COMP3331/COMP9331

Computer Networks and Applications

IPv4

http://www.cse.unsw.edu.au/~cs3331/

Lecture overview

- Key concepts
  - Classful addressing
  - Network mask
  - Subnetting
  - Supernetting
  - Classless addressing
- Reference: Forouzan, TCP/IP Protocol Suite, 4th Ed. McGraw Hill

IP addressing basics

- The Internet is used to "move" data from host to host
- All devices connected to the Internet must have a globally *unique* IP address
  - No two devices can have the same public IP address
  - This address can be permanent or temporary
- IPv4 addresses are 32 bits (= 4 octets) long
  - This gives 2^32 ~ 4.29 billion addresses

Notation

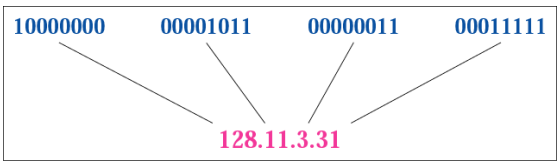
- IPv4 addresses can be written using the following notation
  - Binary
  - Dotted Decimal
  - Hexadecimal

Binary Notation

01110101 10010101 00011101 11101010

Figure 4-1

Dotted-decimal notation



Hexadecimal Notation

0111 0101 1001 0101 0001 1101 1110 1010

75 95 1D EA

0x75951DEA

Exercises

- Exercise 1:
  Change the following IP address from binary notation to dotted-decimal notation.
  10000001 00001011 00001011 11101111
- Exercise 2:
  Change the following IP address from dotted-decimal notation to binary notation.
  111.56.45.78

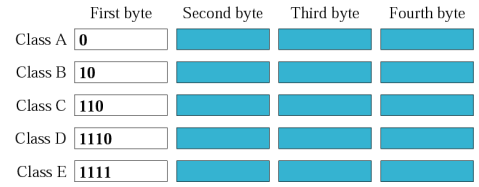
Solutions

- Exercise 1:
  129.11.11.239
- Exercise 2:
  01101111 00111000 00101101 01001110.

Classful addressing

- IP addresses were divided into 5 classes: A,B,C,D and E
  - This is the original scheme known as classful addressing
  - From mid-90's, classless addressing is introduced
  - However, classful addressing is still used

Finding the class in binary notation



Example: Any address whose first bit is 0 belongs to class A.
Any address whose first 2 bits are 10 belongs to class B etc.

Exercises

1. Find the class of these IP addresses:
   a) 11000001 10000011 00011011 11111111
   b) 10000001 10000011 00011011 11111111
2. How many class B addresses are there altogether?
3. What is the range of class B addresses? Answer this by giving the first and last class B addresses in dotted decimal notation.

Solution

1. a) First 3 bits are 110 -> Class C.
   b) First 2 bits are 10 -> Class B.
2. Class B addresses: the first two bits are 10 then followed by 30 bits of 1/0
   -> 2^30 addresses

3. The first and last class B addresses in binary are:

10000000 00000000 00000000 00000000

10111111 11111111 11111111 11111111

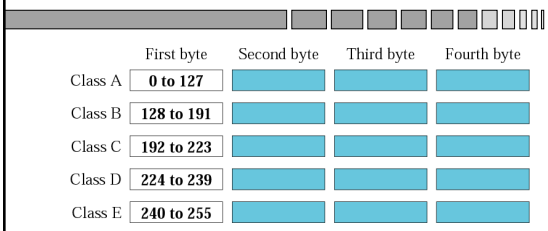
In dotted decimal notation, they are:

128.0.0.0 and 191.255.255.255

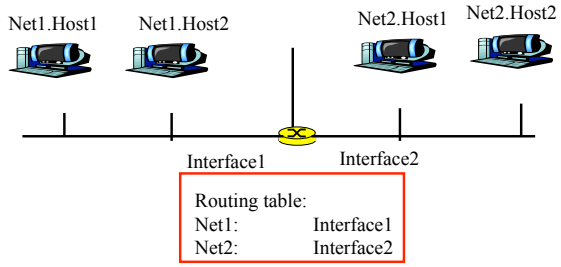
Finding the class in dotted decimal notation

- Given an IP address in dotted decimal notation, we can identify its class by looking at the first byte.
- Example: The first byte of a class C address is of the form 110x xxxx where x is either 0 or 1, which means that it ranges from 1100 0000 (192) to 1101 1111 (223)

Finding the class in decimal notation



IP addresses are hierarchical

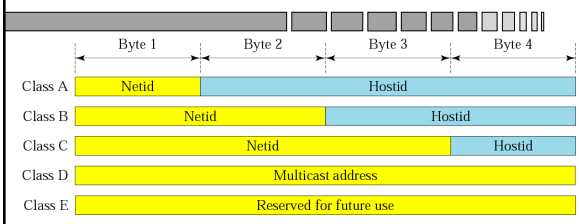


Routing is based on network address.

Netid and hostid

- IP addresses in classes A,B and C are divided into netid and hostid
  - Netid: Identifying the network
  - Hostid: Identifying a host within the network
- Hosts within a network
  - Have the same netid
  - But different hostid

Netid and hostid



Classes and blocks

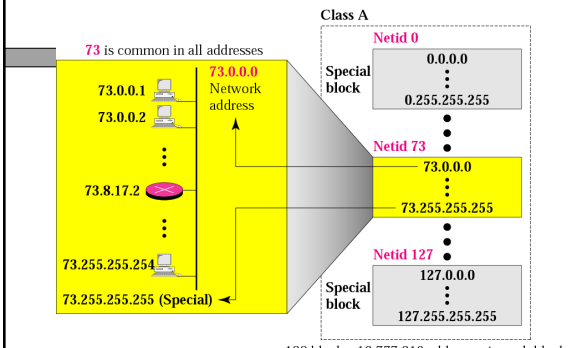
All addresses within a block have the same netid.
For the class A block with netid = 0, the addresses in the block are:

netid	hostid			
00000000	00000000	00000000	00000000	0.0.0.0
00000000	00000000	00000000	00000001	0.0.0.1
00000000	00000000	00000000	00000010	0.0.0.2
• • •				
00000000	11111111	11111111	11111111	0.255.255.255

Classes and blocks

- Class A is divided into 128 blocks
  - Each block has a different netid
  - 1st block: 0.0.0.0 to 0.255.255.255 (netid = 0)
  - 2nd block: 1.0.0.0 to 1.255.255.255 (netid = 1)
  - Last block: 127.0.0.0 to 127.255.255.255 (netid = 127)
- *Network address*: the first address of the block

Blocks in class A



128 blocks: 16,777,216 addresses in each block

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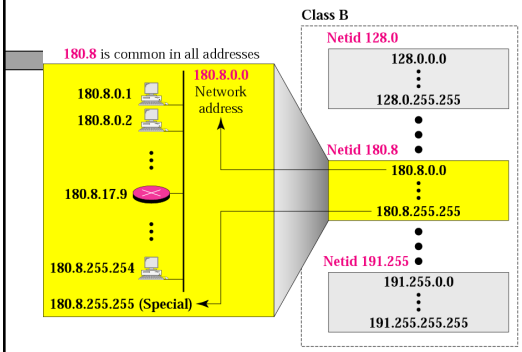
Blocks in class B



16,384 blocks: 65,536 addresses in each block

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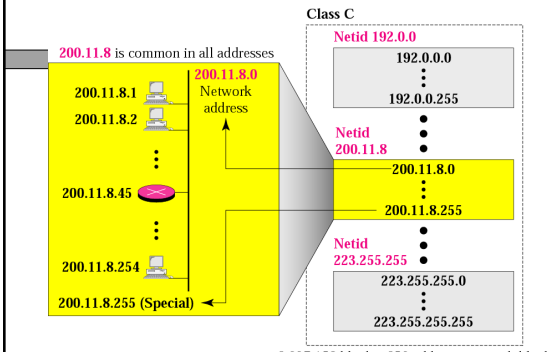
Blocks in class C



2,097,152 blocks: 256 addresses in each block

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Use of addresses

- Classes A, B and C addresses can be assigned to hosts, router ports etc
  - They are also known as unicast addresses
- Class D addresses are for multicast
  - Multicast: One sender, multiple recipients
- Class E addresses are reserved for special purposes

Network addresses

- The network address is the first address in the block
- The network address defines the network to the rest of the Internet
  - Routers route packets based on network address
- Given the network address, we can find the class of the address and the range of the address in the block

Exercise

- Given the network address 132.21.0.0, find the class, the block, and the range of the addresses.

Solution

- Solution:
  - The class is B because the first byte is between 128 and 191.
  - The block has a netid of 132.21.
  - The addresses range from 132.21.0.0 to 132.21.255.255.

Finding netid from IP address

- Given an IP address, we can identify the network address by
  - Finding which class it belongs to and then obtain the netid part
  - E.g. Given 134.45.78.2
    - » This is class B. The netid is the first 2 bytes. The network address is 134.45.0.0
- An alternative is to use network mask

Network mask

- Let & denote the bitwise AND operation
  - Example: 1100 & 1010 = 1000
- A network mask is
  - 32 bit binary number
  - Often written in dotted decimal notation
  - Is chosen such that the following relation holds

Network address =
IP address & Network mask

Network mask (cont'd)

- The network mask is different for each class
  - Class A
    - » 11111111 00000000 00000000 00000000 or 255.0.0.0
  - Class B
    - » 11111111 11111111 00000000 00000000 or 255.255.0.0
  - Class C
    - » 11111111 11111111 11111111 00000000 or 255.255.255.0
- Essentially:
  - '1' indicates that the bit is a netid bit
  - '0' indicates that the bit is a hostid bit

Example

- A host has IP address 129.11.11.239 and network mask 255.255.0.0, find the network to which this host belongs.
- Method 1:

10000001 00001011 00001011 11101111
& 11111111 11111111 00000000 00000000
= 10000001 00001011 00000000 00000000
= 129.11.0.0

Example (cont'd)

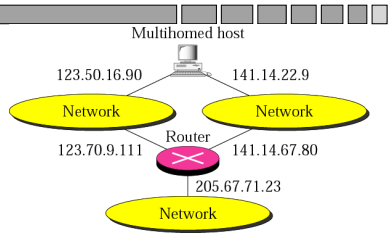
- Let X denote a byte, then
  - X & 0 = 0 and X & 255 = X
- Method 2:

129. 11. 11. 239
& 255. 255. 0. 0
= 129. 11. 0. 0

Why network mask?

- A host is specified by two attributes
  - An IP address
  - A network mask
- We can find the netid from these two attributes without finding which class the address belongs to
  - This makes it easier to program
  - You'll see the importance of network mask later when we study subnetting and classless addressing

Multihomed devices

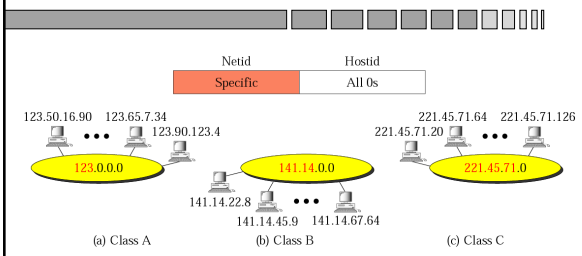


Strictly speaking, IP addresses are assigned to network interfaces.

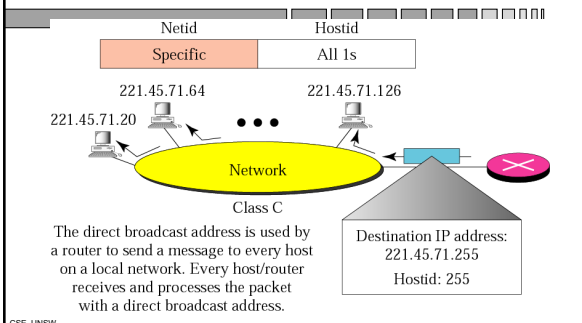
Special IP addresses

- Some IP addresses have been assigned special meaning
- They are not meant to be assigned to individual hosts

Network addresses



Example of direct broadcast address

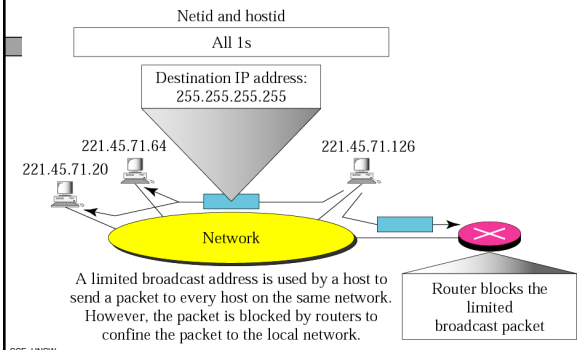


The direct broadcast address is used by a router to send a message to every host on a local network. Every host/router receives and processes the packet with a direct broadcast address.

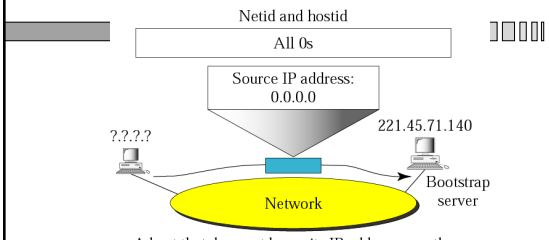
Assignable IP addresses

- These IP addresses cannot be assigned to individual hosts
  - Netid + All-zero-hostid
  - Netid + All-one-hostid
- Example, although each Class C network, has 256 different hostid's, the number of assignable addresses is only 254

Example of limited broadcast address

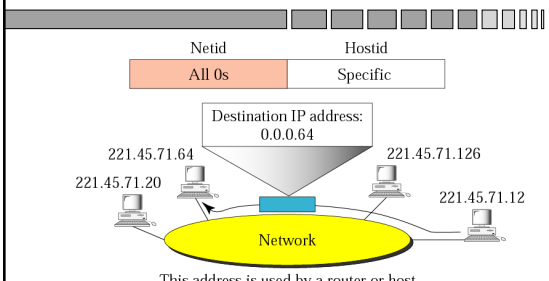


Example of *this* host on *this* address

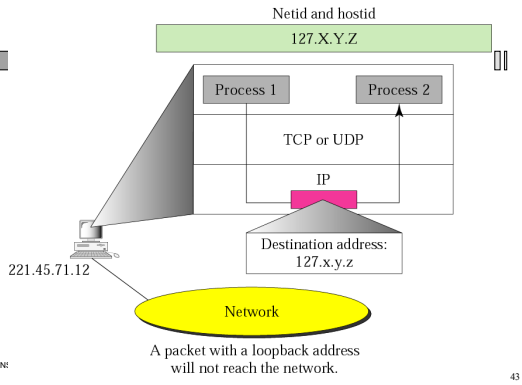


To find out more: BOOTP and DHCP protocols (Chap 17)

Example of specific host on *this* network



Example of loopback address

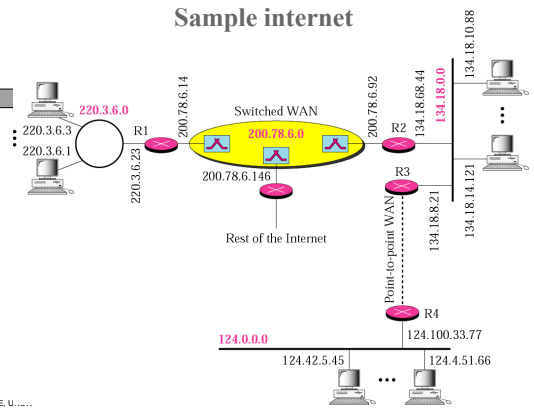


A packet with a loopback address will not reach the network.

Private addresses

- Some IP addresses are reserved to be used as private addresses
- A host can use private address if it is not directly connected to the Internet
  - To connect to the Internet, Network Address Translation is required
- The following netids are designated as private
  - 10, 172.16-172.31, 192.168.0-192.168.255

Sample internet



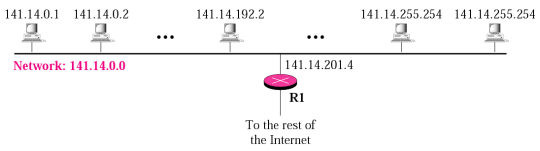
Sample Internet - commentary

- The Internet is organised into networks
- Routers interconnect these networks into the Internet
- All hosts within the same network have the same netid

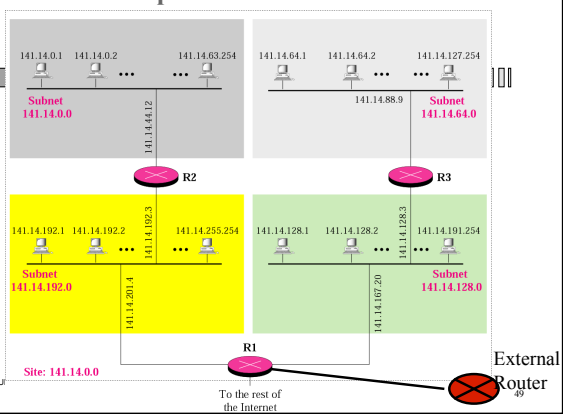
Motivation for subnetting

- Classful addressing means network must be of size: 65536 (2^16) for Class B and 256 (2^8) for Class C
- If an organisation wants to have 4 networks each with 300 hosts, then it needs 4 Class B networks
  - More than 200,000 addresses are wasted
- Subnetting was introduced in 1980s to solve this problem
  - In subnetting, a network is divided into subnets (short for sub-networks)

A network which is not subnetted



Example of a subnetted network



Transparency of subnetting

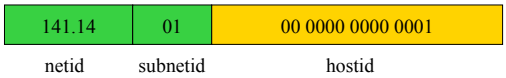
- In the example on the previous page, only R1, R2 and R3 need to know about the subnets
  - Each subnet requires an entry in their routing table
- Routers external to the network do not need to know about subnetting
  - The external router requires only an entry for the network (i.e. 141.14.0.0) in its routing table

Subnetid

141.14.64.1 is an address in the subnet 141.14.64.0 (subnet number)

Before subnetting

After subnetting



Subnet mask

- When we configure a host, we need to specify
  - The IP address of the host, and
  - The subnet mask
- The subnet mask has the same role as network mask
  - '1' indicates that bit is a netid or subnetid bit
  - '0' indicates that bit is a hostid bit

Subnet mask example

Given the following netid, subnetid and hostid
(Note: 1st 2 bytes are in dotted decimal, last 2 bytes in binary)

netid subnetid hostid

The corresponding subnet mask is

In dotted decimal notation, it is 255.255.192.0

Subnet mask

- The subnet number is computed from
  Subnet Address =
  IP Address & Subnet Mask
- Exercise: What is the subnet address if the IP address is 200.45.34.56 and the subnet mask is 255.255.240.0?

Solution - Method 1

11001000 00101101 00100010 00111000

11111111 11111111 1111**0000** **00000000**

11001000 00101101 0010**0000** **00000000**

The subnetwork address is **200.45.32.0**.

Short-Cut Method

** If the byte in the mask is 255, copy the byte in the address.

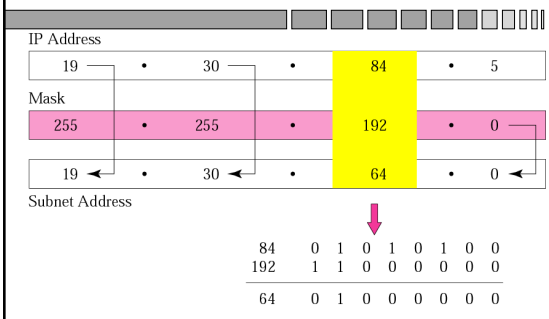
** If the byte in the mask is 0, replace the byte in the address with 0.

** If the byte in the mask is neither 255 nor 0, we write the mask and the address in binary and apply the AND operation.

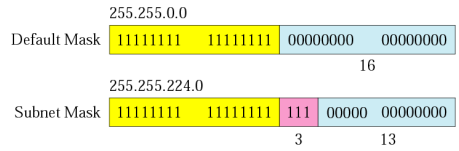
Exercise

- What is the subnet address if the IP address is 19.30.84.5 and the mask is 255.255.192.0?

Example 2



Comparison of a default mask and a subnet mask



Since subnetid has 3 bits, the number of subnets allowed is 2^3.

Since the hostid has 13 bit, the number of addresses per subnet is 2^13.

Address range in a subnet

- A subnet has an subnet address of 141.14.64.0, find the address range in the subnet if its subnet mask is

1. 255.255.224.0
2. 255.255.240.0

Solution

If the network mask is 255.255.224.0 (netid - 16bits, subnetid - 3bits)
The address range is:

141.14	010	0 0000 0000 0000
netid	subnetid	hostid
141.14	010	1 1111 1111 1111

to

If the network mask is 255.255.240.0 (netid - 16bits, subnetid - 4bits)
The address range is:

141.14	0100	0000 0000 0000
netid	subnetid	hostid
141.14	0100	1111 1111 1111

to

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Notes on subnetting

- To define a subnet, you must define both
  - Subnet address and
  - Subnet mask
- It's not enough to give only the subnet address

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Example 3

A company is granted the site address 201.70.64.0 (class C). The company needs six subnets. Design the subnets.

Solution

The number of 1s in the default mask is 24 (class C).

Solution (Continued)

The company needs six subnets. This number 6 is not a power of 2. The next number that is a power of 2 is 8 (2^3). We need 3 more 1s in the subnet mask. The total number of 1s in the subnet mask is 27 (24 + 3).

The total number of 0s is 5 (32 - 27). The mask is

Solution (Continued)

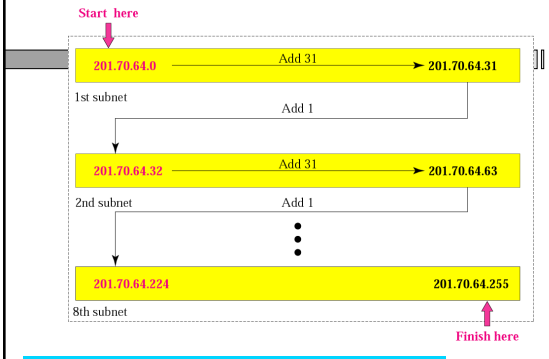
11111111 11111111 11111111 11100000

or

255.255.255.224

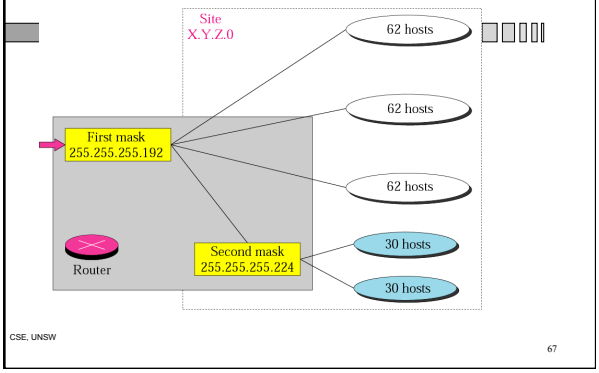
The number of subnets is 8.
The number of addresses in each subnet is 2^5 (5 is the number of 0s) or 32.

The address range for the subnets are:



The subnet number is the first address in the subnet.

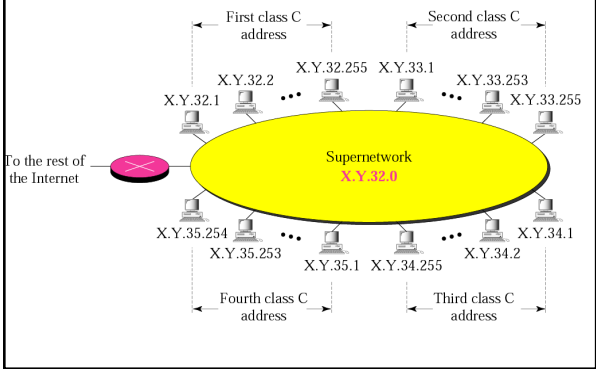
Variable-length subnetting



Supernetting

- Background
  - Class B addresses were running out
  - There were still plenty of class C addresses but each class C network has only 256 addresses
- If an organisation wants 1000 addresses, supernetting allows 4 class C networks to be merged to form a supernet with 1024 addresses

A supernetwork



Address assignment

- If a subnet consists of 100 Class C networks and if these addresses are randomly chose
  - The routers external to the supernet requires 100 entries (one for each Class C network) for the supernet
- It would be desirable if only 1 entry is required
- This can be achieved by carefully assigning addresses

Address assignment rules

- The number of blocks must be a power of 2 (1, 2, 4, 8, 16, . . .).
- The blocks must be contiguous in the address space (no gaps between the blocks).
- The third byte of the first address in the superblock must be evenly divisible by the number of blocks. In other words, if the number of blocks is N, the third byte must be divisible by N.

Exercise

A company needs 600 addresses. Which of the following set of class C blocks can be used to form a supernet for this company?

a)198.47.32.0 198.47.33.0 198.47.34.0

b)198.47.32.0 198.47.42.0 198.47.52.0 198.47.62.0

c)198.47.31.0 198.47.32.0 198.47.33.0 198.47.34.0

d)198.47.32.0 198.47.33.0 198.47.34.0 198.47.35.0

Solution

a)198.47.32.0 198.47.33.0 198.47.34.0

Not acceptable. #blocks not a power of 2.

b)198.47.32.0 198.47.42.0 198.47.52.0 198.47.62.0

Not acceptable. Not contagious.

c)198.47.31.0 198.47.32.0 198.47.33.0 198.47.34.0

Not acceptable. 3rd byte of 1st address not divisible by 4.

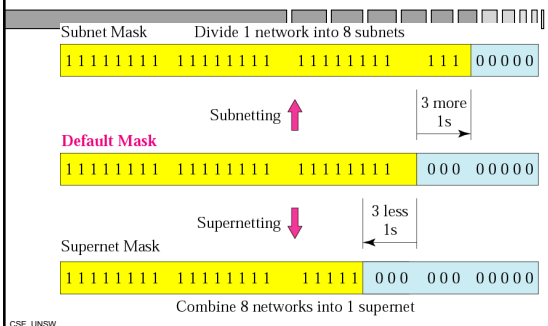
d)198.47.32.0 198.47.33.0 198.47.34.0 198.47.35.0

Acceptable.

Specifying a supernet

- Analogous to a subnet, a supernet is specified by
  - A supernet address
  - A supernet mask

Comparison of subnet, default, and supernet masks



Example

We need to make a supernetwork out of 16 class C blocks. What is the supernet mask?

Solution

We need 16 blocks. For 16 blocks we need to change four 1s to 0s in the default mask. So the mask is

11111111 11111111 1111**0000** 00000000

or

255.255.240.0

Example

A supernet has a first address of 205.16.32.0 and a supernet mask of 255.255.248.0. How many blocks are in this supernet and what is the range of addresses?

Solution

The supernet mask has 21 1s. The default mask has 24 1's. Since the difference is 3, there are 2^3 or 8 blocks in this supernet.

The blocks are 205.16.32.0, 205.16.33.0, …, 205.16.39.0.

The first address is 205.16.32.0. The last address is 205.16.39.255.

Classless addressing

- Classful addressing: The number of addresses in a network can only be 2^8, 2^16 or 2^24
- A supernet consisting of multiple Class C networks can have 256 * 2^n (n=2,...7) addresses
- The number of addresses in a *classless network* can be any number as long as it is a power of 2
  - Classless network is part of the Classless Interdomain Routing Protocol (CIDR)

Beginning address

- The addresses in a classless network must be chosen carefully so that only one entry in the routing table is required
- The beginning address of a classless network must be divisible by the number of addresses in the network

Beginning address (cont'd)

- The IP address in dotted decimal a.b.c.d is actually the decimal number:

  $a\ 256^3 + b\ 256^2 + c\ 256 + d$

- E.g. to check whether an IP address is divisible by 16, we only need to check whether the last byte is divisible by 16

Example 9

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 10

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.

Classless networks

- A classless network is specified by
  - A network address
  - A mask
- Since a mask consists of a number of 1's at the left followed by a number of 0's, instead of specifying the mask in dotted decimal, we can specify the number of 1's

CIDR notation

- A classless network is usually written as A.B.C.D/n
  - 'n' specifies the number of 1's in the mask
  - This is known as slash notation or CIDR notation
  - The first n bits of A.B.C.D is known as the prefix and n is known as the prefix length
  - The last (32-n) bits are known as the suffix

Example

A small organization has the network **205.16.37.24/29**. What is the range of the block?

Solution

The beginning address is 205.16.37.24. To find the last address we keep the first 29 bits and change the last 3 bits to 1s.

Beginning: **11001111 00010000 00100101 00011**000
Ending : **11001111 00010000 00100101 00011**111

There are only 8 addresses in this block.

Example 13

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

Solution

The prefix length is 27, which means that we must keep the first 27 bits as 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.

Subnetting classless network

- A classless network also be subnetted
- Example:

  An organization is granted the block 130.34.12.64/26. The organization needs to have four subnets. What are the subnet addresses and the range of addresses for each subnet?

Solution

Since the prefix length is 26. This means the last 6 bits are available as hostid, the total number of addresses in the block is 64 (2^6). If we create four subnets, each subnet will have 16 addresses.

Solution (Continued)

Let us first find the subnet prefix (subnet mask). We need four subnets, which means we need to add two more 1s to the site prefix. The subnet prefix is then /28.

Subnet 1: 130.34.12.64/28 to 130.34.12.79/28.

Subnet 2 : 130.34.12.80/28 to 130.34.12.95/28.

Subnet 3: 130.34.12.96/28 to 130.34.12.111/28.

Subnet 4: 130.34.12.112/28 to 130.34.12.127/28.