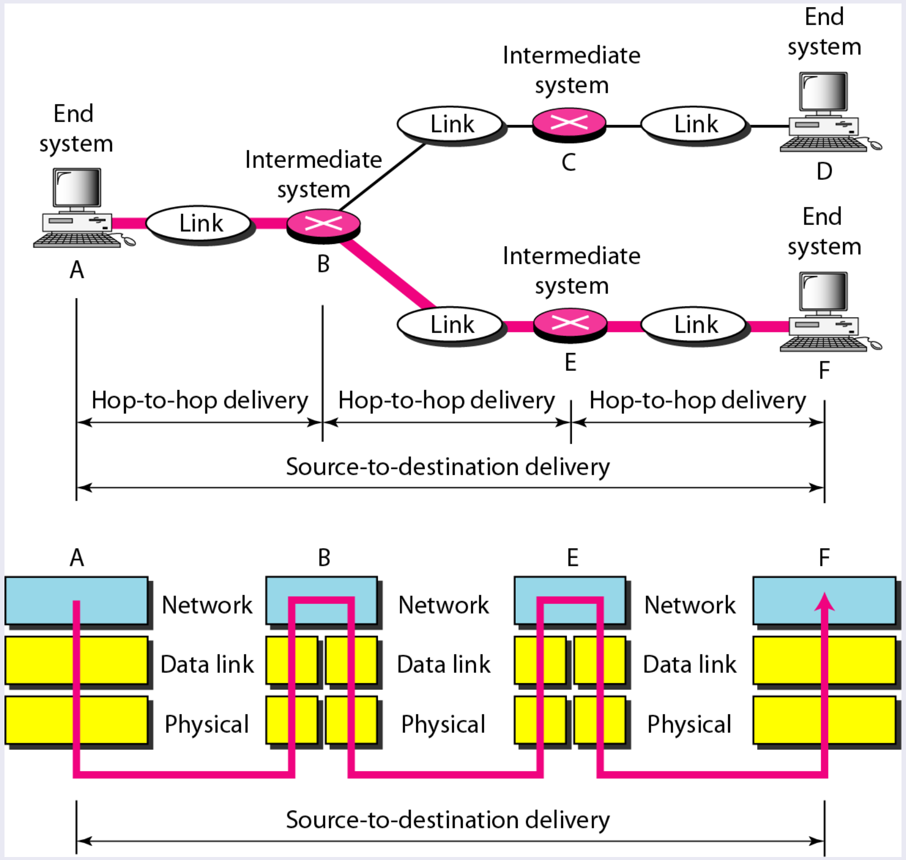
NETWORK LAYER

Sanjaya Kumar Jena

Introductiom

Responsibilities: It is responsible for the delivery of individual **packets** from the source host to the destination host (i.e. End to end delivery).

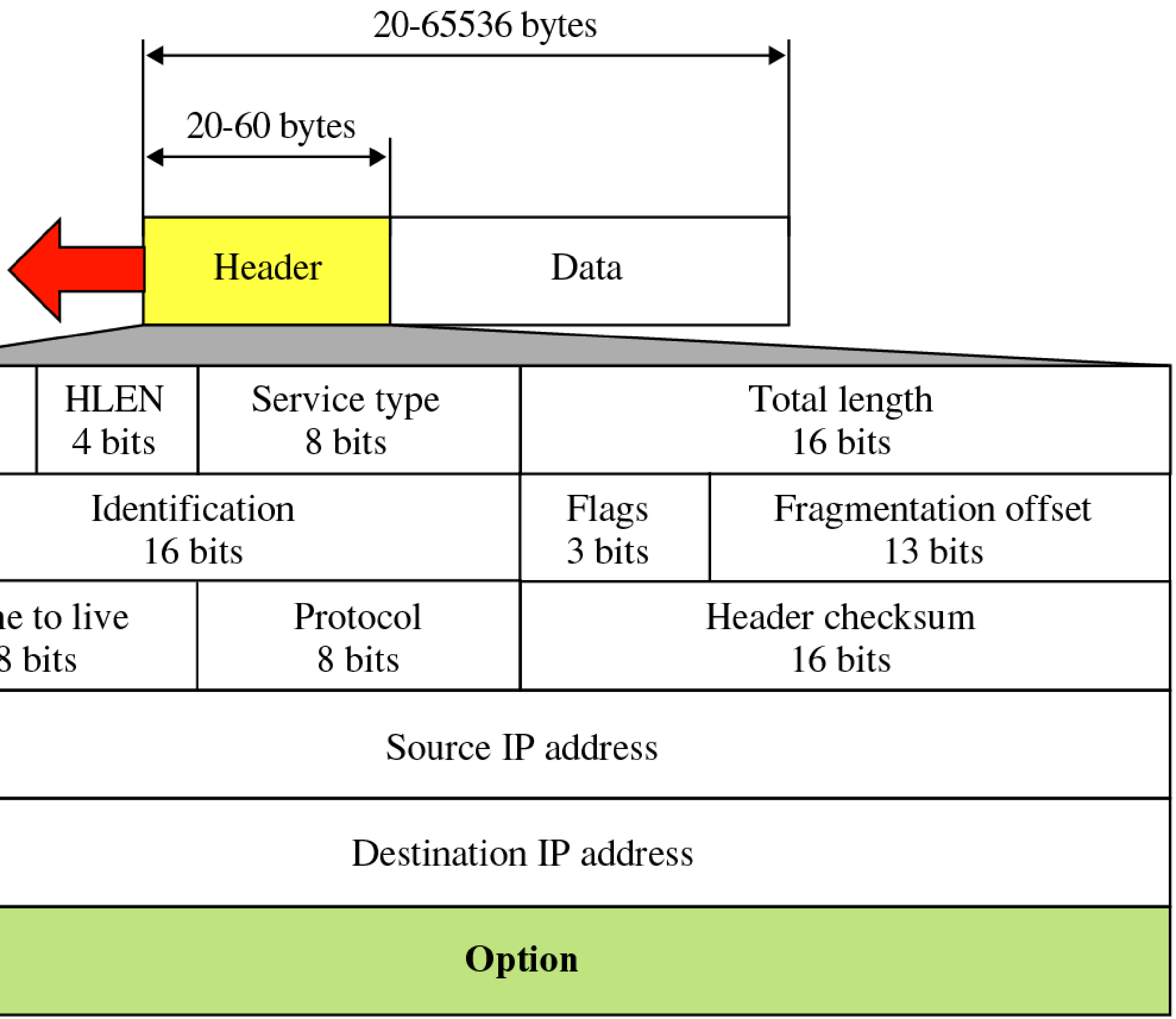
Source-to-destination delivery :Network Layer



Other Issues

- Logical addressing (IP addressing)
- Routing

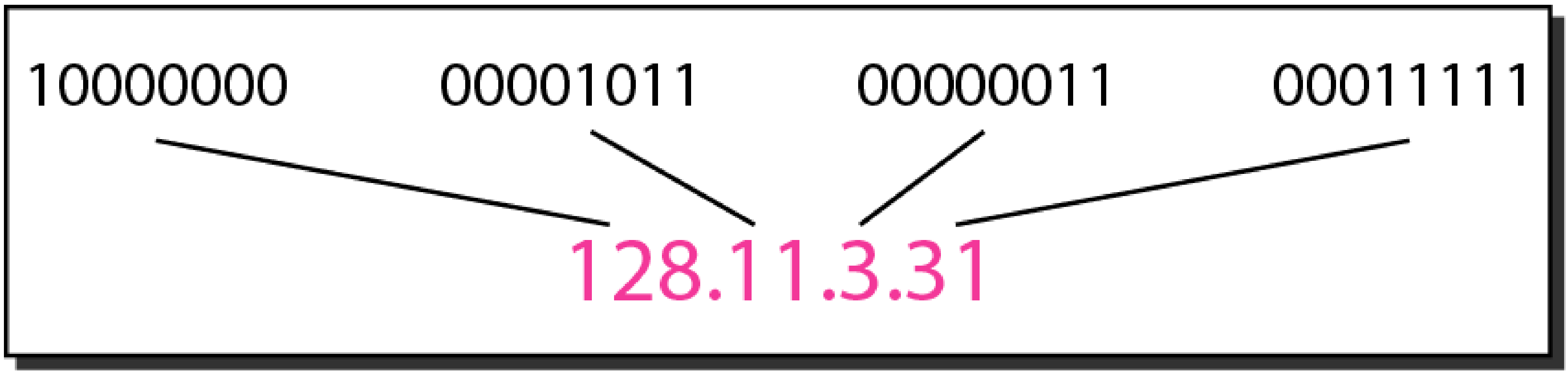
Packet Format



IPv4 ADDRESSES

An IPv4 address is a 32-bit address that uniquely and universally defines the connection of a device (for example, a computer or a router) to the Internet.

Dotted-decimal notation and binary notation for an IPv4 address



Example

- Change the following IPv4 addresses from binary notation to dotted-decimal notation.

Finding the classes in binary and dotted-decimal notation

	First byte	Second byte	Third byte	Fourth byte
Class A	0			
Class B	10			
Class C	110			
Class D	1110			
Class E	1111			

a. Binary notation

	First byte	Second byte	Third byte	Fourth byte
Class A	0–127			
Class B	128–191			
Class C	192–223			
Class D	224–239			
Class E	240–255			

b. Dotted-decimal notation

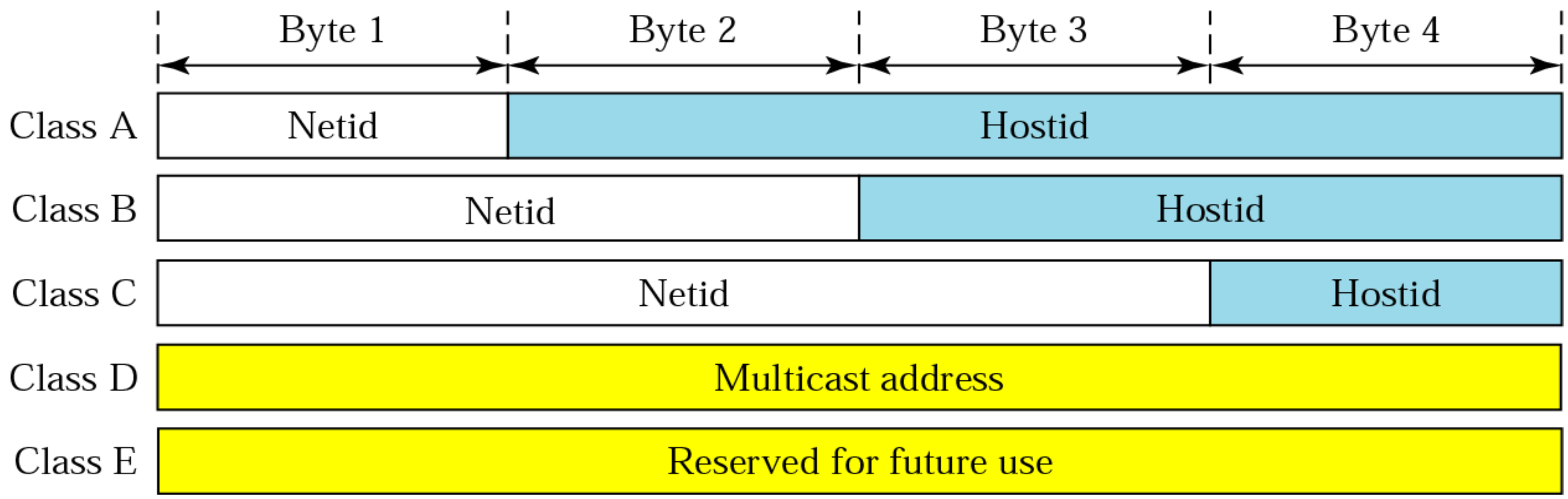
Example

- Find the class of each address.
  1. 00000001 00001011 00001011 11101111
  2. 11000001 10000011 00011011 11111111
  3. 14.23.120.8
  4. 252.5.15.111

Netid(NID) and Hostid (HID)

In classful addressing, an IP address in class A, B, or C is divided into **netid** and **hostid**. These parts are of varying lengths, depending on the class of the address.

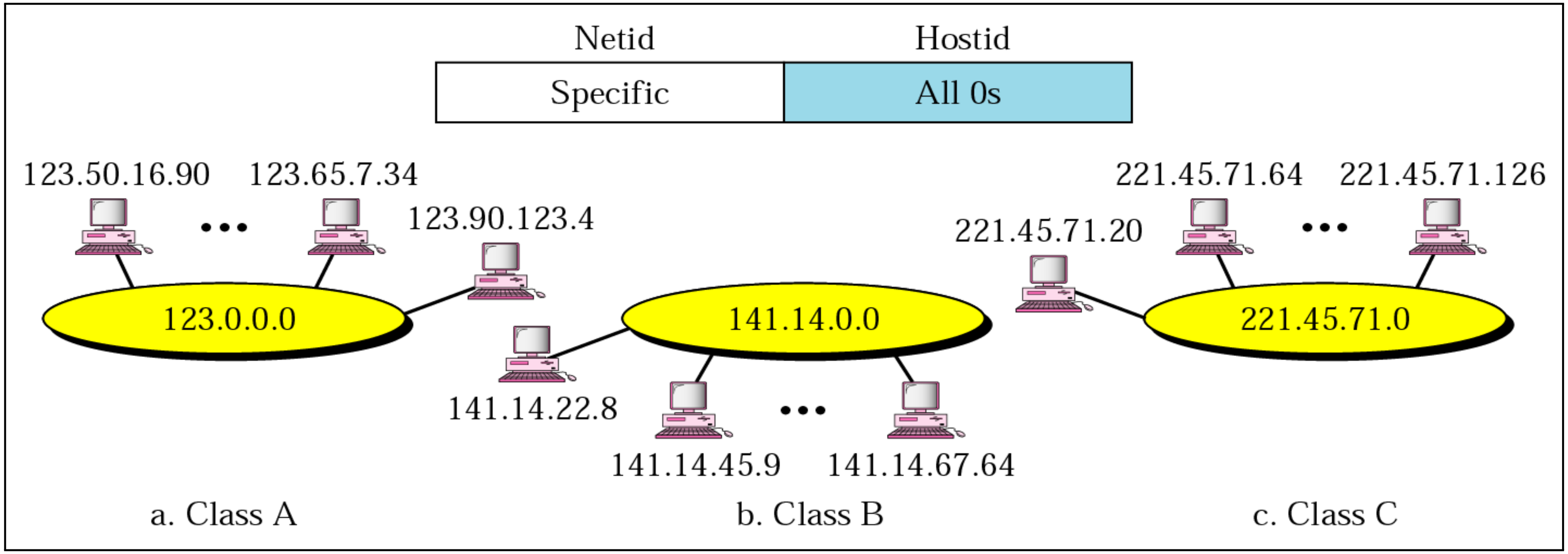
	Netid	Hostid	# bits reserved	# Networks/blocks
Class A	1 byte	3 byte	1 bit	2^7
Class B	2 byte	2 byte	2 bits	2^{14}
Class C	3 byte	1 byte	3 bits	2^{21}



Number of blocks and block size in classful IPv4 addressing

Class	*Number of Blocks*	*Block Size*	*Application*
A	128	16,777,216	Unicast
B	16,384	65,536	Unicast
C	2,097,152	256	Unicast
D	1	268,435,456	Multicast
E	1	268,435,456	Reserved

Network Address



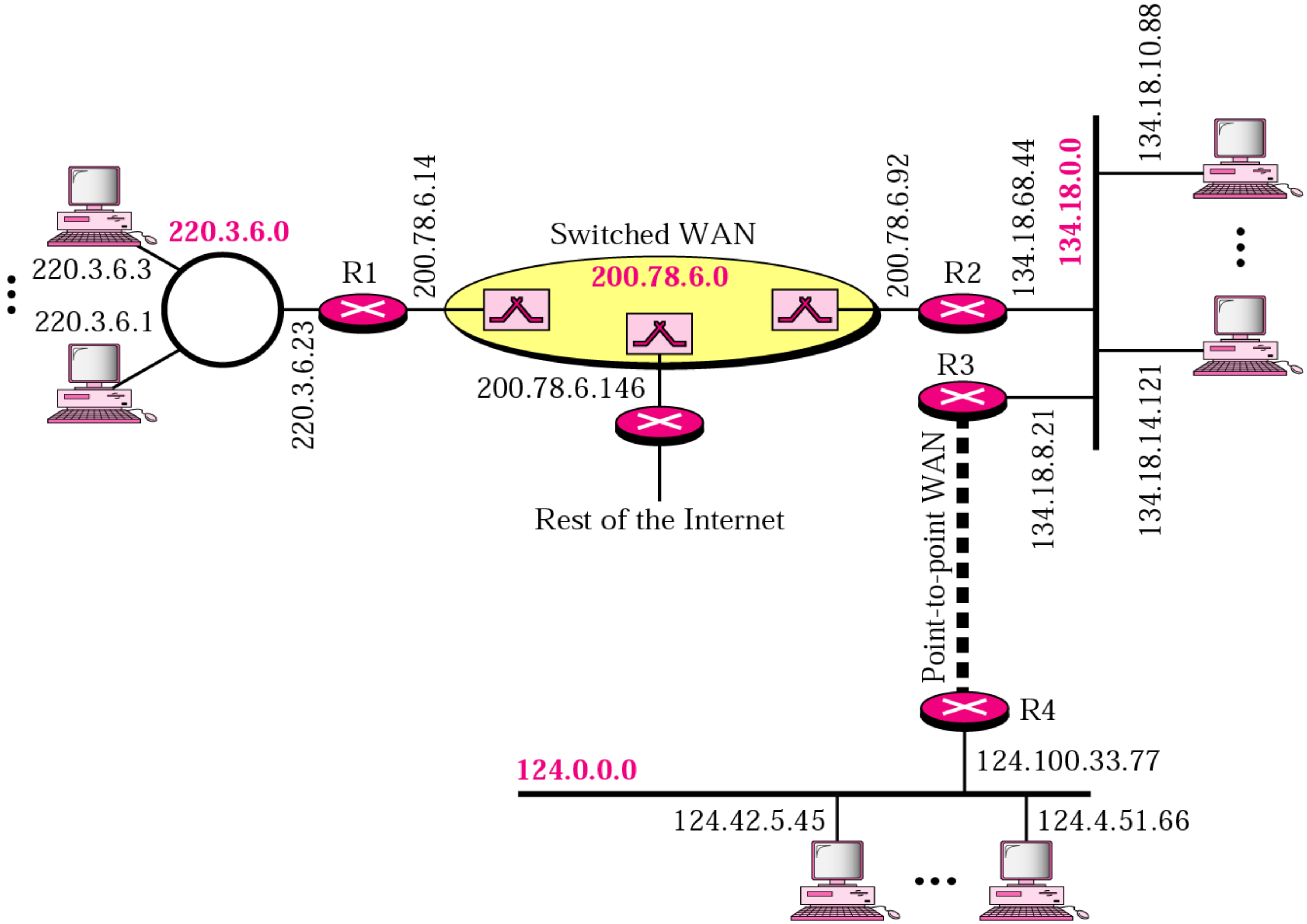
- It is a 32-bit address that define the network itself.
- All host bits are zero
- The network address define the network to the rest of the Internet. A router can route a packet based on the network address.
- The network address is the first address in the block.
- It can not be assigned to any host.
- The class of the address can be determined from the given network address.

Example

- Given the address 23.56.7.91, find the network address.
- Given the address 132.6.17.85, find the network address.
- Given the network address 17.0.0.0, find the class.

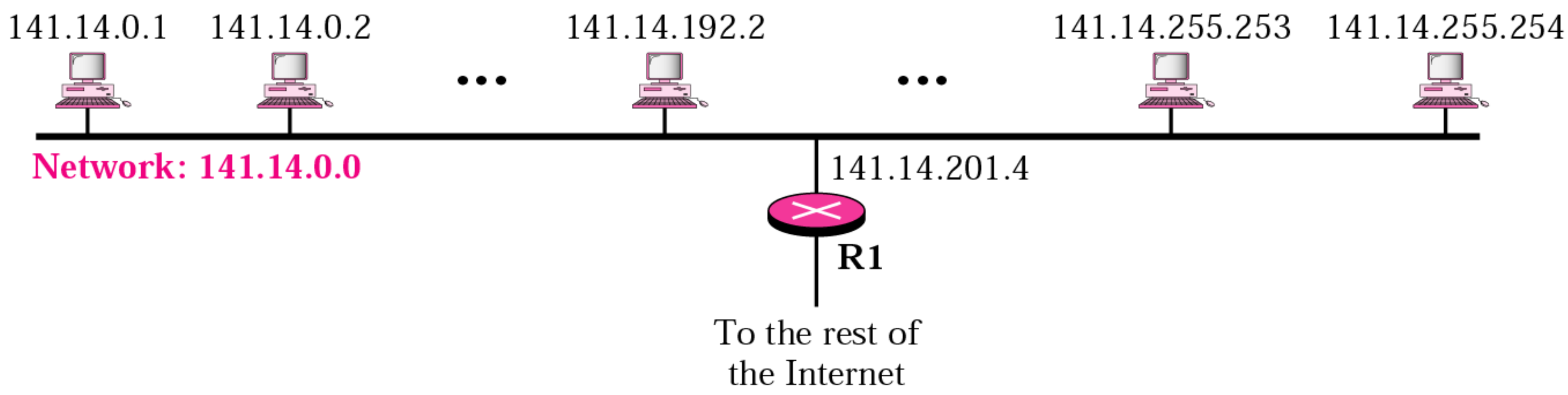
A network address is different from a netid. A network address has both netid and hostid, with 0s for the hostid.

Sample internet



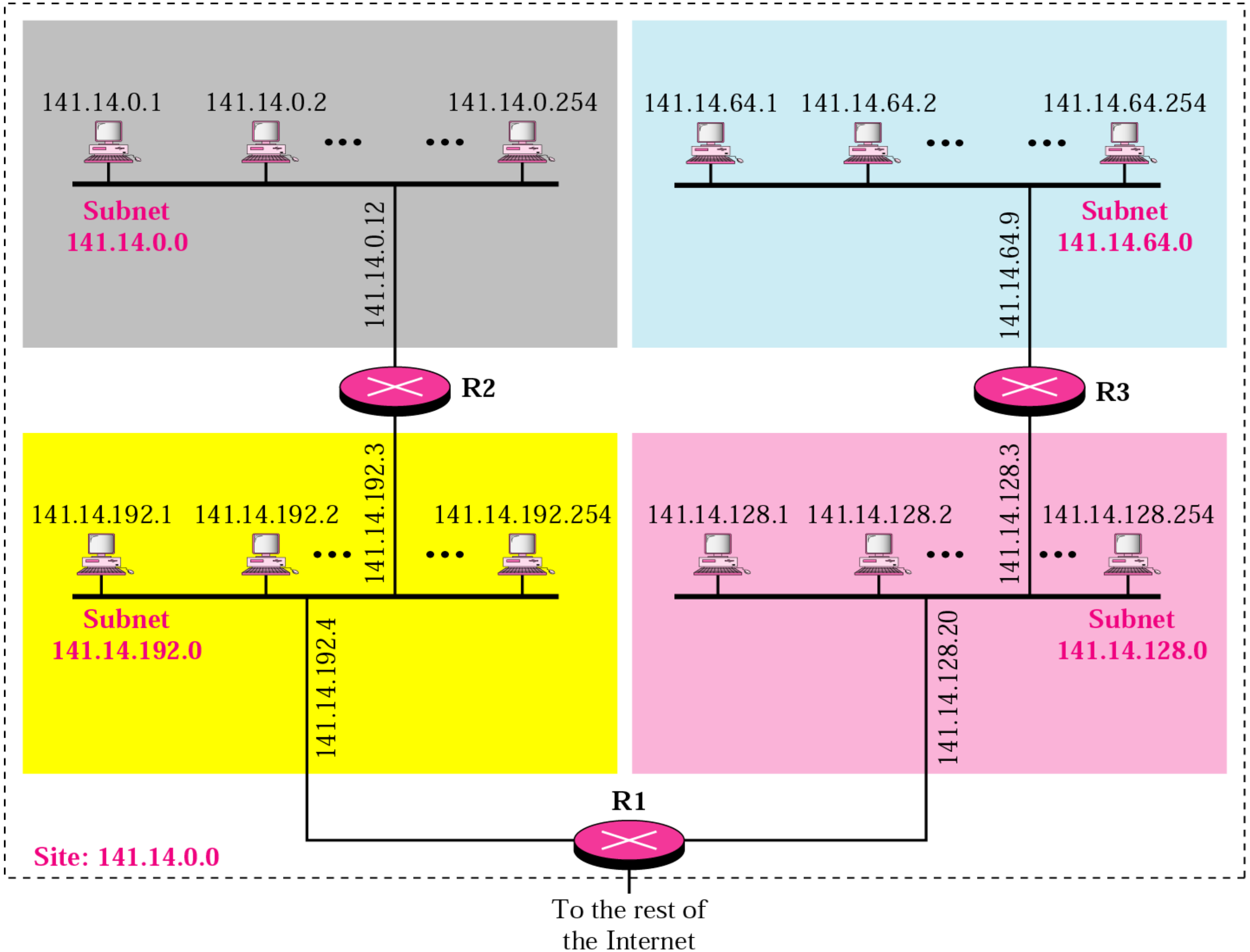
A network with two levels of hierarchy

Netid	Hostid

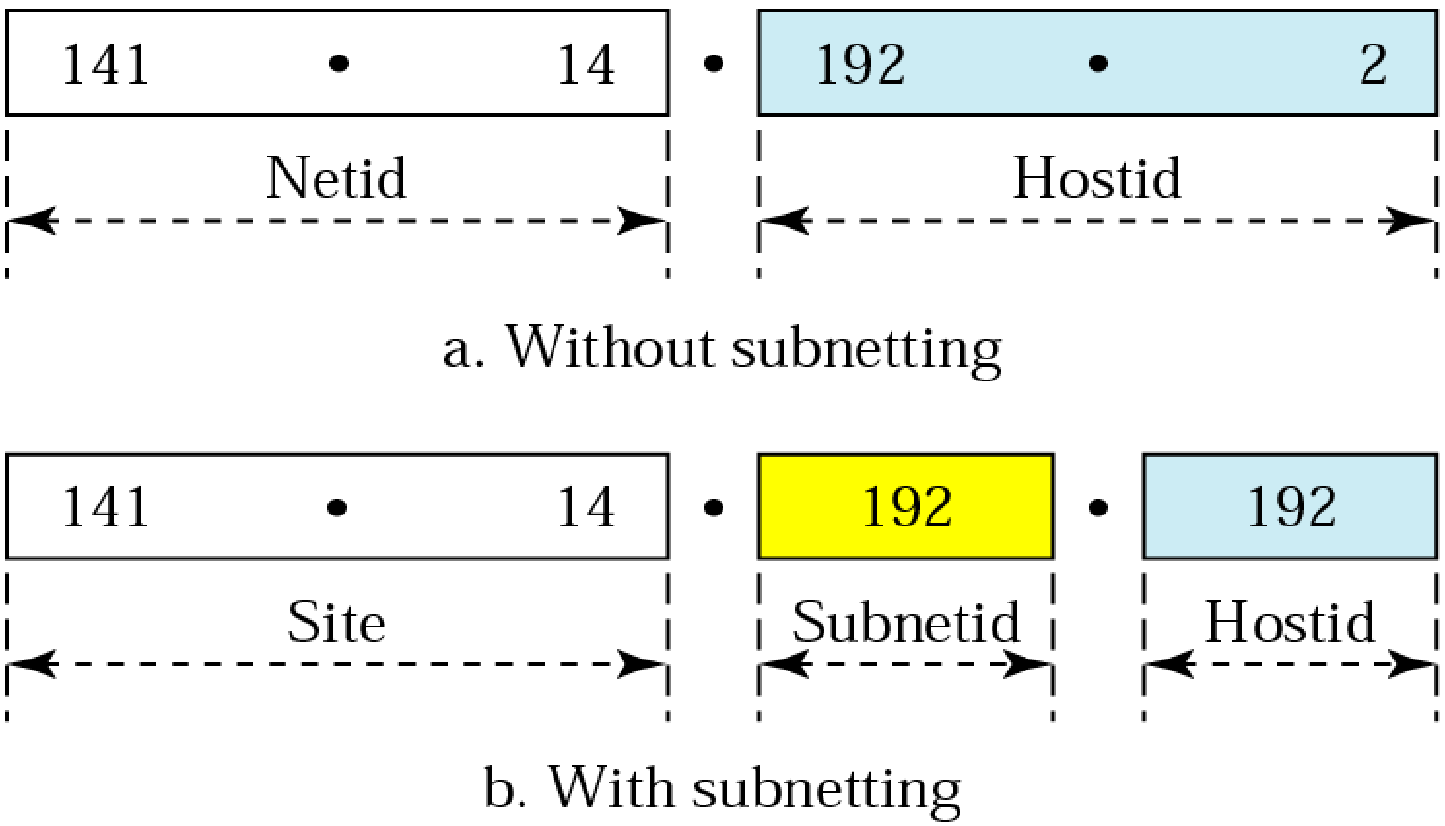


A network with three levels of hierarchy

Netid	Subnetid	Hostid



Addresses in a network with and without subnetting



Default mask

Class	In Binary	In Dotted Decimal	Using slash
Class A	11111111 00000000 00000000 00000000	255.0.0.0	/8
Class B	11111111 11111111 00000000 00000000	255.255.0.0	/16
Class C	11111111 11111111 11111111 00000000	255.255.255.0	/24

Subnet mask

- It is a 32 bit binary number that masks an IP address and divides the IP address into network number and host number.
Netid	Subnetid	Hostid
All 1s	All 1s	All 0s
- It is used to idenify **network address** of an IP address by performing a bitwise AND operation on the mask.
- It is required to find the interface to forward the packet for the desired network or the node.
- Network mask helps to know which portion of the address identifies the network and which portion identifies the host.

use of Subnet mask: An example

A class A IP address and mask given as 8.20.15.1 and 255.0.0.0. Find the network address using mask.

Answer

IP address **bitwise AND** Mask = Network address

8.20.15.1 **bitwise AND** 255.0.0.0 = 8.0.0.0

Subnetwork Address

Netid	Subnetid	Hostid
Specific	Specific	All 0s

- It is a 32-bit address that define the subnetwork itself.
- All host bits are zero
- The subnetwork address define the network to the rest of the Internet. A router can route a packet onto the network based on the subnetwork address.
- The subnetwork address is the first address in the block.
- It can not be assigned to any host.
- The class of the address can be determined from the given subnetwork address.

Casting

How to send the packet from one host to other.

- **Unicast:** One-to-one
- **Broadcast:**Host to all other host
  1. **Limited broadcast (Local network broadcast):**

     Host to all other host in the same network

Netid	Subnetid	Hostid
All 1s	All 1s	All 1s

  2. **Directed broadcast (Distant network broadcast):**

     Host to all other host in the other network

Netid	Subnetid	Hostid
Specific	Specific	All 1s

Special IP addresses

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0		This host
0 0 . . . 0 0	Host	A host on this network
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1		Broadcast on the local network
Network	1 1 1 1 . . . 1 1 1 1	Broadcast on a distant network
127	(Anything)	Loopback

Subnet, Subnet Masking, & Routing

- Design 4 subnets for the given class C IP 200.1.2.0. Find the network address for each subnet and subnet mask of the network.
- Let us consider a routing table is given below. Find the interface on which the packet will move with the destination address 200.1.2.22

Network address	**subnet mask**	**Interface**
200.1.2.0	255.255.255.192	a
200.1.2.64	255.255.255.192	b
200.1.2.128	255.255.255.192	c
200.1.2.192	255.255.255.192	d
0.0.0.0	0.0.0.0.0	e (default entry)

Example

Suppose a router has build up the routing table shown in the table-2. The router can deliver packet directly over the interface 0 and 1 or it can forward packet to routers R_2, R_3, and R_4. Describe what the router does with the packet addressed to each of the following destinations.

(a) 128.96.39.10

(b) 128.96.40.12

(c) 128.96.40.151

(d) 192.4.153.17

(e) 192.4.153.90

Network address	Subnet mask	Interface
128.96.39.0	255.255.255.128	0
128.96.39.128	255.255.255.128	1
128.96.40.0	255.255.255.128	R_2
192.4.153.0	255.255.255.192	R_3
default	—-	R_4

Table 1 : Routing table

Note

If multiple network addresses match, then use the interface with maximum 1s in the network mask. It is called longest prefix match.

Example

Suppose a router has build up the routing table shown in the table-2. The router can deliver packet directly over the interface 0 and 1 or it can forward packet to routers R_2, R_3, and R_4. Describe what the router does with the packet addressed to each of the following destinations.

(a) 128.96.171.92
(b) 128.96.167.151
(c) 128.96.163.151
(d) 128.96.169.192
(e) 128.96.165.121

Network address	**Subnet mask**	**Interface**
128.96.170.0	255.255.254.0	0
128.96.168.0	255.255.254.0	1
128.96.166.0	255.255.254.0	R_2
128.96.164.0	255.255.252.0	R_3
default	—-	R_4

Table 2 : Routing table

Variable Length Subnet Masking(VLSM)

- Consider a Class C IP 200.1.2.0. Design 3 subnets each of IPs 128, 64 and 64 respectively. Find the range of address, subnetwork address, and subnet mask.
- Let us consider a routing table is given below. Find the interface on which the packet will move with the destination address 200.1.2.194

Network address	**subnet mask**	**Interface**
200.1.2.0	255.255.255.128	a
200.1.2.128	255.255.255.192	b
200.1.2.192	255.255.255.192	c
0.0.0.0	0.0.0.0.0	e (default entry)

Practice Question

- A network on the Internet has a classful subnet mask of 255.255.240.0. What is the maximum number of hosts it can handle?
- Suppose that instead of using 16 bits for the network part of a class B address originally, 20 bits had been used. How many class B networks would there have been?
- Mask in classful address is given as 255.192.0.0. Find out the number of Hosts, and subnet present.
- What is a mask in IPv4 addressing? What is a default mask in IPv4 addressing?
- What is the network address in a block of addresses? How can we find the network address if one of the addresses in a block is given?

Classless IP Addressing or CIDR Representation

Blockid	Hostid

CIDR(classless Inter Domain Routing) representation or classless representation- x.y.z.t/ n

n- number of bits in blockid or networkid

Example: 20.10.50.120 / 20

Networkid=20 bits

Hostid=32-20=12

Total number of IP addresses=2^{32-n}

Rules for forming CIDR Block

1. The addresses in a block must be contiguous, one after another.
2. The number of addresses in a block must be a power of 2 (1, 2, 4, 8, ...).
3. The first address must be evenly divisible by the number of addresses in the block.

Example

Test Whether the given addresses is a CIDR block or not.

- 100.1.2.32
- 100.1.2.33
- $\vdots$
- 100.1.2.47

Solution

Rules

- IP addresses are contiguous- Yes
- Number of addresses power of 2- Yes
- First IP address is evenly divisible by 16- Yes

So, It is a valid CIDR block

Practice

Test Whether the given addresses is a CIDR block or not.

1. - 100.1.2.32
   - 100.1.2.33
   - ⋮
   - 100.1.2.47
2. - 205.16.37.32
   - 205.16.37.33
   - ⋮
   - 205.16.37.47
3. - 150.10.20.64
   - 150.10.20.65
   - ⋮
   - 150.10.20.127

HOW to represent CIDR block?

Let HostID for a block is 7 bits.

Let BlockID(NetID) for that block is 25 bits.

Say, any one IP address of that block is 205.10.22.65, So

CIDR representation of that block is 205.10.22.65/ 25

Derivation of entire block from the given CIDR representation

Let a CIDR block is given as 205.16.37.39/28. Find the entire block.

Derivation: The first address in the block

n=28 bits, BlockId=n= 28 bits, HostId=32-n= 32-28 = 4 bits

- The first address in the block can be found by setting the rightmost 32 - n bits to 0s.

  The first address in the block can be found by setting the rightmost 32 - 28 bits to 0s.

  The binary representation of the given address is 11001101 00010000 00100101 00100111

  Setting 32 - 28 rightmost bits to 0, we get 11001101 0001000 00100101 0010000 or 205.16.37.32.

Derivation of entire block from the given CIDR representation contd...

Let a CIDR block is given as 205.16.37.39/28. Find the entire block.

Derivation: The last address in the block

n=28 bits, BlockId=n= 28 bits, HostId=32-n= 32-28 = 4 bits

- The first address in the block can be found by setting the rightmost 32 - n bits to 1s.

  The first address in the block can be found by setting the rightmost 32 - 28 bits to 1s.

  The binary representation of the given address is 11001101 00010000 00100101 00100111

  Setting 32 - 28 rightmost bits to 1, we get 11001101 00010000 00100101 00101111 or 205.16.37.47.

Entire Block

Let a CIDR block is given as 205.16.37.39/28. Find the entire block.

- **First address:** 205.16.37.32
- **Last address:** 205.16.37.47

We can test whether it is a valid CIDR block or not by applying the rules discussed earlier.

Practice

Given the CIDR block, find the first address and last address, and total number of addresses

1. 20.10.30.35/ 27
2. 100.0.2.35/ 28
3. 100.1.2.35/ 20
4. 205.16.37.39/ 28
5. In a block of addresses, we know the IP address of one host is 25.34.12.56/16. What are the first address and the last address in this block?
6. In a block of addresses, we know the IP address of one host is 182.44.82.16/26. What are the first address and the last address in this block?

Masking in CIDR

- A mask is a 32-bit number in which the n leftmost bits are 1s and the 32 - n rightmost bits are 0s.
- However, in classless addressing the mask for a block can take any value from 0 to 32.
- It is very convenient to give just the value of n preceded by a slash (CIDR notation).

Example- Mask

- /26 or 11111111 11111111 11111111 11000000
- /27 or 11111111 11111111 11111111 11100000
- /18 or 11111111 11111111 11000000 00000000

Network Address in CIDR

- It is a 32-bit address that define the network itself.
- As like classful,

Blockid	Hostid
Specific	All 0s

- All host bits are zero. It can not be assigned to any host.
- The first address is called the network address and defines the organization network. It defines the organization itself to the rest of the world.
- The first address is the one that is used by routers to direct the message sent to the organization from the outside.
- **Example:** for mask 205.16.37.39/28 (i.e 11001101 00010000 00100101 00100111/28), the network address is 11001101 00010000 00100101 0010 $\boxed{0000}$, or 205.16.37.32

Sunbetting in CIDR

- An organization that is granted a large block of addresses may want to create clusters of networks (called subnets) and divide the addresses between the different subnets.
- The rest of the world still sees the organization as one entity; however, internally there are several subnets.
- All messages are sent to the router address that connects the organization to the rest of the Internet; the router routes the message to the appropriate subnets.
- The organization, however, needs to create small subblocks of addresses, each assigned to specific subnets.
- The organization has its own mask; each subnet must also have its own.

Example Subnetting in CIDR

Asssume a CIDR block is given as 20.30.40.10/25. Divide the block in two subblocks, and find the first address, last address, subnet mask of each block.

Subnetting

Block id= 25 bits, host id=32-25=7 bits, total addresses $= 2^7 = 128$ to be divided into two blocks

$\boxed{\textbf{Block 1:}}$ 20.30.40.0$\boxed{0}$000000 $\cdots$ 20.30.40.0$\boxed{0}$111111

20.30.40.0 $\cdots$ 20.30.40.63

CIDR representation of block 1= 20.30.40.1/26

$\boxed{\textbf{Block 2:}}$ 20.30.40.0$\boxed{1}$000000 $\cdots$ 20.30.40.0$\boxed{1}$111111

20.30.40.64 $\cdots$ 20.30.40.127

CIDR representation of block 2= 20.30.40.66/26

Example Subnetting in CIDR

Asssume a CIDR block is given as 20.30.40.10/25. Divide the block in 4 subblocks, and find the first address, last address, subnet mask of each block.

Subnetting

Block id= 25 bits, host id=32-25=7 bits, total addresses $= 2^7 = 128$ to be divided into **four** blocks

$\boxed{\textbf{Block 1:}}$ 20.30.40.0$\boxed{00}$00000 $\cdots$ 20.30.40.0$\boxed{00}$11111

20.30.40.0 $\cdots$ 20.30.40.31

CIDR representation of block 1= 20.30.40.1/27

$\boxed{\textbf{Block 2:}}$ 20.30.40.0$\boxed{01}$00000 $\cdots$ 20.30.40.0$\boxed{01}$11111

20.30.40.32 $\cdots$ 20.30.40.63

CIDR representation of block 2= 20.30.40.1/27

$\boxed{\textbf{Block 3:}}$ 20.30.40.0$\boxed{10}$00000 $\cdots$ 20.30.40.0$\boxed{10}$11111

20.30.40.64 $\cdots$ 20.30.40.95

CIDR representation of block 3= 20.30.40.64/27

$\boxed{\textbf{Block 4:}}$ 20.30.40.0$\boxed{11}$00000 $\cdots$ 20.30.40.0$\boxed{11}$11111

20.30.40.96 $\cdots$ 20.30.40.127

Practice Question

- suppose an organization is given the block 17.12.40.0/26, which contains 64 addresses. The organization has three offices and needs to divide the addresses into three subblocks of 32, 16, and 16 addresses. Find the first address, last address , and sunet mask of each block.
- An ISP is granted a block of addresses starting with 190.100.0.0/16 (65,536 addresses). The ISP needs to distribute these addresses to three groups of customers as follows:
  a. The first group has 64 customers; each needs 256 addresses.
  b. The second group has 128 customers; each needs 128 addresses.
  c. The third group has 128 customers; each needs 64 addresses.

  Design the subblocks and find out how many addresses are still available after these allocations.
- An address space has a total of 1024 addresses. How many bits are needed to represent an address?

Practice Question-1

- An ISP is granted a block of addresses starting with 120.60.4.0/22. The ISP wants to distribute these blocks to 100 organizations with each organization receiving just eight addresses. Design the subblocks and give the slash notation for each subblock. Find out how many addresses are still available after these allocations.
- Find the netid and the hostid of the following classful IP addresses.
  a. 114.34.2.8
  b. 132.56.8.6
  c. 208.34.54.12
- Find the mask of the block, if the CIDR block is represented as 12.36.56.1/27
- A large number of consecutive IP addresses are available starting at 198.16.0.0. Suppose that four organizations, A, B, C, and D, request 4000, 2000, 4000, and 8000 addresses, respectively, and in that order. For each of these, give the first IP address assigned, the last IP address assigned, and the mask in the w.x.y.z/s notation.