IP Addresses (IPv4)

ICT 2255

What is an IP Address?

- *The identifier used in the IP layer of the TCP/IP protocol suite to identify each device connected to the Internet.*
- A 32-bit address that ***uniquely*** and ***universally*** defines the connection of a host or a router to the Internet.
- An IP address is the address of the interface.

Address Space

- The total number of addresses used by the protocol.
- If a protocol uses '*b*' bits to define an address, the address space is 2^b.
- Address Space of IPv4:

  2^{32}= **4,294,967,296.**

Notation

- Base-2
- Base-16
- Base-256
  - **Dotted-decimal notation**

10000001 00001011 00001011 11101111

128. 12.14.254

. *0X810B0BEF*

Questions

Change the following IP addresses from binary notation to dotted-decimal notation.

a. 10000001 00001011 00001011 11101111
b. 11000001 10000011 00011011 11111111

Solution

We replace each group of 8 bits with its equivalent decimal number and add dots for separation:

a. 129.11.11.239 b. 193.131.27.255

Questions

Change the following IP addresses from dotted-decimal notation to binary notation.

a. ***111.56.45.78*** b. ***221.34.7.82***

We replace each decimal number with its binary equivalent:

a. ***01101111 00111000 00101101 01001110***
b. ***11011101 00100010 00000111 01010010***

Questions

Find the error, if any, in the following IP addresses:

a. ***111.56.045.78*** b. ***221.34.7.8.20***

c. ***75.45.301.14*** d. ***11100010.23.14.67***

a. ***There are no leading zeroes in dotted-decimal notation (045).***

b. ***We may not have more than four numbers in an IP address.***

c. ***In dotted-decimal notation, each number is less than or equal to 255; 301 is outside this range.***

d. ***A mixture of binary notation and dotted-decimal notation is not allowed.***

Questions

Change the following IP addresses from binary notation to hexadecimal notation.

a. 10000001 00001011 00001011 11101111

b. 11000001 10000011 00011011 11111111

Solution

We replace each group of 4 bits with its hexadecimal equivalent.

a. $0X810B0BEF$ ***or*** $810B0BEF_{16}$
b. $0XC1831BFF$ ***or*** $C1831BFF_{16}$

Range of Addresses

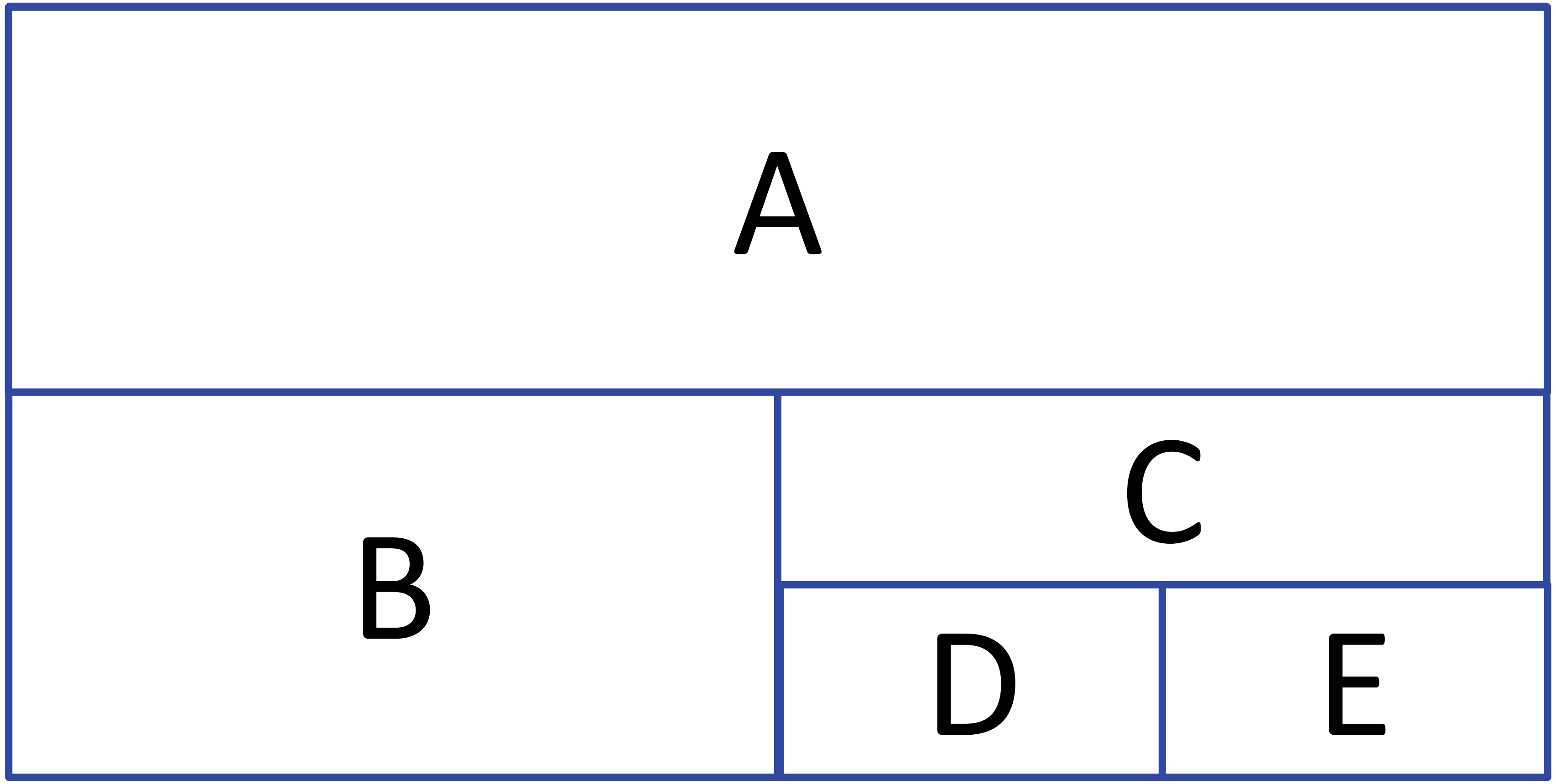
- First address
- Last address
- Range
- Perform addition or subtraction in the corresponding base.
- Questions.

Operations

- Bitwise NOT
- Bitwise AND
- Bitwise OR

Classful Addressing

Classes



Classes

Class A	50 %	$2^{32}/2 = 2^{31}$	2, 147, 483, 648 addresses
Class B	25 %	$2^{32}/2^{2} = 2^{30}$	1, 073, 741, 824 addresses
Class C	12.5 %	$2^{32}/2^{3} = 2^{29}$	536, 870, 912 addresses
Class D	6.25 %	$2^{32}/2^{4} = 2^{28}$	268, 435, 456 addresses
Class E	6.25 %	$2^{32}/2^{4} = 2^{28}$	268, 435, 456 addresses

Recognizing Classes

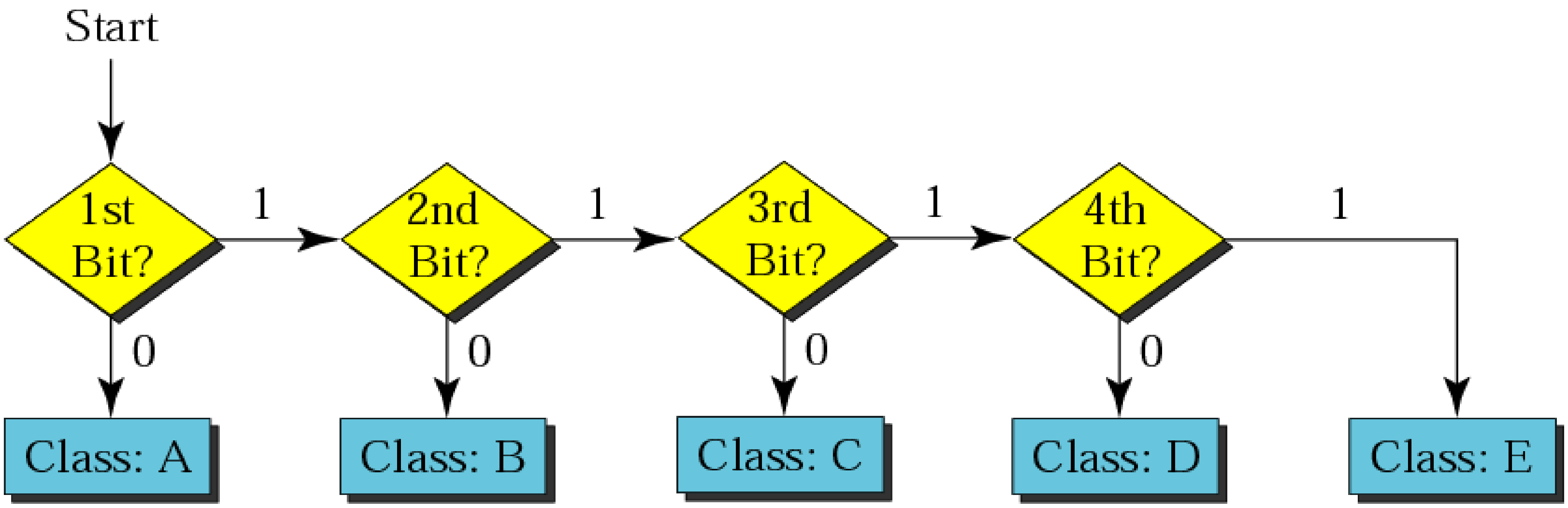
	Octet 1	Octet 2	Octet 3	Octet 4
Class A	0........			
Class B	10......			
Class C	110.....			
Class D	1110....			
Class E	1111....			

Binary notation

	Byte 1	Byte 2	Byte 3	Byte 4
Class A	0–127			
Class B	128–191			
Class C	192–223			
Class D	224-239			
Class E	240–255			

Dotted-decimal notation

Recognizing Address Class: Continuous Checking



Examples

How can we prove that we have 2,147,483,648 addresses in class A?

Solution

In class A, only 1 bit defines the class. The remaining 31 bits are available for the address. With 31 bits, we can have 2^{31} or 2,147,483,648 addresses.

Examples

Find the class of each address:

a. 00000001 00001011 00001011 11101111
b. 11000001 10000011 00011011 11111111
c. 10100111 11011011 10001011 01101111
d. 11110011 10011011 11111011 00001111

Solution

a. The first bit is 0. This is a class A address.
b. The first 2 bits are 1; the third bit is 0. This is a class C address.
c. The first bit is 0; the second bit is 1. This is a class B address.
d. The first 4 bits are 1s. This is a class E address..

Examples

Find the class of each address:

a. 227.12.14.87 b.193.14.56.22 c.14.23.120.8
d. 252.5.15.111 e.134.11.78.56

Solution

a. The first byte is 227 (between 224 and 239); the class is D.
b. The first byte is 193 (between 192 and 223); the class is C.
c. The first byte is 14 (between 0 and 127); the class is A.
d. The first byte is 252 (between 240 and 255); the class is E.
e. The first byte is 134 (between 128 and 191); the class is B.

Examples

Class A has 2^{31} (2,147,483,648) addresses. How can we prove this same fact using dotted-decimal notation?

Solution

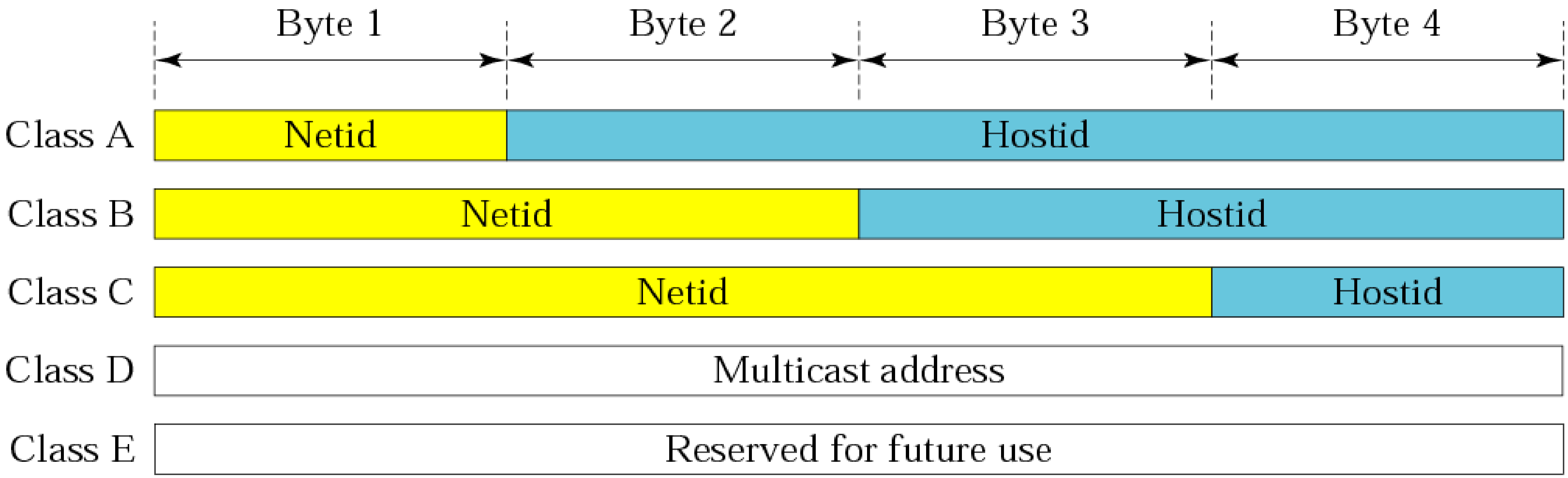
The addresses in class A range from 0.0.0.0 to 127.255.255.255.

Last address: $127 \times 256^3 + 255 \times 256^2 + 255 \times 256^1 + 255 \times 256^0 = 2{,}147{,}483{,}647$

First address: $= 0$

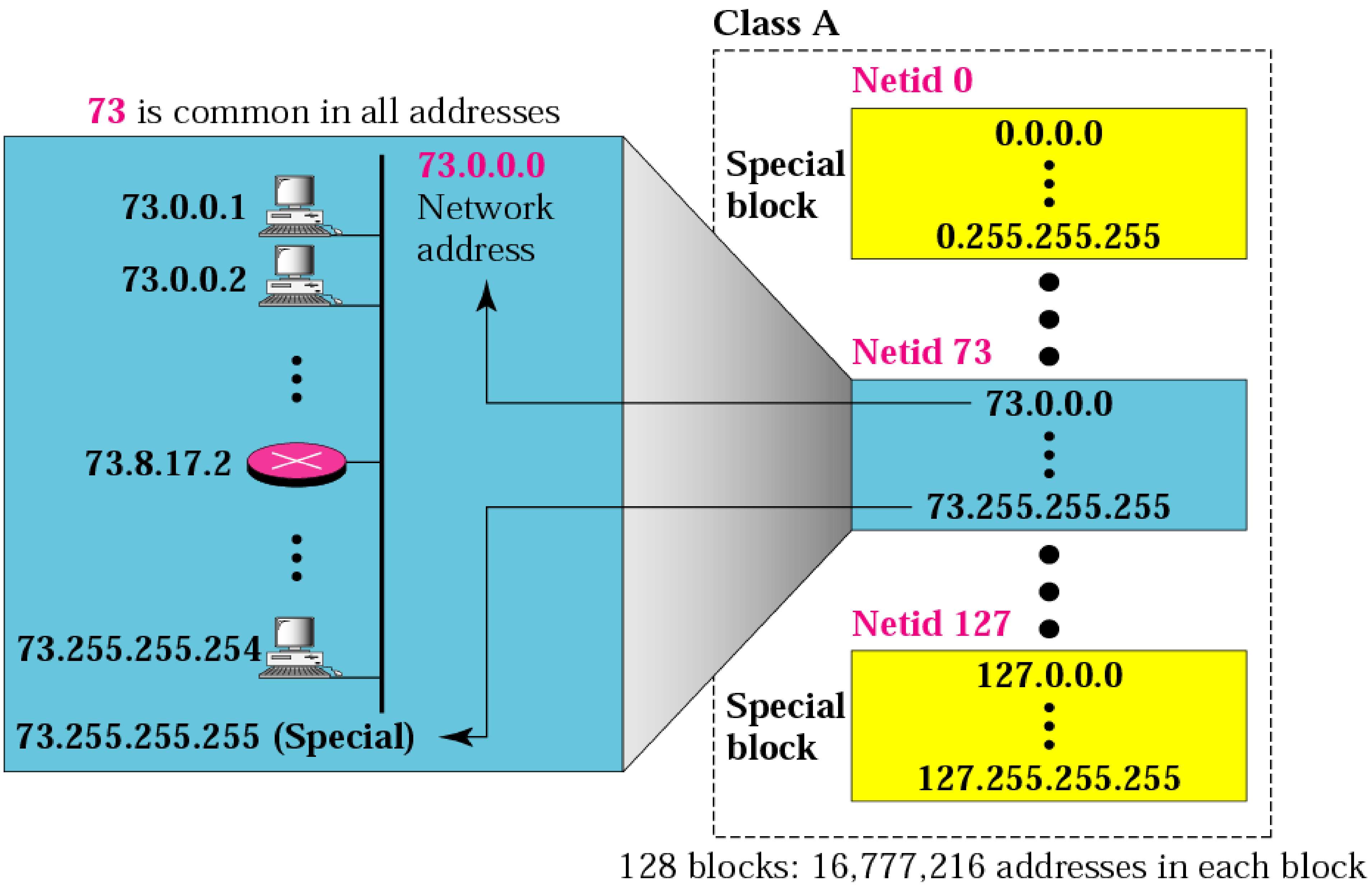
If we subtract the first from the last and add 1 to the result (remember we always add 1 to get the range), we get 2,147,483,648 or 2^{31}.

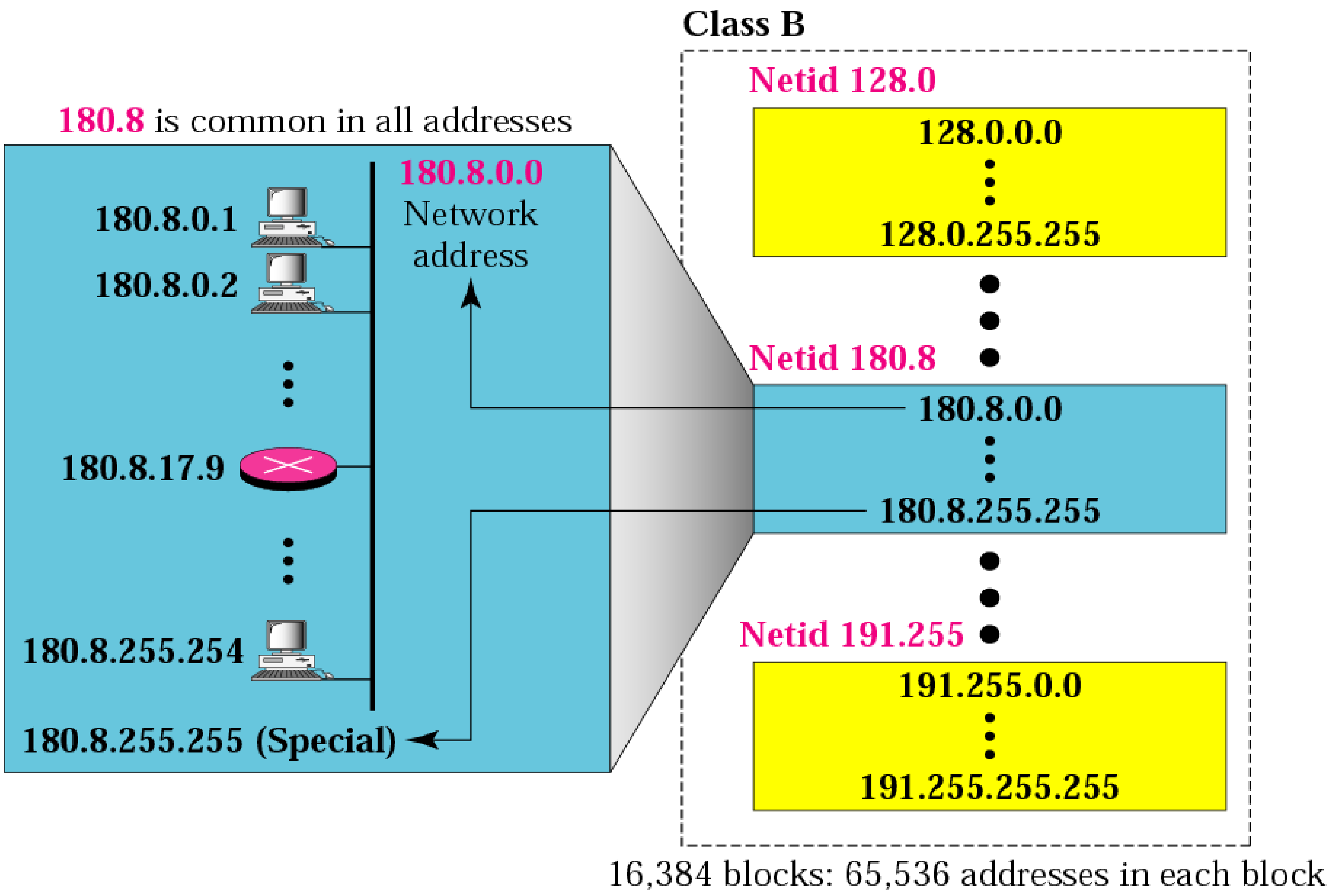
Netid and Hostid

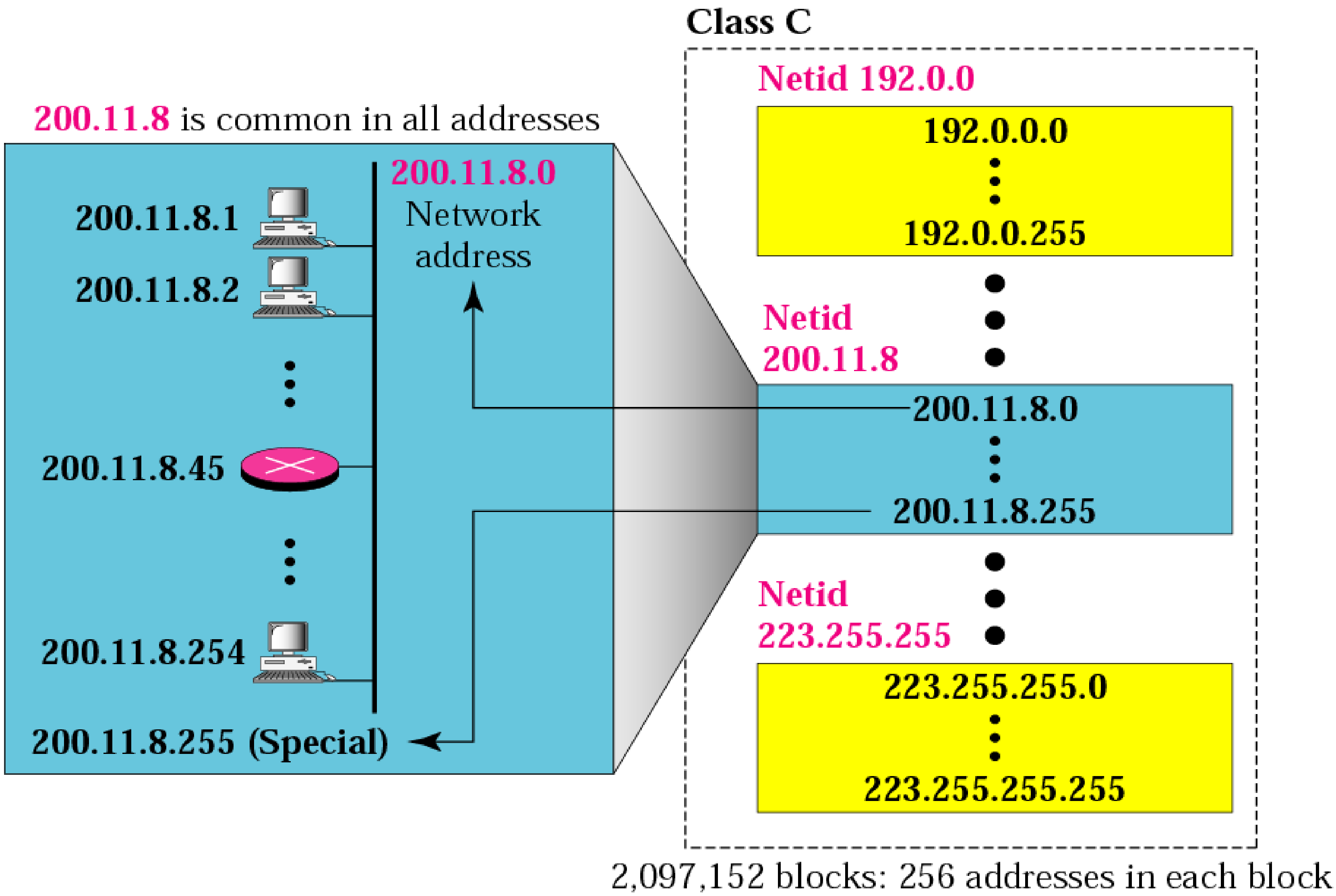


Summary of Classes

Class	# bits in netid	# bits fixed	Total number of blocks	# addresses in each block	Remarks
A					
B					
C					
D					
E					


Class A
73 is common in all addresses
73.0.0.0
Network address
73.0.0.1
73.0.0.2
73.8.17.2
73.255.255.254
73.255.255.255 (Special)
Netid 0
Special block
0.0.0.0
0.255.255.255
Netid 73
73.0.0.0
73.255.255.255
Netid 127
Special block
127.0.0.0
127.255.255.255
128 blocks: 16,777,216 addresses in each block


Class B
Netid 128.0
128.0.0.0
128.0.255.255
180.8 is common in all addresses
180.8.0.0
Network address
180.8.0.1
180.8.0.2
180.8.17.9
180.8.255.254
180.8.255.255 (Special)
Netid 180.8
180.8.0.0
180.8.255.255
Netid 191.255
191.255.0.0
191.255.255.255
16,384 blocks: 65,536 addresses in each block


Class C
Netid 192.0.0
192.0.0.0
192.0.0.255
Netid
200.11.8
200.11.8.0
200.11.8.255
Netid
223.255.255
223.255.255.0
223.255.255.255
200.11.8 is common in all addresses
200.11.8.0
Network
address
200.11.8.1
200.11.8.2
200.11.8.45
200.11.8.254
200.11.8.255 (Special)
2,097,152 blocks: 256 addresses in each block

Classes and Blocks: Class D and Class E

- Class D addresses are used for multicasting; there is only one block in this class.
- Class E addresses are reserved for future purposes.

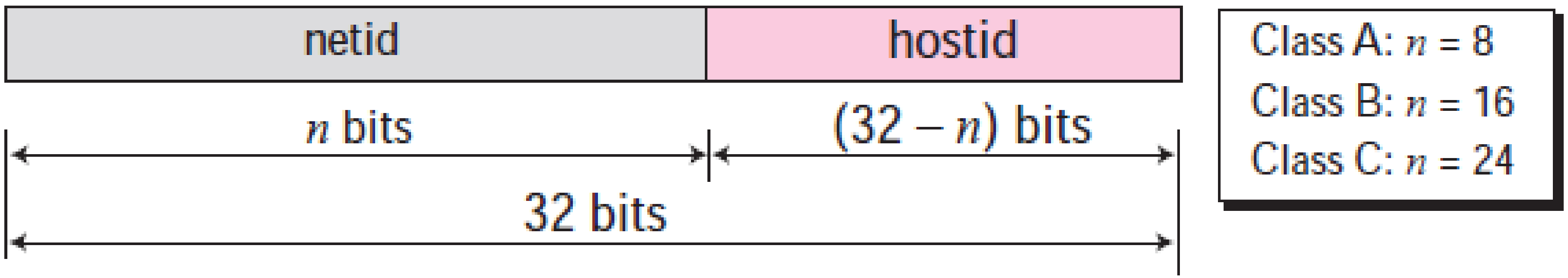
Examples

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

Addresses	Class	Netid of block	Range
17.0.0.0	A	17	17.0.0.0 to 17.255.255.255
131.21.0.0	B	131.21	132.21.0.0 to 132.21.255.255
220.34.76.0	C	220.34.76	220.34.76.0 to 220.34.76.255

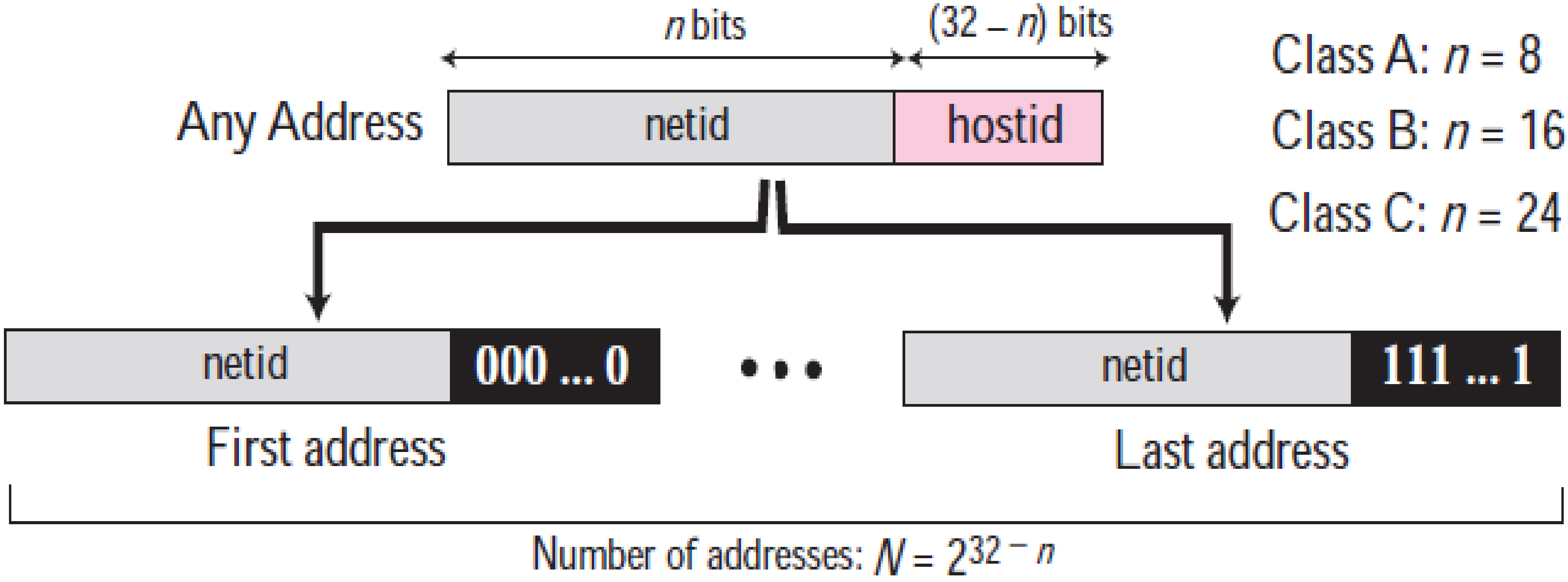
Two-Level Addressing

- First address: network address → assigned to organization.
- The range of addresses can automatically be inferred from the network address.

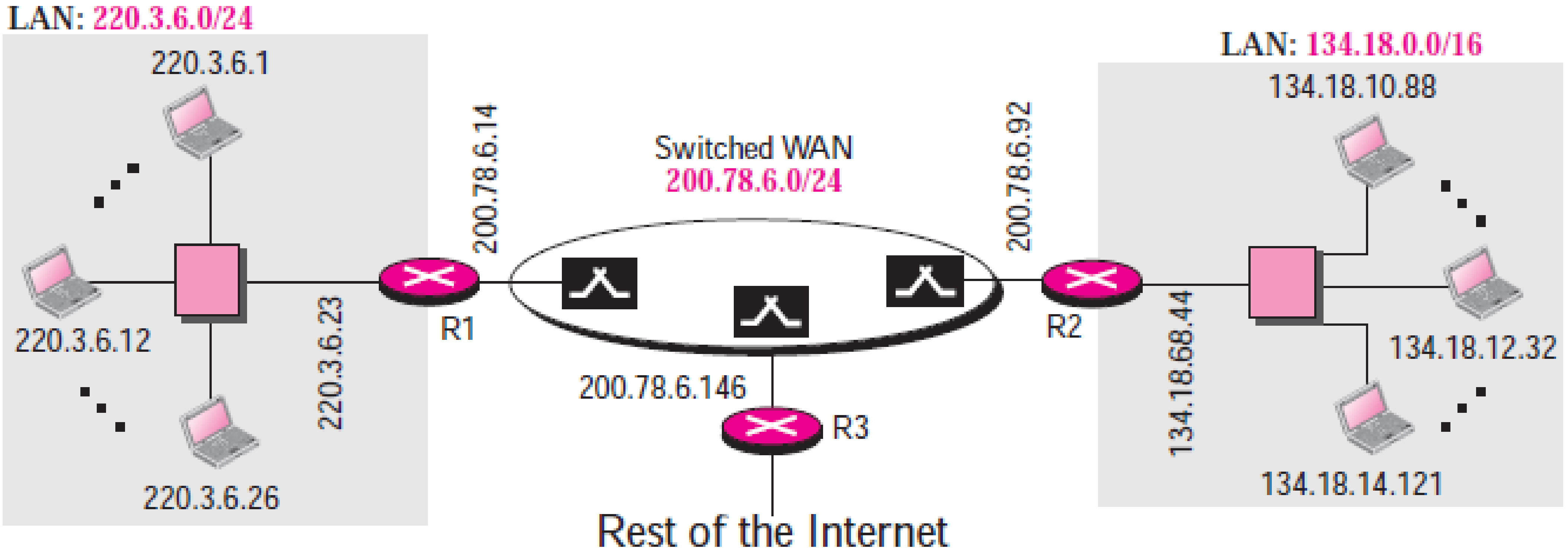


Extracting Information in a block

- # addresses
- First address
- Last address



Example

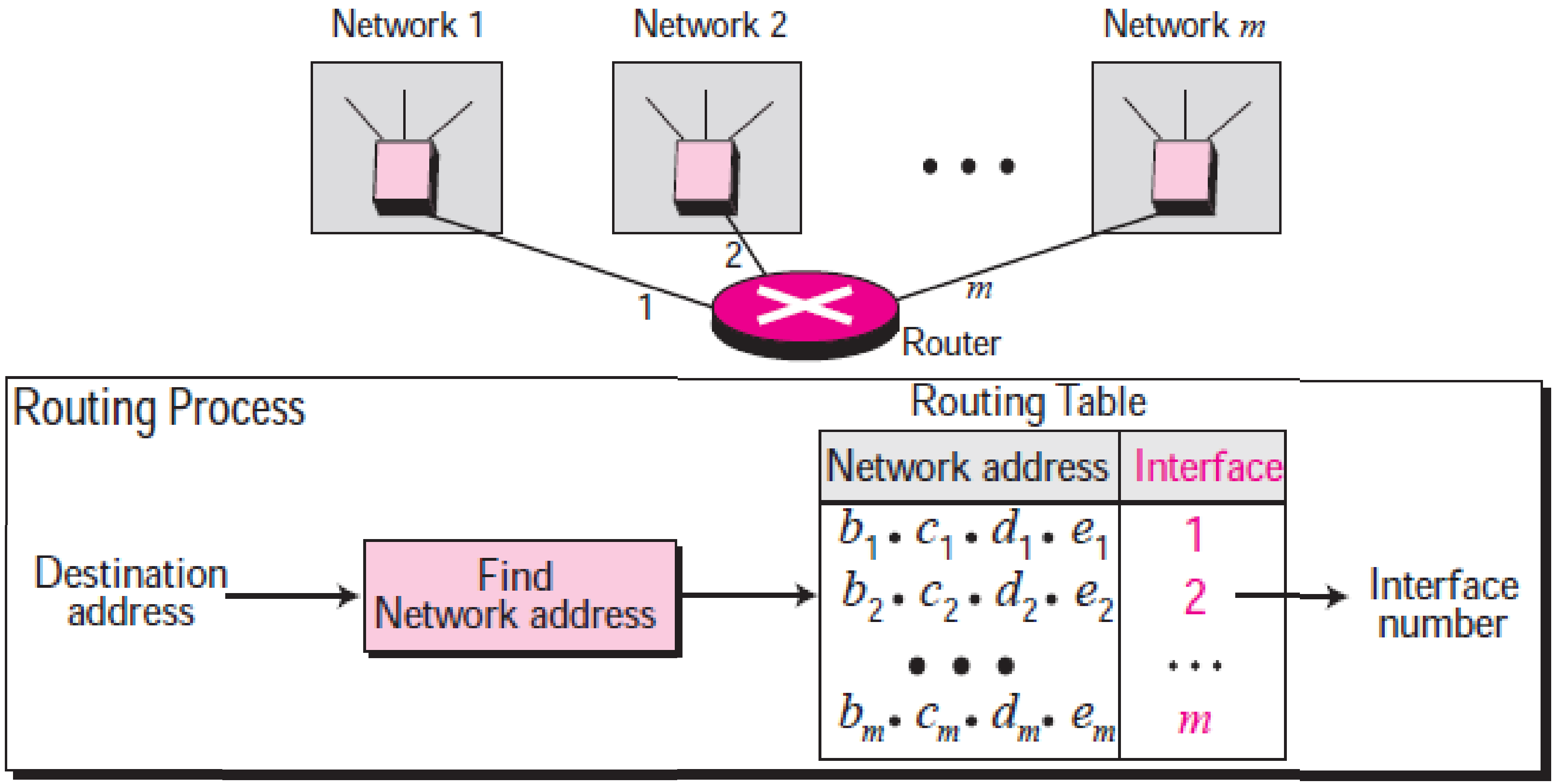


LAN: 220.3.6.0/24
220.3.6.1
220.3.6.12
220.3.6.26
220.3.6.23
200.78.6.14
R1
Switched WAN
200.78.6.0/24
200.78.6.146
R3
Rest of the Internet
200.78.6.92
R2
LAN: 134.18.0.0/16
134.18.10.88
134.18.12.32
134.18.14.121
134.18.68.44

Network Address

The network address is the **identifier of a network.**

- Used in routing a packet to its destination network.

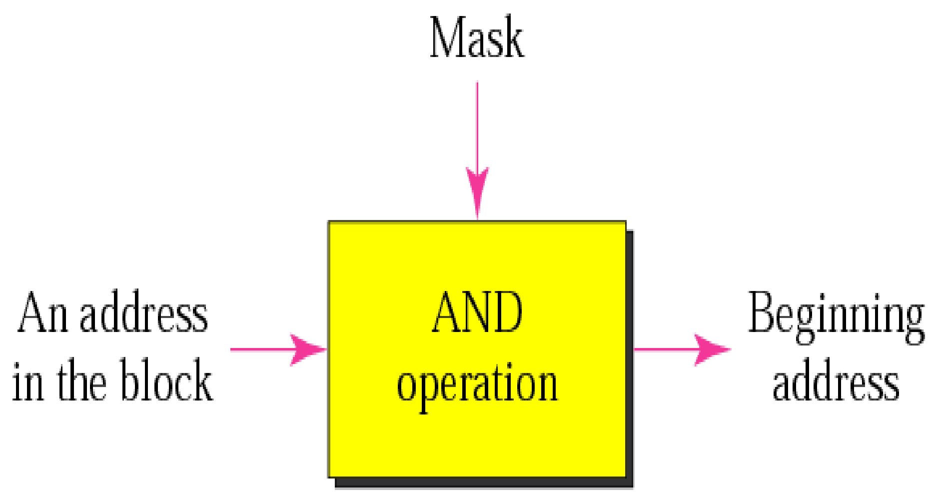


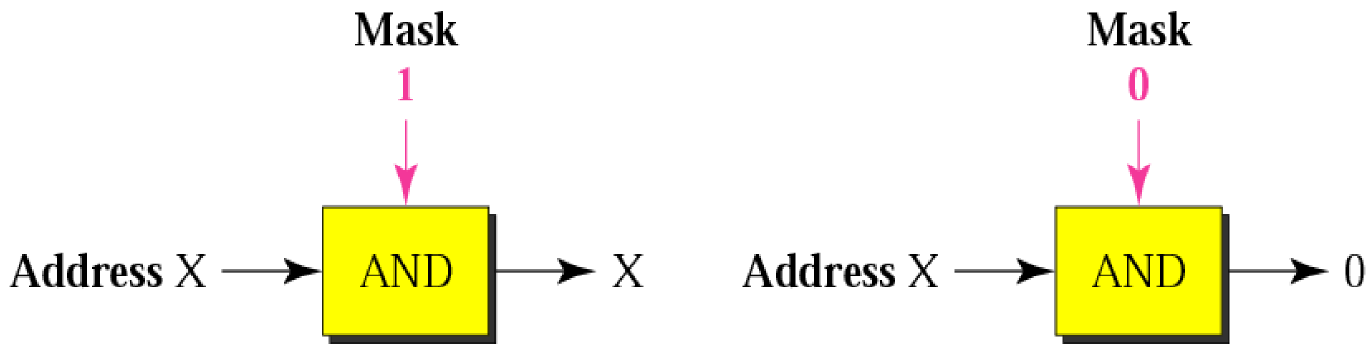
Network Mask

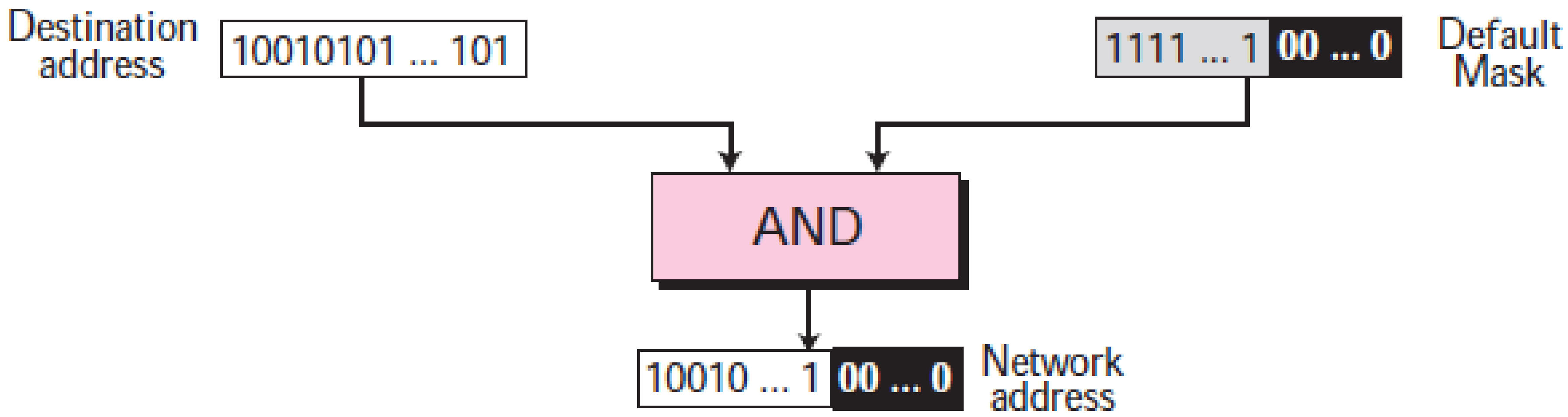
- How to extract the network address from the destination address?
- What is it?
- A 32-bit number with n leftmost bits all set to 1s and $(32 - n)$ rightmost bits all set to 0s.

Network Mask

- How to extract the network address from the destination address?
- What is it?
- A 32-bit number with *n* leftmost bits all set to 1s and (32 − *n*) rightmost bits all set to 0s.


Mask
An address in the block
AND operation
Beginning address


Mask
1
Address X
AND
X
Mask
0
Address X
AND
0


Destination address
10010101 ... 101
1111 ... 1 00 ... 0
Default Mask
AND
10010 ... 1 00 ... 0
Network address

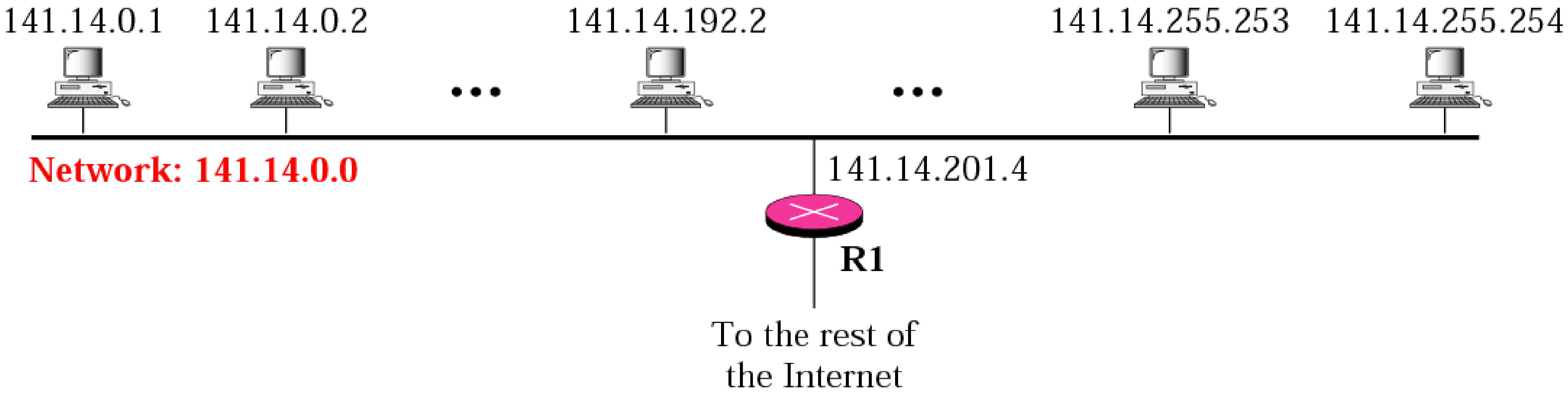
The network address is the beginning address of each block.

It can be found by applying the default mask to any of the addresses in the block (including itself).

It retains the netid of the block and sets the hostid to zero.

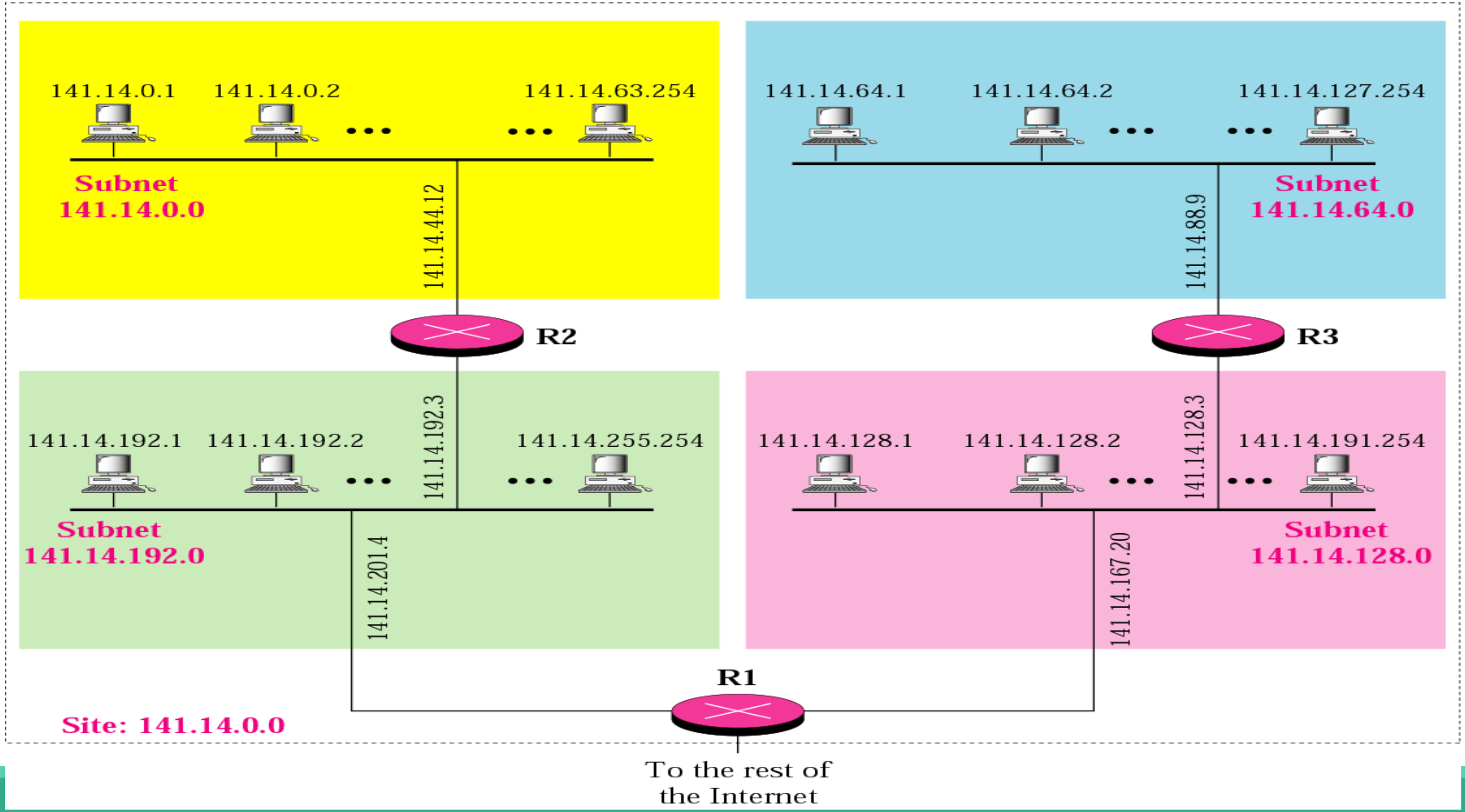
Subnetting and Supernetting

Network without subnetting

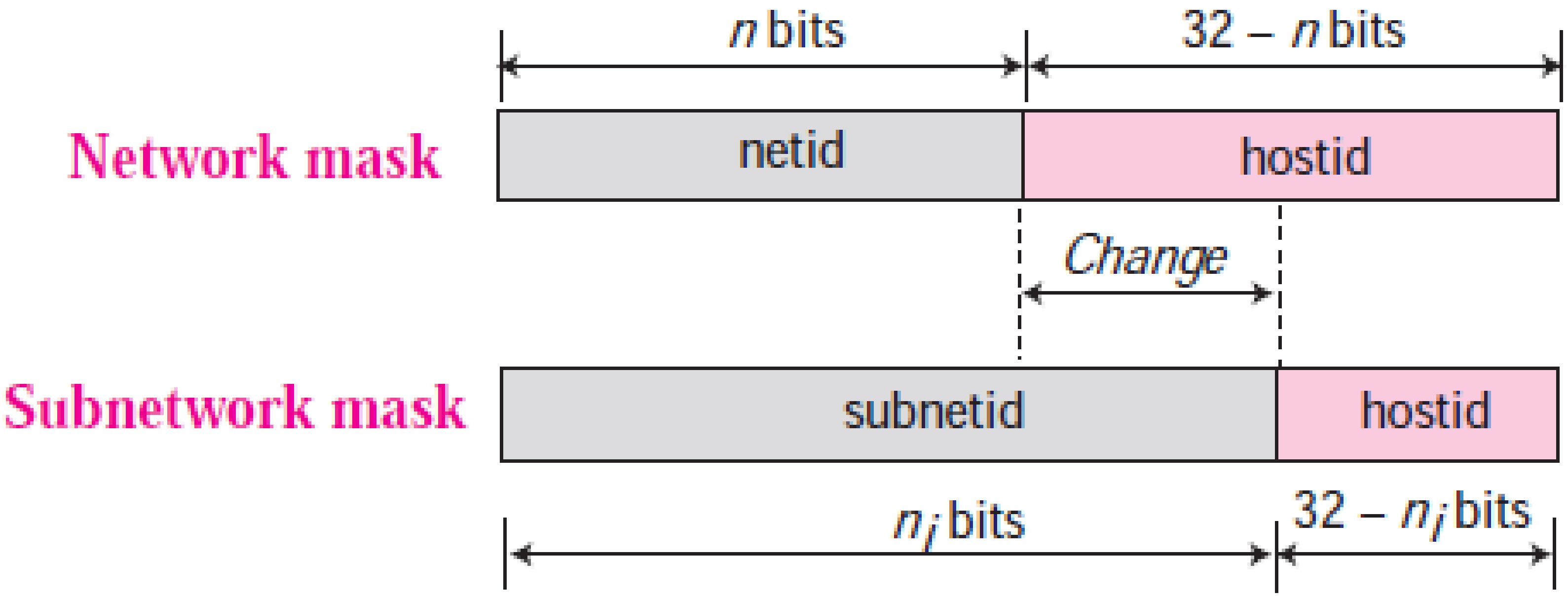


Subnetted Network

Why subnetting?

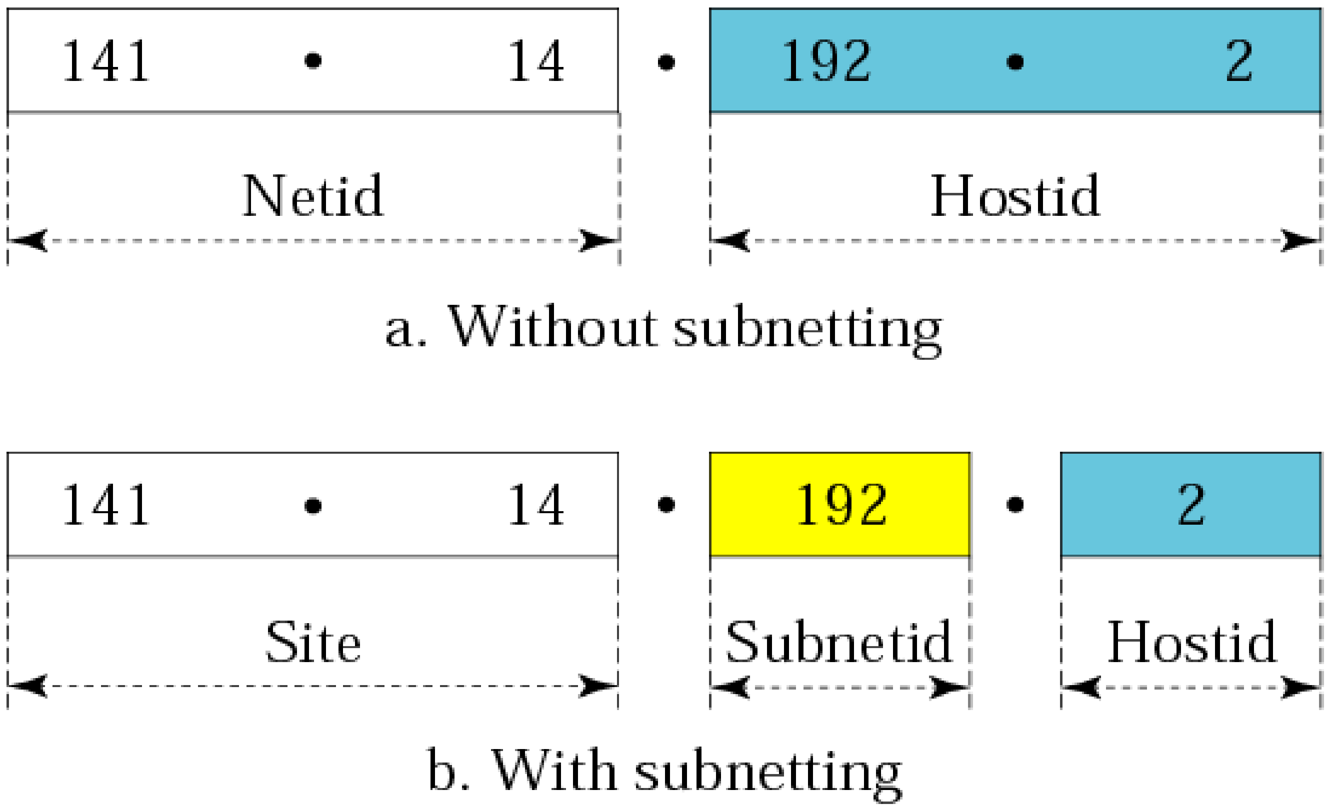


Subnet Mask

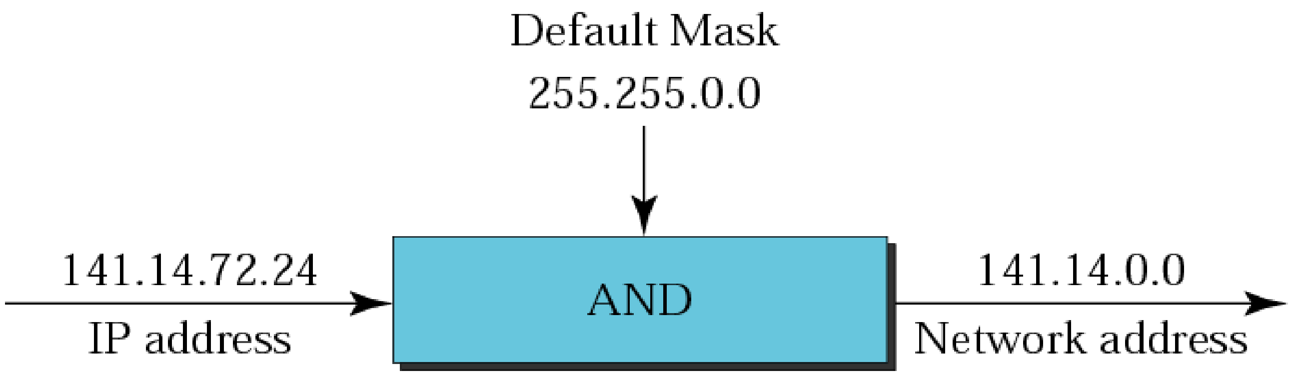


n bits
32 – n bits
Network mask
netid
hostid
Change
Subnetwork mask
subnetid
hostid
n_i bits
32 – n_i bits

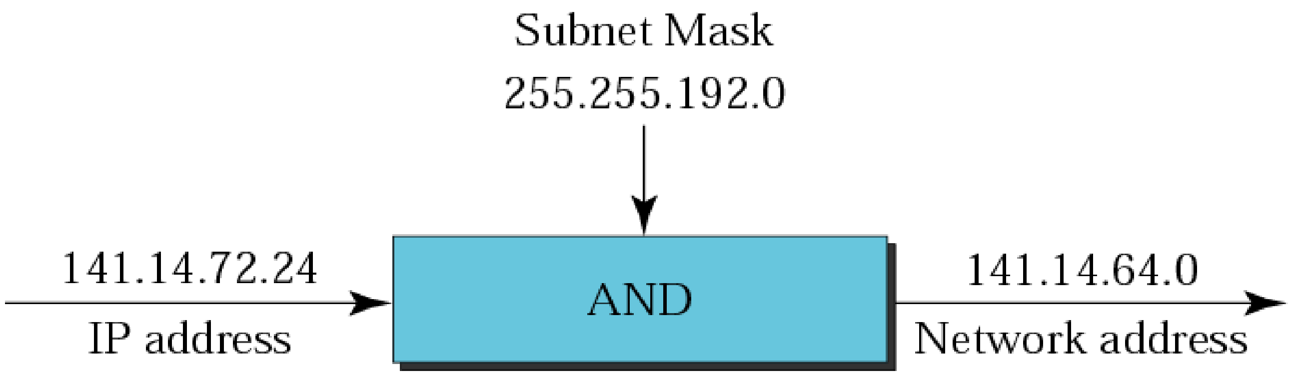
Addresses: Before and After



Default Mask and Subnet Mask



a. Without subnetting



b. With subnetting

Example

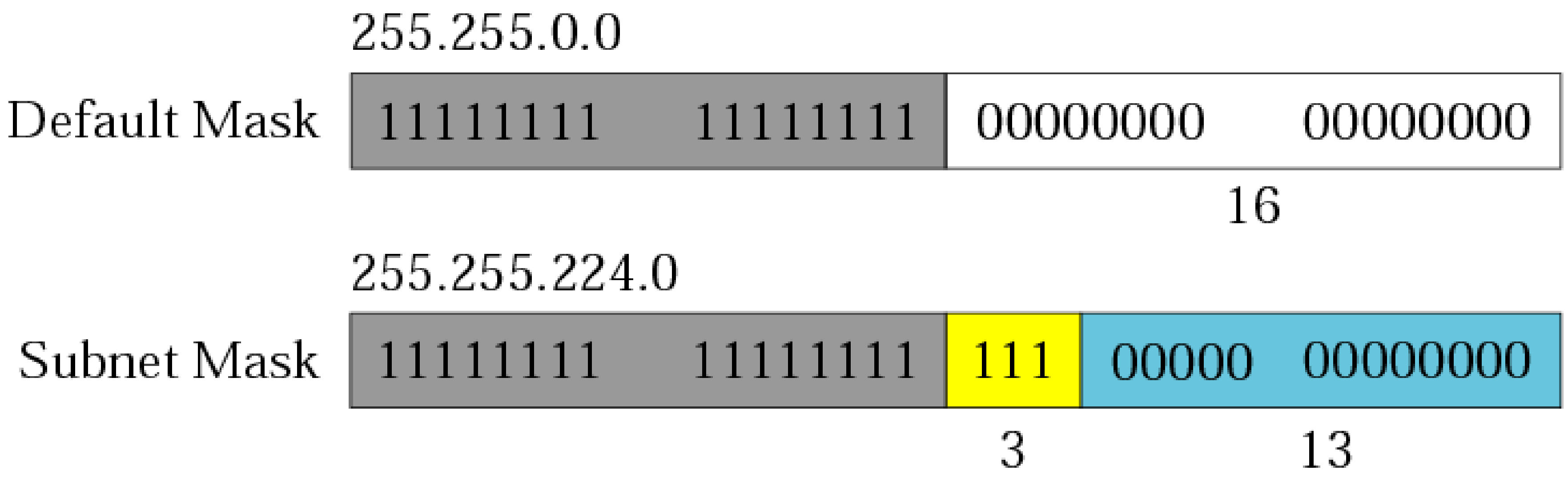
What is the subnetwork address if the destination address is 200.45.34.56 and the subnet mask is 255.255.240.0?

Solution

We apply the AND operation on the address and the subnet mask.

Address	*11001000 00101101 00100010 00111000*
Subnet Mask	*11111111 11111111 11110000 00000000*
Subnetwork Address	*11001000 00101101 00100000 00000000.*

Comparison of a default mask and a subnet mask



Example

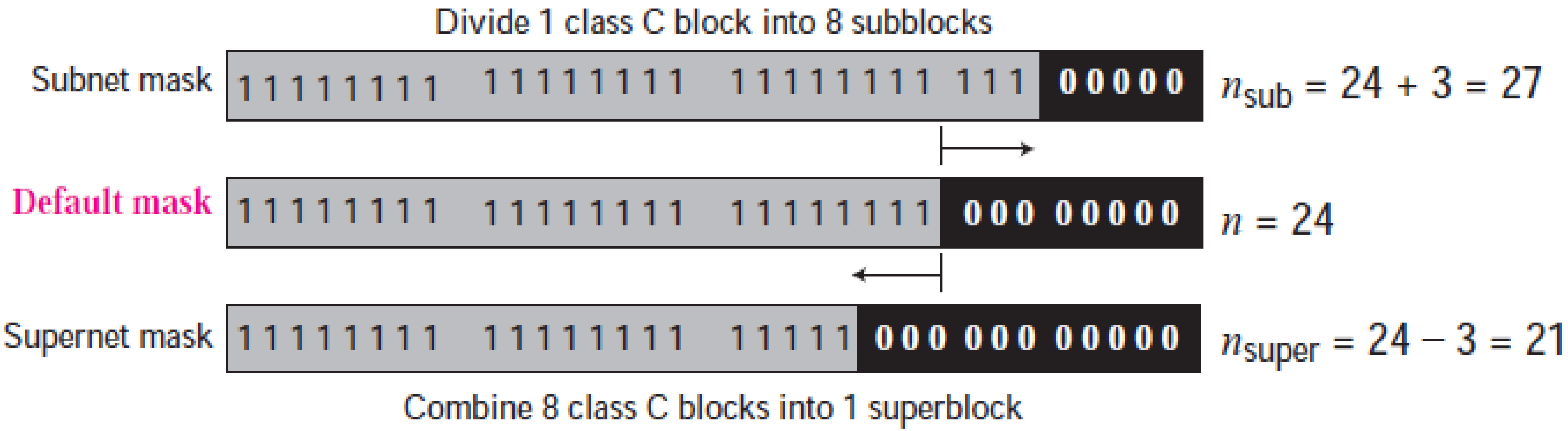
- Beginning Address: 141.14.0.1. If 4 subnets are done, derive the range of subnets.

- New netid for subnet, $n_{sub} = n + \log_2 s$
- s : number of subnets, n: netid before subnetting

Question

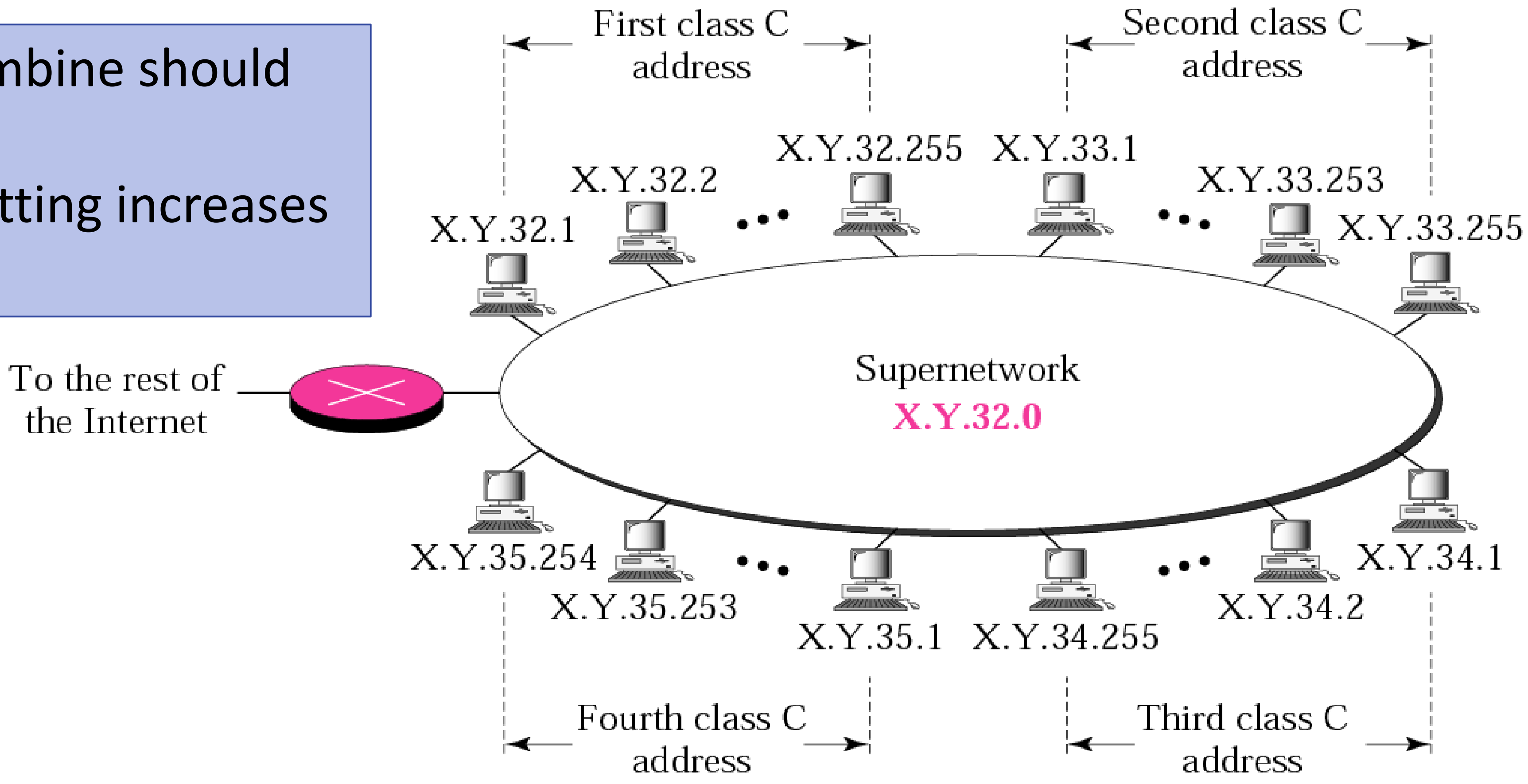
Supernetting

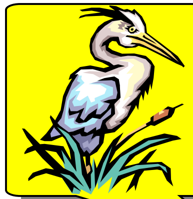
- $n_{super} = n - \log_2 c$



A Supernetwork

- Number of blocks to combine should be a power of 2.
- Supernetting and subnetting increases routing complexity.





Note:

- In subnetting, we need the first address of the subnet and the subnet mask to define the range of addresses.
- In supernetting, we need the first address of the supernet and the supernet mask to define the range of addresses.

The idea of subnetting and supernetting of classful addresses is almost obsolete.

Questions

Note that we must not apply the default mask of one class to an address belonging to another class.

- Given the address 23.56.7.91, find the beginning address (network address).

Solution

The default mask is 255.0.0.0, which means that only the first byte is preserved and the other 3 bytes are set to 0s. The network address is 23.0.0.0.

- Given the address 132.6.17.85, find the beginning address (network address).

Solution

The default mask is 255.255.0.0, which means that the first 2 bytes are preserved and the other 2 bytes are set to 0s. The network address is 132.6.0.0.

- Given the address 201.180.56.5, find the beginning address (network address).

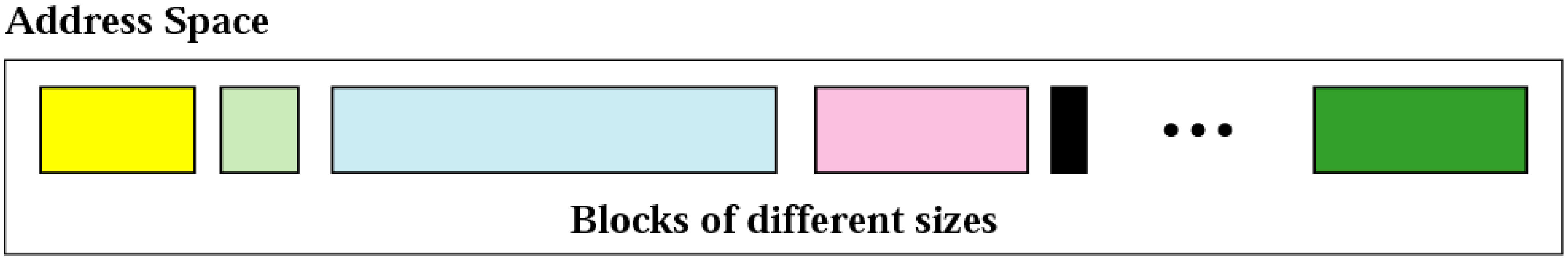
Solution

The default mask is 255.255.255.0, which means that the first 3 bytes are preserved and the last byte is set to 0. The network address is 201.180.56.0.

Classless Addressing

Variable Length Blocks

- Variable-length blocks are assigned that belong to no class.



- Only restriction: Addresses in a block is that it must be a power of 2.
- The first address of a particular block must always be divisible by the total number of addresses in that block.

Examples

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

a. 205.16.37.32 b.190.16.42.44

c. 17.17.33.80 d.123.45.24.52

Solution

Only two are eligible (a and c). 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.

Examples

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

a.205.16.37.32 b.190.16.42.0

c.17.17.32.0 d.123.45.24.52

Solution

In this case, the right-most byte must be 0. As we know, the IP addresses use base 256 arithmetic. When the right-most byte is 0, the total address is divisible by 256. Only two addresses are eligible (b and c).

Examples

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

a. 205.16.37.32 b.190.16.42.0

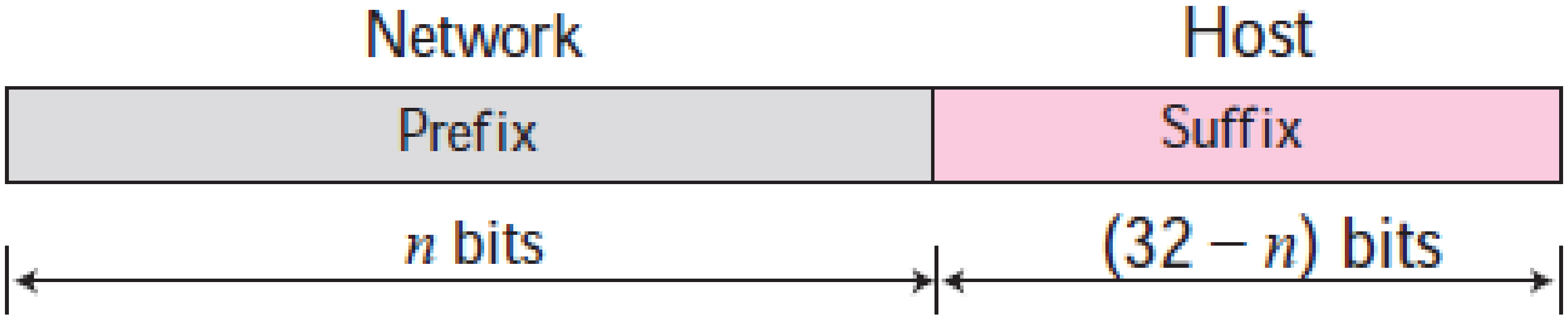
c. 17.17.32.0 d.123.45.24.52

Solution

In this case, we need to check two bytes because
$1024 = 4 \times 256$. The right-most byte must be divisible by 256. The second byte (from the right) must be divisible by 4. Only one address is eligible (c).

Two-Level Addressing

- In classful addressing: *netid* and *hostid*.
- In classless addressing: **prefix** and **suffix.**
- All addresses in the block have the same prefix; each address has a different suffix.
- Prefix length can be 1 to 32. Suffix length= 32-prefix length.



Question

- If Internet is considered as one single block, what is the prefix length and suffix length?
- What is the prefix length and suffix length if the Internet is divided into 4,294,967,296 blocks and each block has one single address?
- The number of addresses in a block is ___________ (directly/inversely) related to the value of the prefix length, *n*.
- A small *n* means a larger block; a large *n* means a small block.

Slash or CIDR notation

- In classful addressing, the **netid length** is inherent in the address. Given an address, we know the class of the address that allows us to find the netid length (8, 16, or 24).
- What about classless addressing?
- In classless addressing, we need to include the prefix length to each address if we need to find the block of the address.
- The prefix length, *n*, is added to the address separated by a slash. The notation is informally referred to as **slash notation** and as **CIDR notation,** formally.

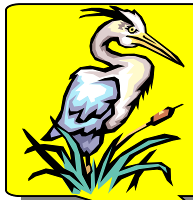
Prefix Lengths

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

Examples

- The address **230.8.24.56** can belong to many blocks some of them are shown below with the value of the prefix associated with that block:

Prefix length:16	→	Block:	230.8.0.0	to	230.8.255.255
Prefix length:20	→	Block:	230.8.16.0	to	230.8.31.255
Prefix length:26	→	Block:	230.8.24.0	to	230.8.24.63
Prefix length:27	→	Block:	230.8.24.32	to	230.8.24.63
Prefix length:29	→	Block:	230.8.24.56	to	230.8.24.63
Prefix length:31	→	Block:	230.8.24.56	to	230.8.24.57



Note:

Classful addressing is a special case of classless addressing.

Network Mask

- A 32-bit number with the *n* leftmost bits all set to 1s and the rest of the bits all set to 0s.

Examples

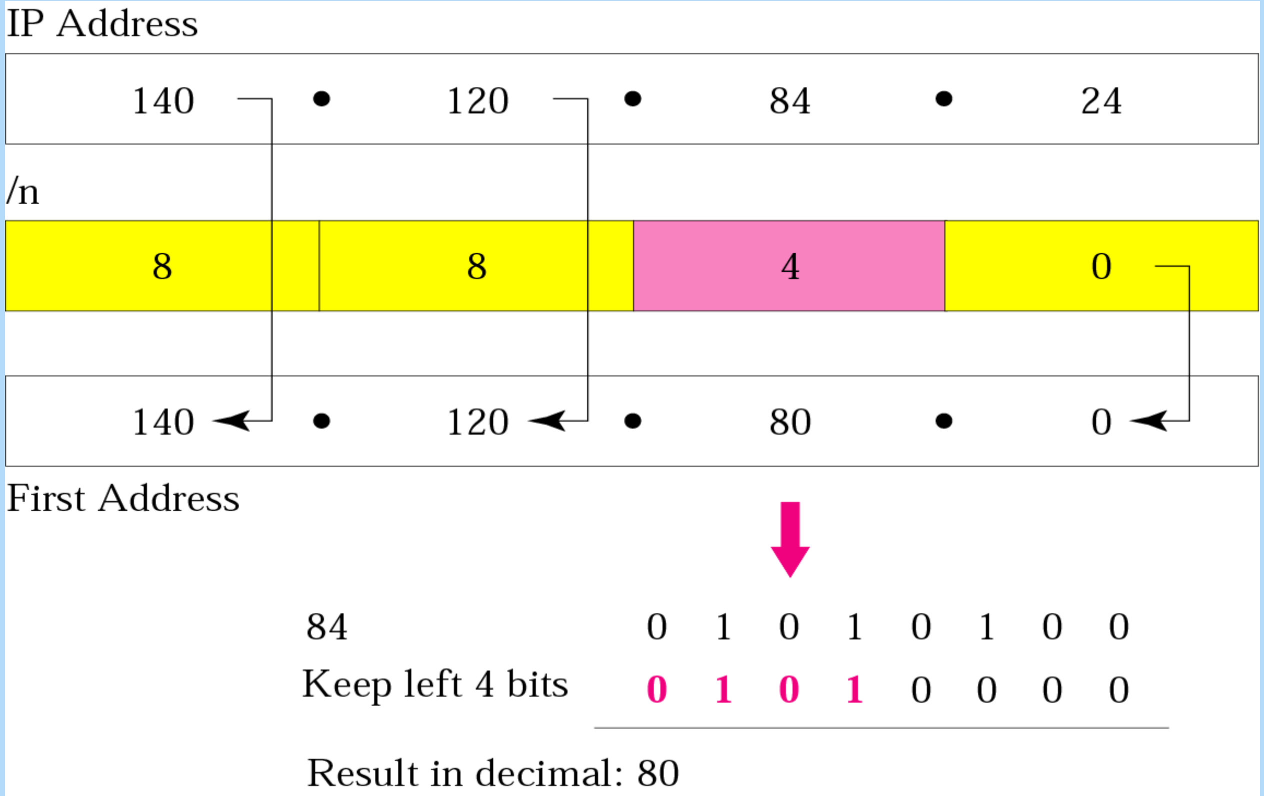
What is the first address in the block if one of the addresses is 167.199.170.82/27?

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 following shows the process:

Address in binary: **10100111 11000111 10101010 01010010**
Keep the left 27 bits: **10100111 11000111 10101010 01000000**
Result in CIDR notation: *167.199.170.64/27*

Examples



- 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.

Extracting Information from a block

- Total no. of addresses, N= $2^{(32-n)}$
- First Address= (Any address) **AND** (Network Mask)
- Last Address= (Any address) **OR** [**NOT** (Mask)]
- Any other way of representation?

Examples

- Find the number of addresses, first and last 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 2^{12} or 4096.

The first address is 140.120.80.0/20

Note that this is a large block with 4096 addresses.

The last address is 140.120.95.255/20

Block Allocation

For the proper operation of the CIDR, three restrictions need to be applied to the allocated block.

1. The number of requested addresses, *N*, needs to be a power of 2. Why?
2. The value of prefix length can be found from the number of addresses in the block. **What is n?**
3. The requested block needs to be allocated where there are a contiguous number of unallocated addresses in the address space. The beginning address needs to be divisible by the number of addresses in the block. To see this restriction, we can show that the beginning address can be calculated as $X \times 2^{32-n}$ in which X is the decimal value of the prefix. In other words, the beginning address is $X \times N$.

Examples

An ISP has requested a block of 1000 addresses. The following block is granted.

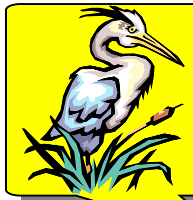
a. Since 1000 is not a power of 2, 1024 addresses are granted ($1024 = 2^{10}$).

b. The prefix length for the block is calculated as $n = 32 - \log_2 1024 = 22$.

c. The beginning address is chosen as 18.14.12.0 (which is divisible by 1024).

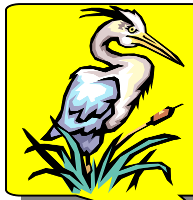
The granted block is 18.14.12.0/22. The first address is 18.14.12.0/22 and the last address is 18.14.15.255/22.

Address Aggregation : Many blocks of addresses are aggregated in one block and granted to one ISP.



Note:

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



Note:

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

Subnetting

- Steps needed to be carefully followed to guarantee the proper operation of the subnetworks.

1. The number of addresses in each subnetwork should be a power of 2.

2. The prefix length for each subnetwork should be found using the following formula:

$$n_{sub} = n + \log_2 (N/N_{sub})$$

3. The starting address in each subnetwork should be divisible by the number of addresses in that subnetwork. This can be achieved if we first assign addresses to larger networks.

Note:

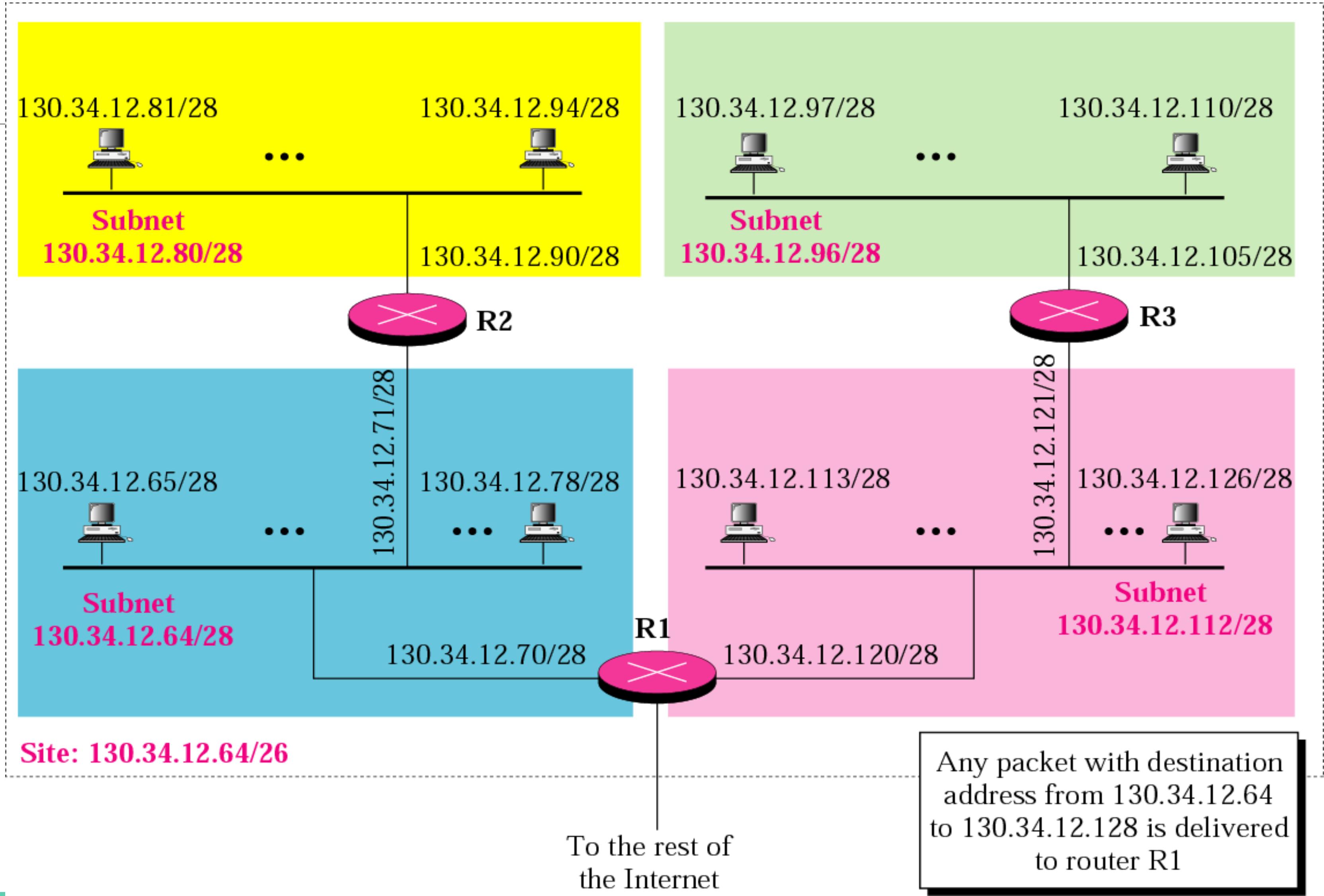
If the number of subnets is s then the number of 1's in the prefix length is increased by $log_2 s$

Examples

- 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, which means we need to add two more 1s ($\log_2 4 = 2$) to the site prefix. The subnet prefix is then /28.

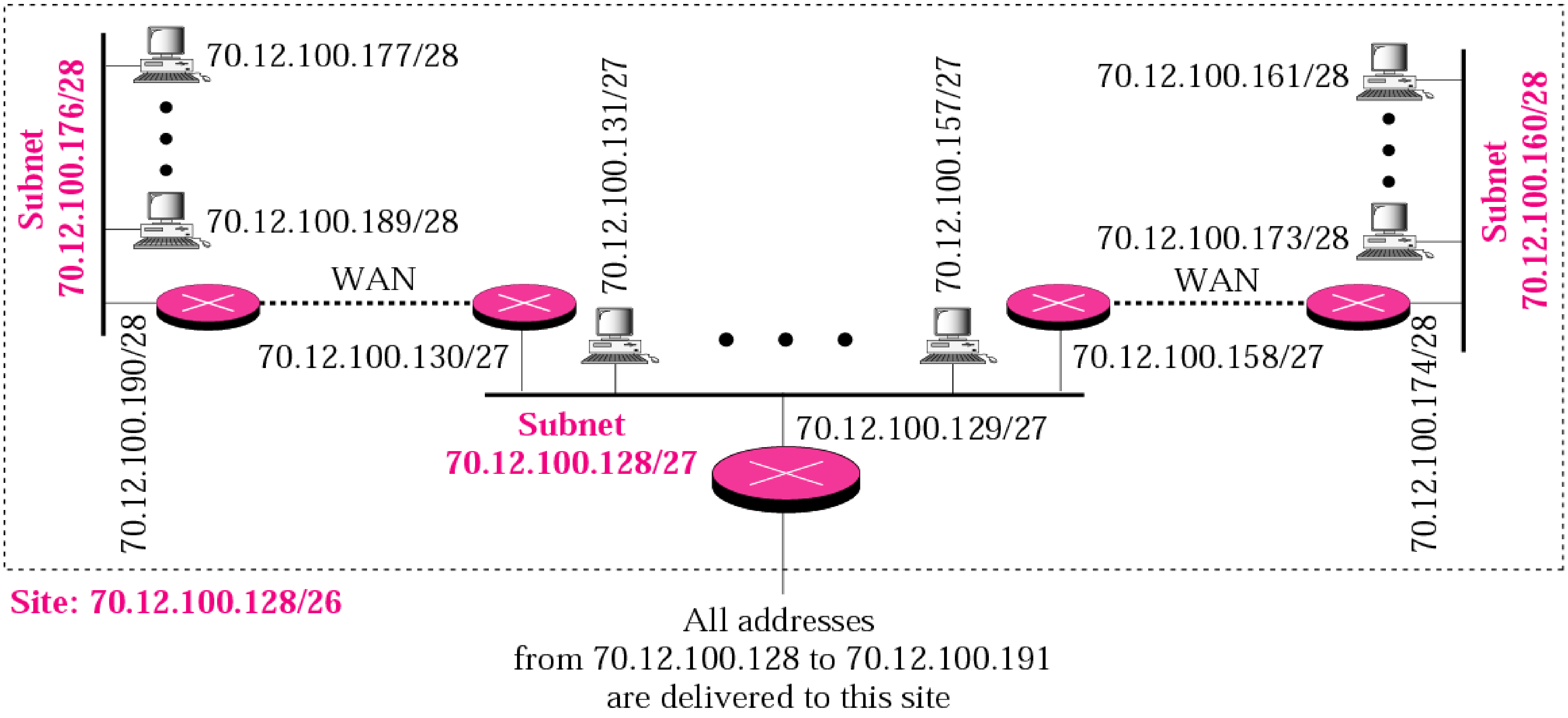
Examples

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

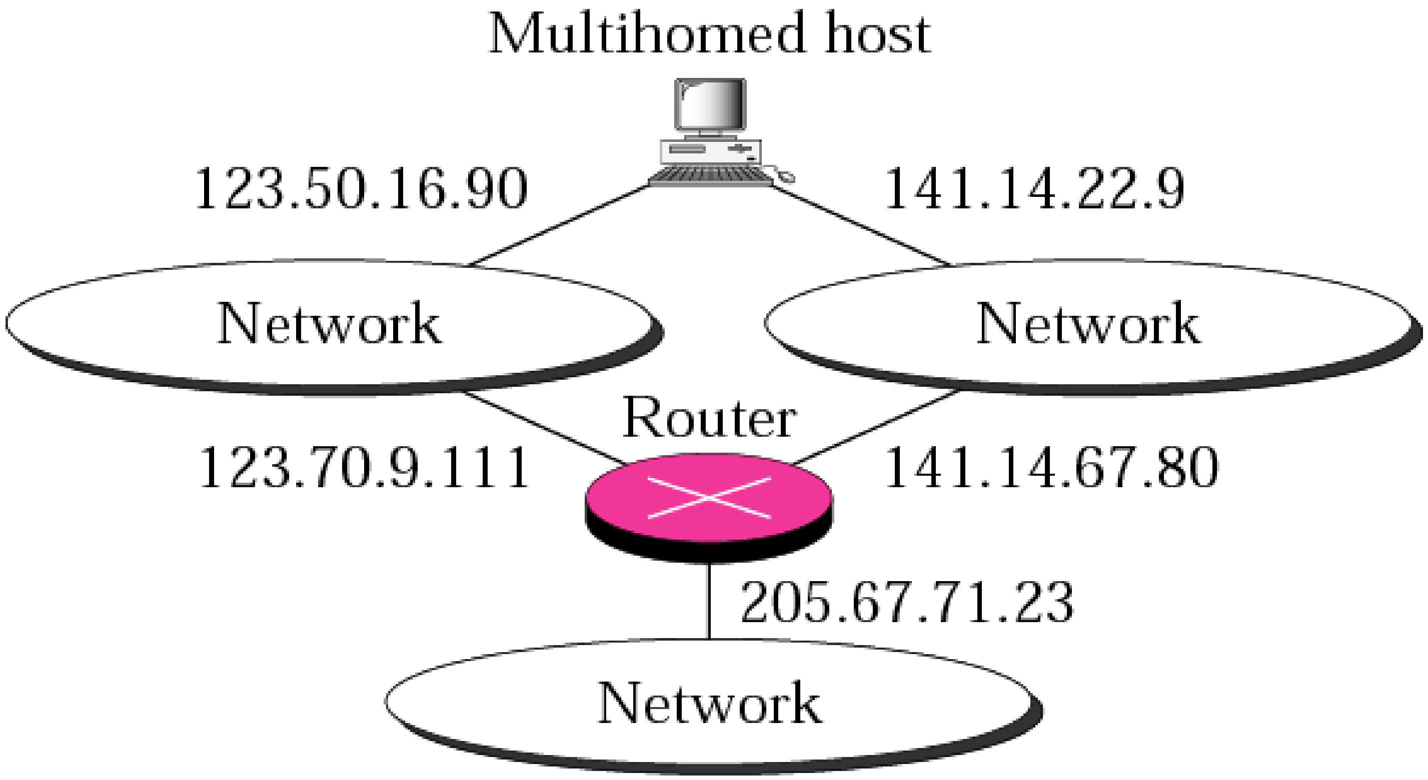


Question

- 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. **Show the configuration designed by the management.**


70.12.100.177/28
Subnet
70.12.100.176/28
70.12.100.189/28
WAN
70.12.100.190/28
70.12.100.130/27
70.12.100.131/27
70.12.100.157/27
70.12.100.161/28
70.12.100.173/28
Subnet
70.12.100.160/28
WAN
70.12.100.158/27
70.12.100.174/28
Subnet
70.12.100.128/27
70.12.100.129/27
Site: 70.12.100.128/26
All addresses
from 70.12.100.128 to 70.12.100.191
are delivered to this site

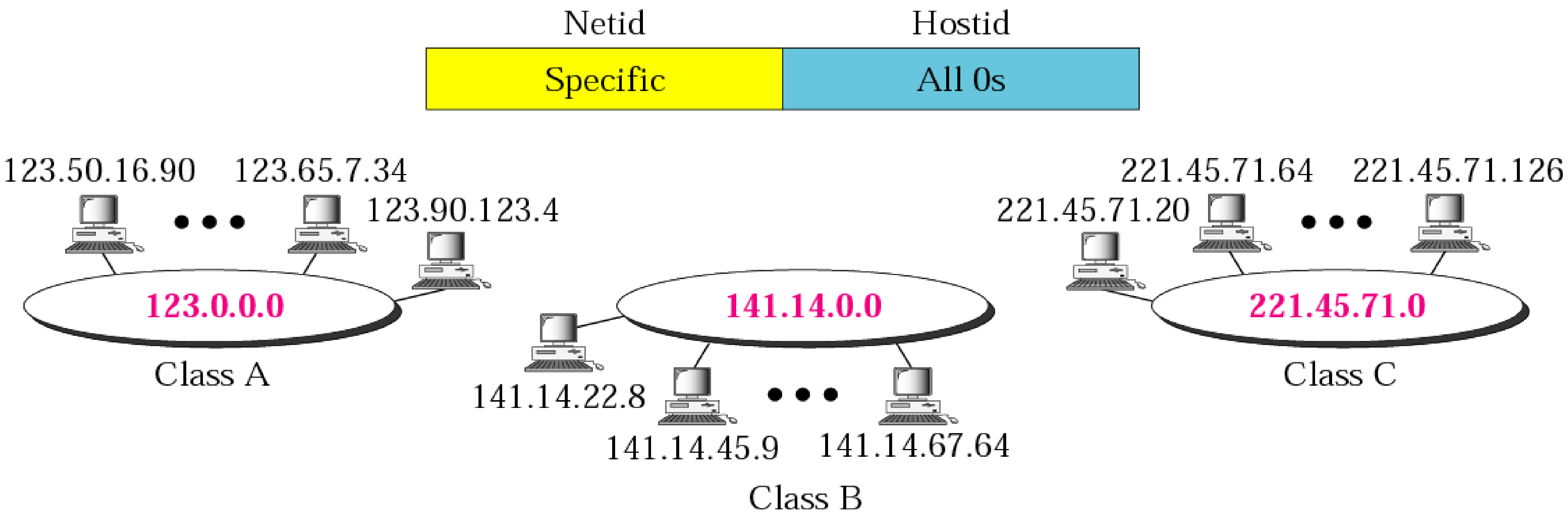
Multihomed Devices



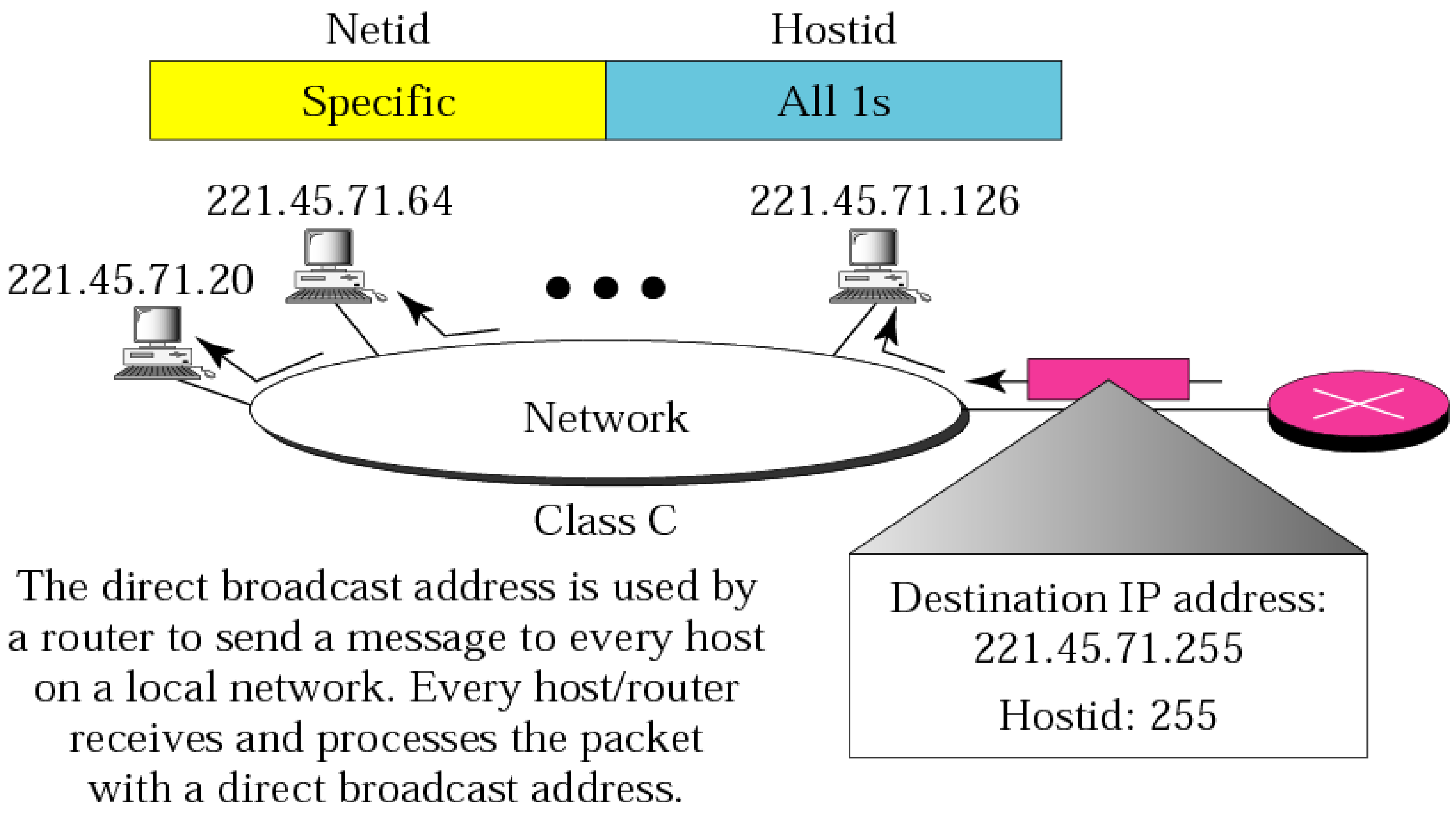
Special addresses

Special Address	*Netid*	*Hostid*	*Source or Destination*
Network address	Specific	All 0s	None
Direct broadcast address	Specific	All 1s	Destination
Limited broadcast address	All 1s	All 1s	Destination
This host on this network	All 0s	All 0s	Source
Specific host on this network	All 0s	Specific	Destination
Loopback address	127	Any	Destination

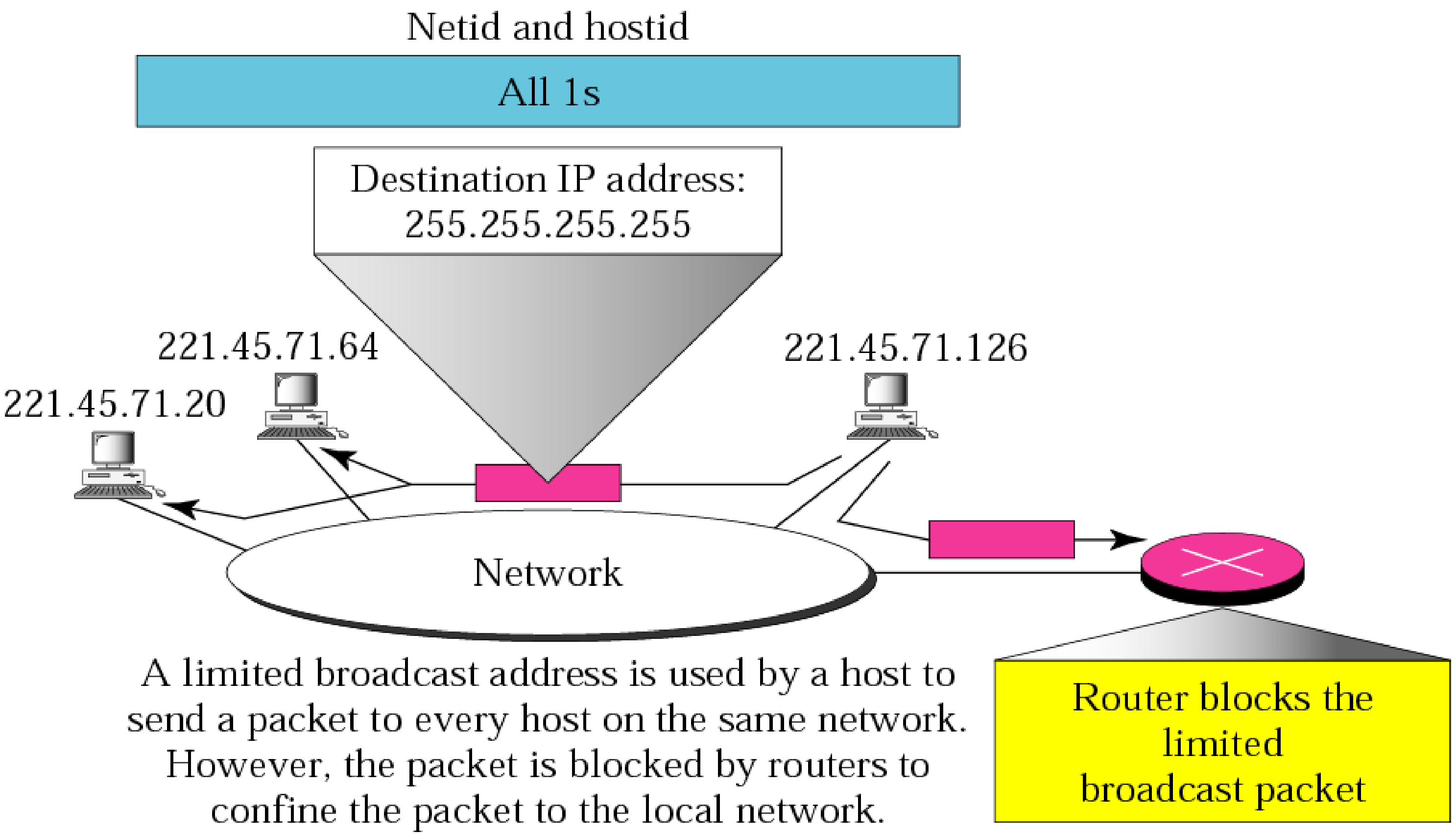
Network Address



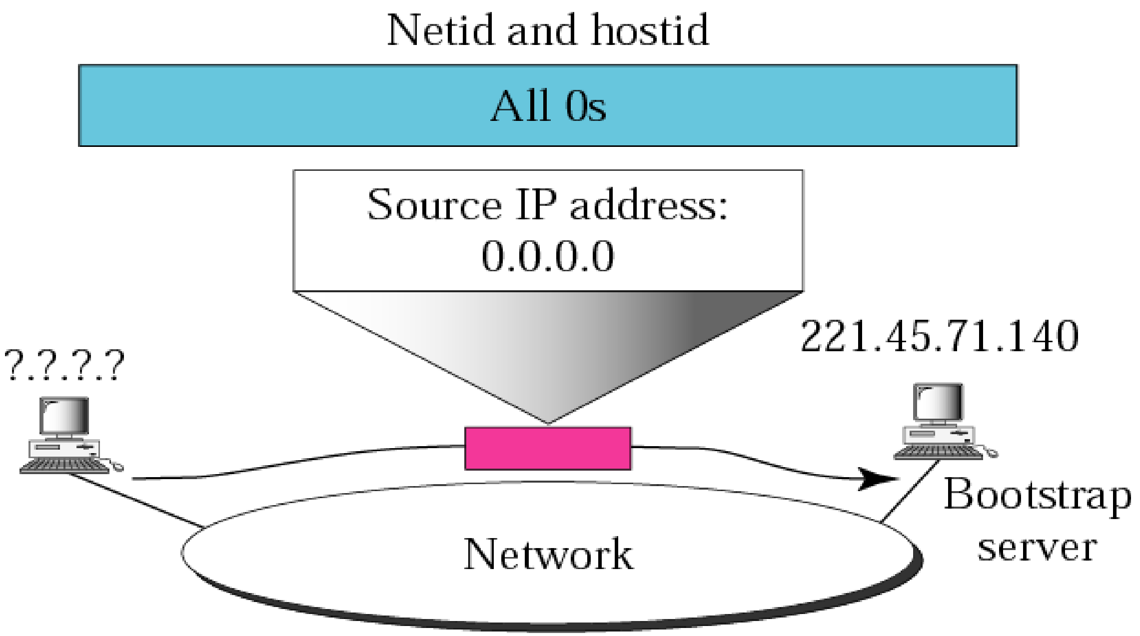
Direct Broadcast Address: Example



Limited Broadcast Address: Example

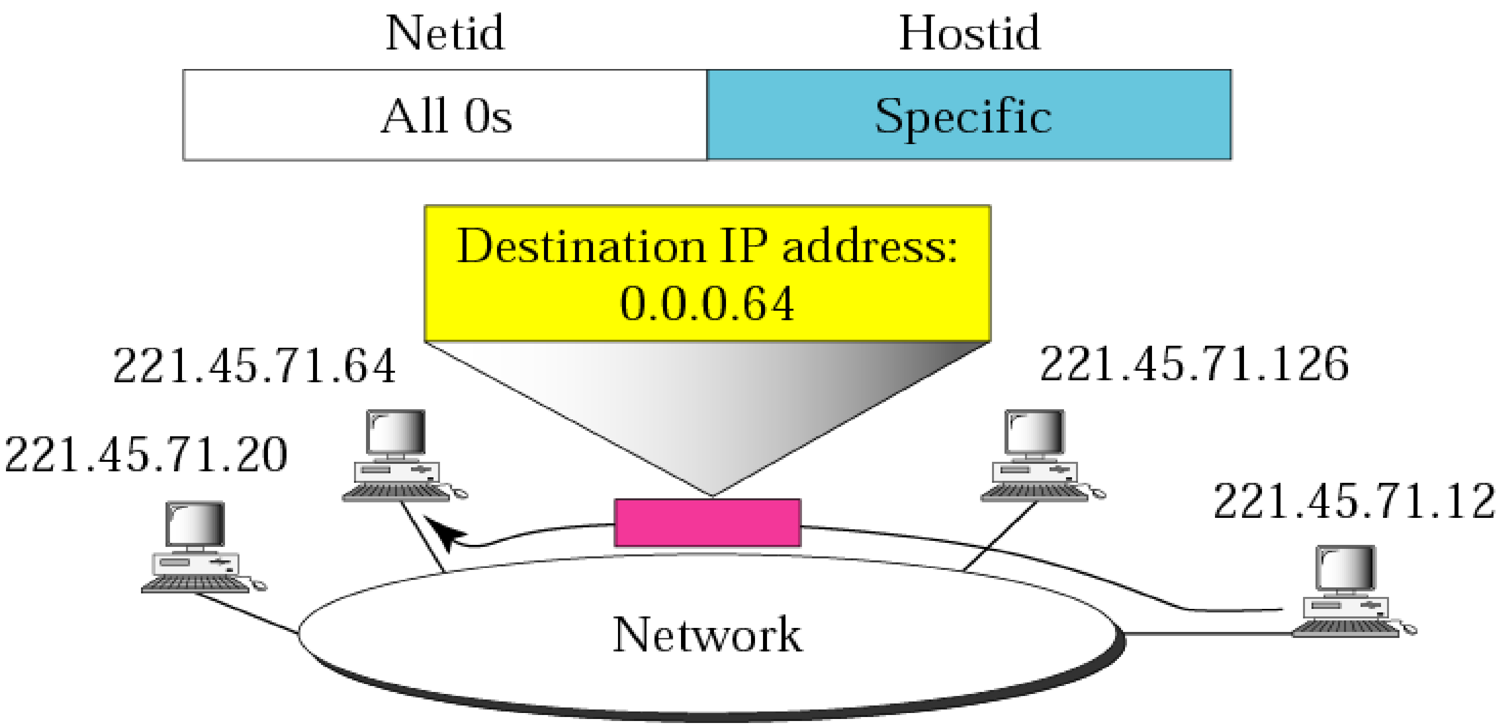


This Host on this Network: Example



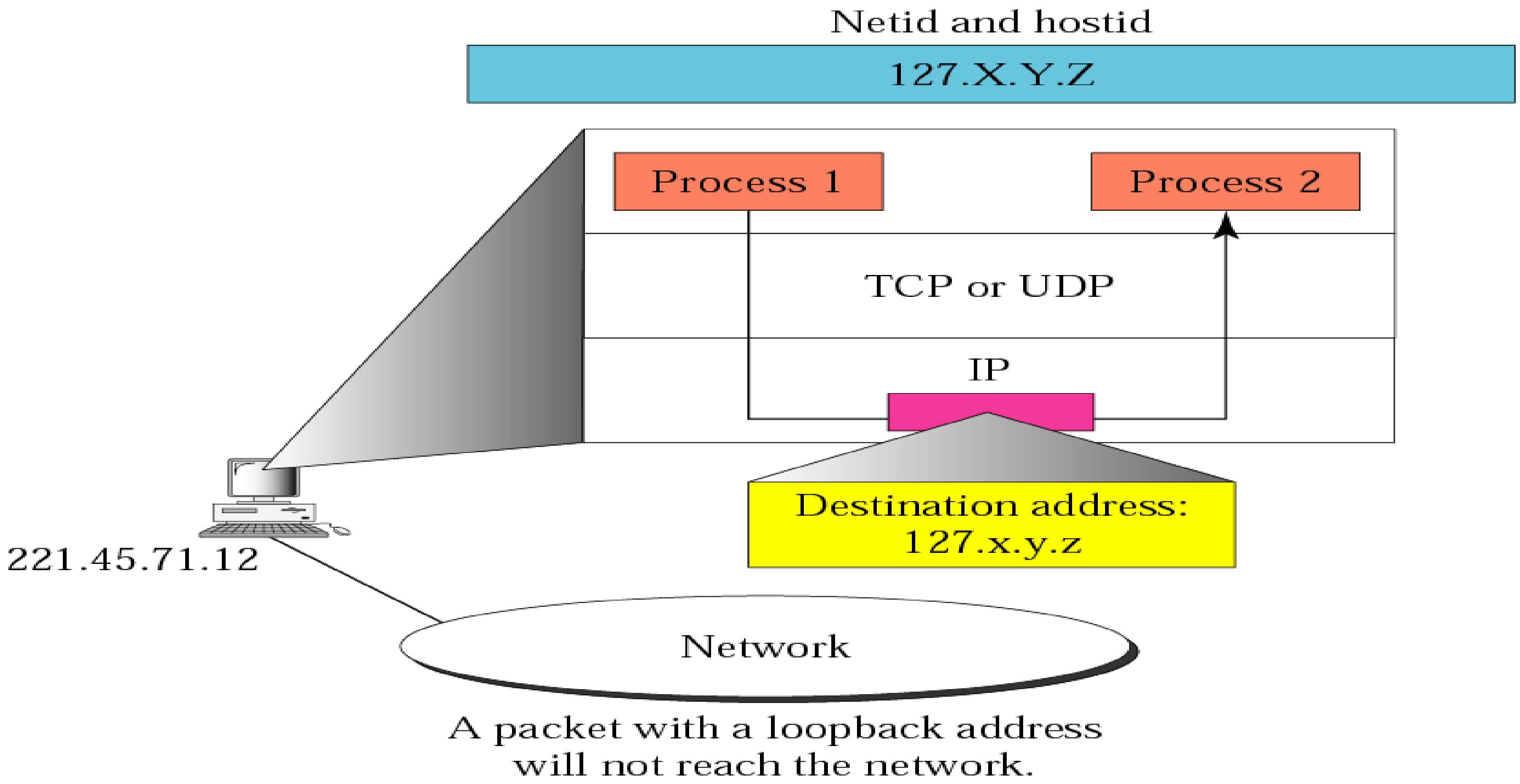
A host that does not know its IP address uses the IP address 0.0.0.0 as the source address and 255.255.255.255 as the destination address to send a message to a bootstrap server.

Specific Host on this Network: Example



This address is used by a router or host
to send a message to a specific host on the same network.

Loopback Address



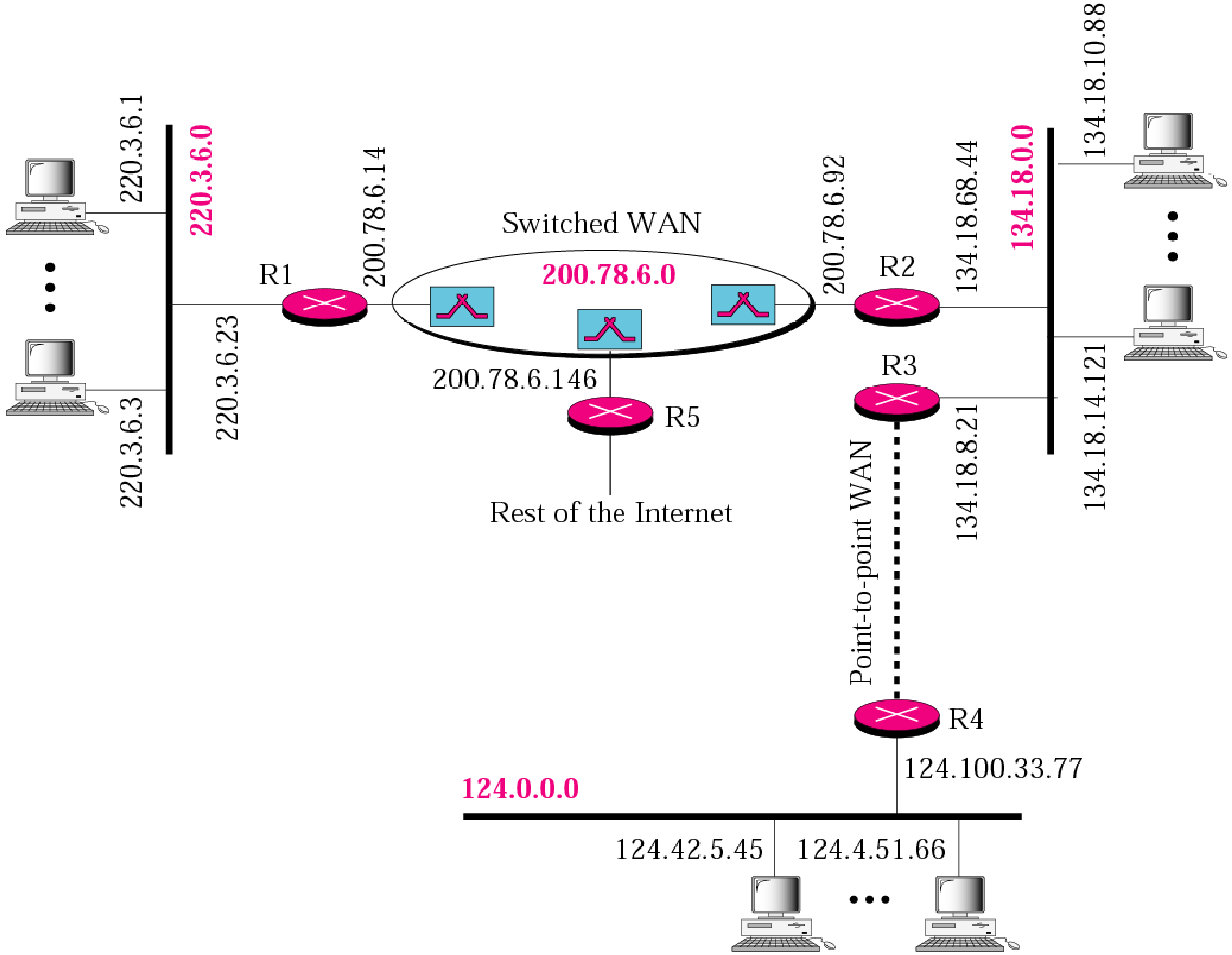
Addresses for Private Networks

Class	*Netids*	*Blocks*
A	10.0.0	1
B	172.16 to 172.31	16
C	192.168.0 to 192.168.255	256

Types of Addresses

- Communication on the Internet can be achieved using unicast, multicast or broadcast address.
- **Unicast communication: Packet sent from** one individual source to one individual destination. [One to One]
- **Multicast** : Packet is sent from an individual source to a group of destinations.
  - Class D address is a multicast address. [One to Many]
  - The entire address defines a group ID.
  - A system in the internet can have more the one multicast address.
  - Note: Class D address can be used as a destination Address only.
- **Broadcast:** Two types of broad cast in **local** level are: The limited broadcast address and direct broadcast address. [One to All]

Sample Internet



Books

1. Forouzan B.A., “TCP/IP Protocol Suite”, 4th edition. Chapter: 5