_2 4 = 2\) to the site prefix.
- The subnet prefix is then /28
Example 13

- What are the subnet addresses and the range of addresses for each subnet in the previous example?

- Solution
  - The site has $2^{32} - 2^6 = 64$ addresses.
  - Each subnet has $2^{32} - 2^8 = 16$ addresses.
Example 13

Site: 130.34.12.64/26

Subnet 130.34.12.80/28

130.34.12.81/28  ...  130.34.12.94/28

Subnet 130.34.12.105/28

130.34.12.97/28  ...  130.34.12.110/28

Subnet 130.34.12.112/28

130.34.12.65/28  ...  130.34.12.71/28

130.34.12.70/28  ...  130.34.12.78/28

130.34.12.113/28  ...  130.34.12.120/28

130.34.12.121/28  ...  130.34.12.126/28

R1

Any packet with destination address from 130.34.12.64 to 130.34.12.128 is delivered to router R1.

To the rest of the Internet
Example 13 (Cont.)

- The first address in the first subnet is **130.34.12.64/28**
  - Note that the first address of the first subnet is the first address of the block.
  - The last address of the subnet can be found by adding 15 (16 – 1) to the first address.
    - The last address is **130.34.12.79/28**

- The first address in the second subnet is **130.34.12.80/28**
  - Found by adding 1 to the last address of the previous subnet.
  - Again adding 15 to the first address, we obtain the last address, **130.34.12.95/28**.
Example 13 (Cont.)

- Similarly, we find the first address of the third subnet to be 130.34.12.96/28 and the last to be 130.34.12.111/28.

- Similarly, we find the first address of the fourth subnet to be 130.34.12.112/28 and the last to be 130.34.12.127/28.
Variable-Length Subnets

- In previous examples
  - All of subnets have the same mask

- Variable-length subnet
  - Design subnets of different sizes
Example 14

- An organization is granted a block of addresses with the beginning address 14.24.74.0/24.
  - There are $2^{(32-24)} = 256$ addresses in this block.

- The organization needs to have 11 subnets as shown below:
  a. two subnets, each with 64 addresses.
  b. two subnets, each with 32 addresses.
  c. three subnets, each with 16 addresses.
  d. four subnets, each with 4 addresses.

Design the subnets
Example 14: Solution

- The first 128 addresses are used for the first two subnets, each with 64 addresses.
  - The mask for each network is /26.
  - The subnet address for each subnet is given in the figure.
- Use the next 64 addresses for the next two subnets, each with 32 addresses.
  - The mask for each network is /27.
  - The subnet address for each subnet is given in the figure.
Example 14: Solution (Cont.)

- Use the next 48 addresses for the next three subnets, each with 16 addresses.
  - The mask for each network is /28.
  - The subnet address for each subnet is given in the figure.

- Use the last 16 addresses for the last four subnets, each with 4 addresses.
  - The mask for each network is /30.
  - The subnet address for each subnet is given in the figure.
Example 14

Site: 14.24.74.0/24

To the rest of the Internet
Example 14: Solution (Cont.)

……
Example 15

- Assume a company has three offices: Central, East, and West.
  - The Central office is connected to the East and West offices via private, point-to-point WAN lines.
  - The company is granted a block of 64 addresses with the beginning address 70.12.100.128/26.
  - The management has decided to allocate 32 addresses for the Central office and divides the rest of addresses between the two offices.
  - Figure 5.8 shows the configuration designed by the management.
Example 15

Site: 70.12.100.128/26

All addresses from 70.12.100.128 to 70.12.100.191 are delivered to this site.
Example 15: Solution

- The company will have three subnets, one at Central, one at East, and one at West.
- The Central office uses the network address 70.12.100.128/27.
  - This is the first address, and the mask /27 shows that there are 32 addresses in this network.
  - The addresses in this subnet are 70.12.100.128/27 to 70.12.100.159/27
  - Note that three of these addresses are used for the routers and the company has reserved the last address in the sub-block.
  - Note that the interface of the router that connects the Central subnet to the WAN needs no address
  - It is a point-to-point connection
Example 15: Solution (Cont.)

- The West office uses the network address 70.12.100.160/28.
  - The mask /28 shows that there are only 16 addresses in this network.
    - The addresses in this subnet are 70.12.100.160/28 to 70.12.100.175/28.
  - Note that one of these addresses is used for the router and the company has reserved the last address in the sub-block.
  - Note also that the interface of the router that connects the West subnet to the WAN needs no address
    - It is a point-to-point connection
Example 15: Solution (Cont.)

- The East office uses the network address 70.12.100.176/28.
  - The mask /28 shows that there are only 16 addresses in this network.
  - The addresses in this subnet are 70.12.100.176/28 to 70.12.100.191/28.
- Note that one of these addresses is used for the router and the company has reserved the last address in the sub-block.
- Note also that the interface of the router that connects the East subnet to the WAN needs no address
  - It is a point-to-point connection
Address Allocation
Address Allocation

- How are the blocks allocated in classless addressing?
  - By the Internet Corporation for Assigned Names and Addresses (ICANN)

- However, ICANN does not allocate addresses to individual organization
  - It assigns a larger block to an ISP
  - Then ISP divided its assigned block into smaller subblocks to its customers

- Aggress aggregation: many blocks of addresses are aggregated in one block and granted to one ISP
Example 16

An ISP is granted a block of addresses starting with 190.100.0.0/16. The ISP needs to distribute these addresses to three groups of customers as follows:

1. The first group has 64 customers; each needs 256 addresses.
2. The second group has 128 customers; each needs 128 addresses.
3. The third group has 128 customers; each needs 64 addresses.

Design the subblocks and give the CIDR notation for each subblock. Find out how many addresses are still available after these allocations.
Solution

Group 1

For this group, each customer needs 256 addresses. This means the suffix length is 8 (\(2^8 = 256\)). The prefix length is then \(32 - 8 = 24\).

01: 190.100.0.0/24 \(\rightarrow\) 190.100.0.255/24

02: 190.100.1.0/24 \(\rightarrow\) 190.100.1.255/24

..................

64: 190.100.63.0/24 \(\rightarrow\) 190.100.63.255/24

Total = 64 \(\times\) 256 = 16,384
Solution (Continued)

Group 2

For this group, each customer needs 128 addresses. This means the suffix length is 7 \((2^7 = 128)\). The prefix length is then \(32 - 7 = 25\). The addresses are:

001: 190.100.64.0/25 \(\Rightarrow\) 190.100.64.127/25
002: 190.100.64.128/25 \(\Rightarrow\) 190.100.64.255/25
128: 190.100.127.128/25 \(\Rightarrow\) 190.100.127.255/25

Total = 128 \(\times\) 128 = 16,384
Group 3

For this group, each customer needs 64 addresses. This means the suffix length is 6 \((2^6 = 64)\). The prefix length is then \(32 - 6 = 26\).

\[
\begin{align*}
001: & 190.100.128.0/26 & \rightarrow & 190.100.128.63/26 \\
002: & 190.100.128.64/26 & \rightarrow & 190.100.128.127/26 \\
\cdots & \cdots & \cdots & \cdots \\
128: & 190.100.159.192/26 & \rightarrow & 190.100.159.255/26 \\
\text{Total} = 128 \times 64 &= 8,192
\end{align*}
\]
Solution (Continued)

ISP

To and from the Internet

Granted Addresses: 190.100.0.0 to 190.100.255.255

Group 1:
190.100.0.0 to 190.100.63.255

Customer 001: 190.100.0.0/24
Customer 064: 190.100.63.0/24

Group 2:
190.100.64.0 to 190.100.127.255

Customer 001: 190.100.64.0/25
Customer 128: 190.100.127.128/25

Group 3:
190.100.128.0 to 190.100.159.255

Customer 001: 190.100.128.0/26
Customer 128: 190.100.159.192/26

Available
190.100.160.0 to 190.100.255.255
Solution (Continued)

Number of granted addresses: 65,536
Number of allocated addresses: 40,960
Number of available addresses: 24,576