Module – 4
Network Layer

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IPv4 Addressing

Introduction

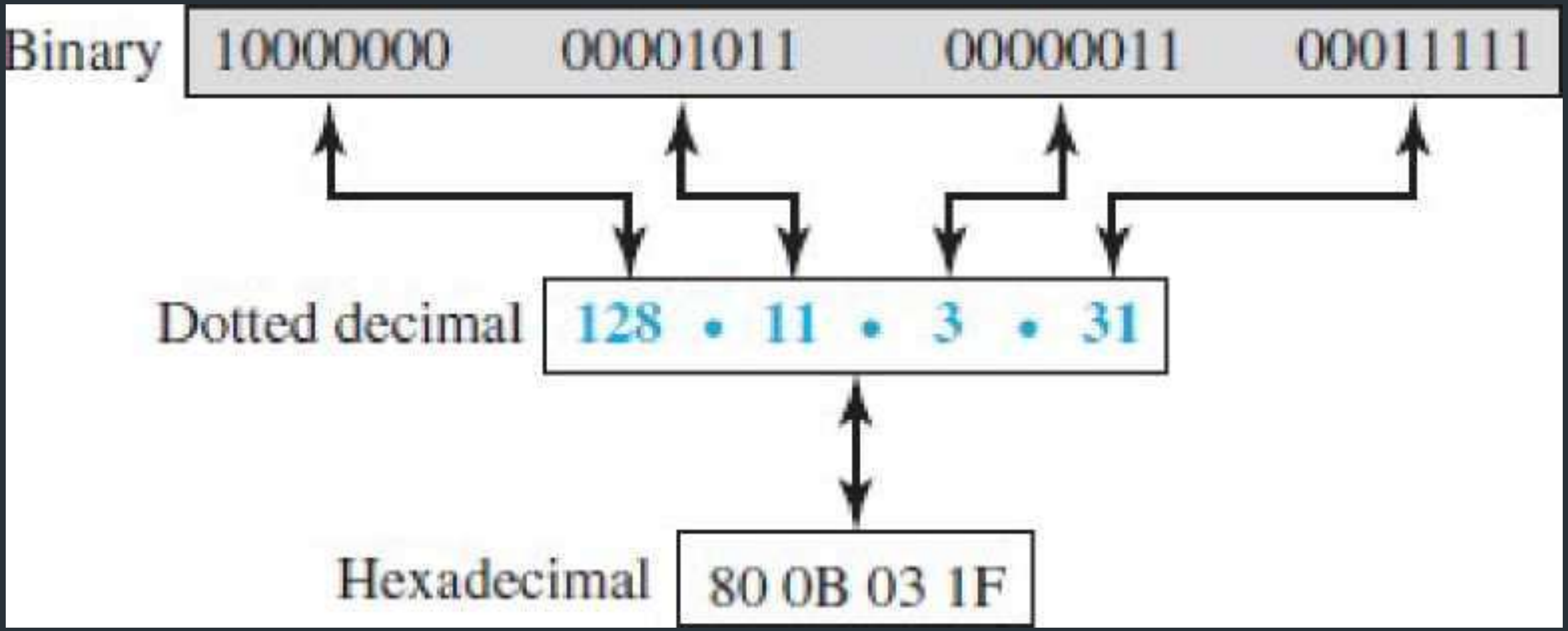
- 32-bit address
- *Unique*
- *Universal*

Address Space

- IPv4 that defines addresses has an address space.
- An address space is the total number of addresses used by the protocol.
- If a protocol uses *N bits to define* an address, the address space is 2^N
- IPv4 uses 32-bit addresses, which means that the address space is 2^{32} or 4,294,967,296 (more than 4 billion).

Notations

- Binary
- Dotted decimal
- Hexa decimal



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Notations (ContcL.)

- In binary notation, an IPv4 address is displayed as 32 bits.
- To make the address more readable, one or more spaces are usually inserted between each octet (8 bits).
- Each octet is often referred to as a byte.
- Each number in the dotted-decimal notation is between 0 and 255.
- Each hexadecimal digit is equivalent to four bits.
- This means that a 32-bit address has 8 hexadecimal digits. This notation is often used in network programming.

Simple Task 1

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

    a. 10000001 00001011 00001011 11101111

    b. 11000001 10000011 00011011 11111111

Simple Task 2

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

  a. 111.56.45.78

  b. 221.34.7.82

Simple Task 3

- Find the error, if any, in the following IPv4 addresses.

  a. 111.56.045.78

  b. 221.34.7.8.20

  c. 75.45.301.14

  d. 11100010.23.14.67

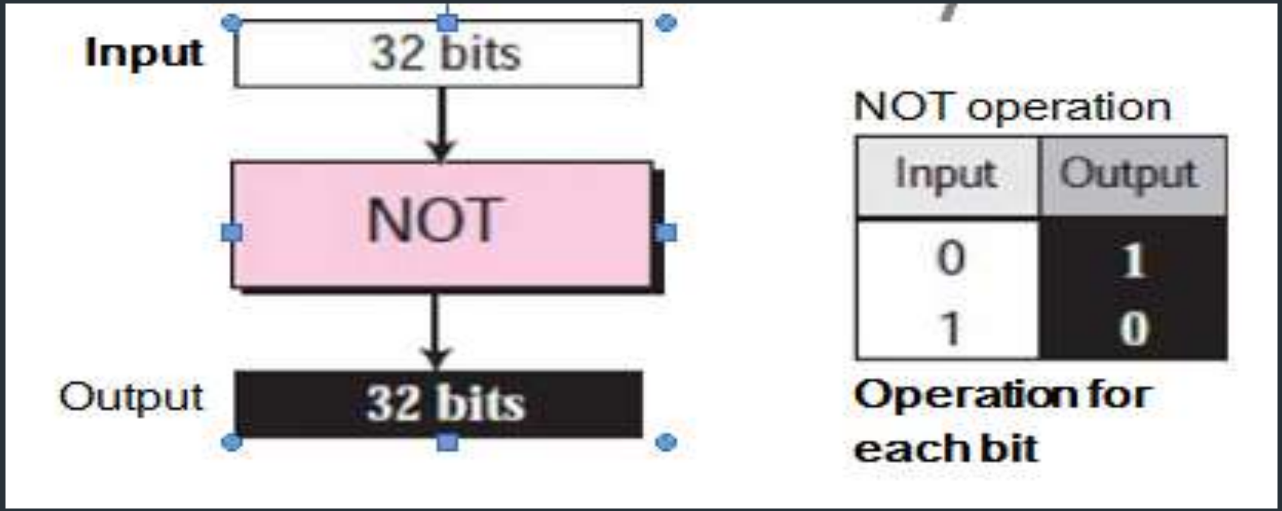
Simple Task 4

- Change the following IPv4 addresses from binary notation to hexadecimal notation.

  a. 10000001 00001011 0000101111101111

  b. 1100000110000011 0001101111111111

Bitwise Not Operation



Original number:	00010001	01111001	00001110	00100011
Original number:	17	. 121	. 14	. 35

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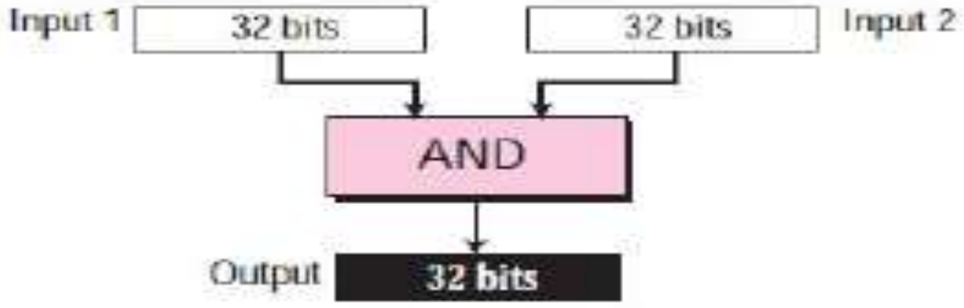
Bitwise AND Operation

- When at least one of the numbers is 0 or 255, the AND operation selects the smaller byte (or one of them if equal).
- When none of the two bytes is either 0 or 255, we can write each byte as the sum of eight terms, where each term is a power of 2.
- We then select the smaller term in each pair (or one of them if equal) and add them to get the result.

Bitwise AND Operation



AND

Input 1	Input 2	Output
0	0	0
0	1	0
1	0	0
1	1	1

Operation for each bit

First number:	00010001	01111001	00001110	00100011
Second number:	11111111	11111111	10001100	00000000

First number:	17 .	121 .	14 .	35
Second number:	255 .	255 .	140 .	0

Powers	2^7		2^6		2^5		2^4		2^3		2^2		2^1		2^0
Byte (14)	0	+	0	+	0	+	0	+	8	+	4	+	2	+	0
Byte (140)	128	+	0	+	0	+	0	+	8	+	4	+	0	+	0
Result (12)	0	+	0	+	0	+	0	+	8	+	4	+	0	+	0

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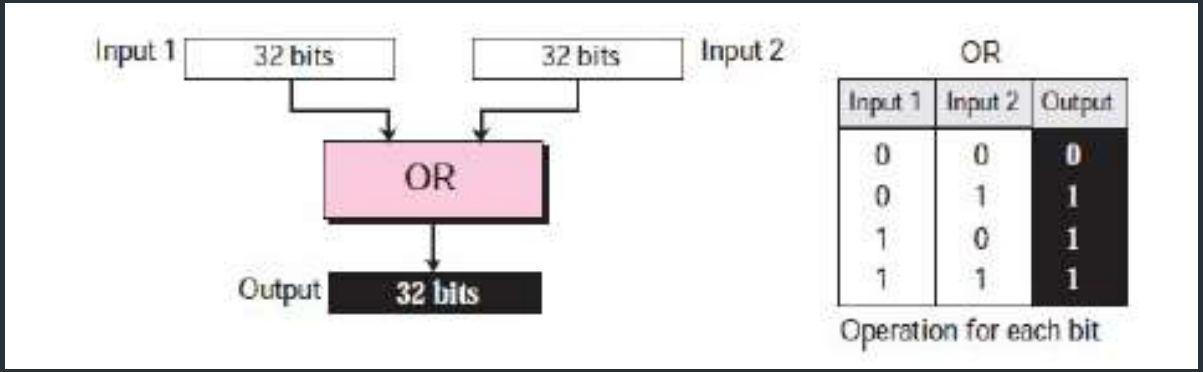
Bitwise OR Operation



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1. When at least one of the two bytes is 0 or 255, the OR operation selects the larger byte (or one of them if equal).
2. When none of the two bytes is 0 or 255, we can write each byte as the sum of eight terms, where each term is a power of 2.
3. We then select the larger term in each pair (or one of them if equal) and add them to get the result of OR operation.

Bitwise OR Operation

First number:	00010001	01111001	00001110	00100011
Second number:	11111111	11111111	10001100	00000000

First number:	17	121	14	35
Second number:	255	255	140	0

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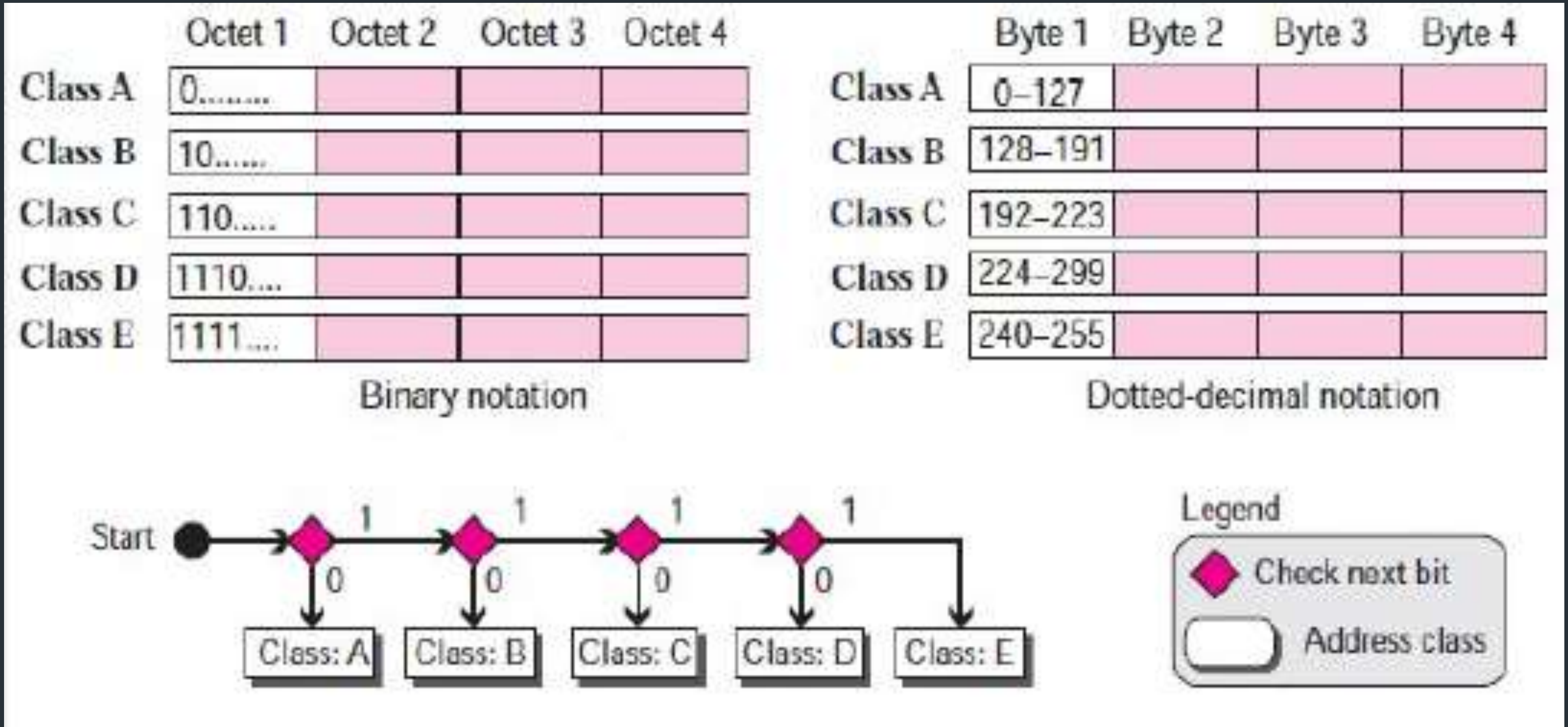
Classful Addressing

Classful Addressing

- Concept of classes
- In classful addressing, the address space is divided into five classes:

  Class A
  Ciass B
  Class C
  Class D
  Class E

Classful Addressing (Contd..)



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Classful Addressing (Contd..)

- 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

Classful Addressing (Contd..)

- Find the class of each address:

a. 227.12.14.87

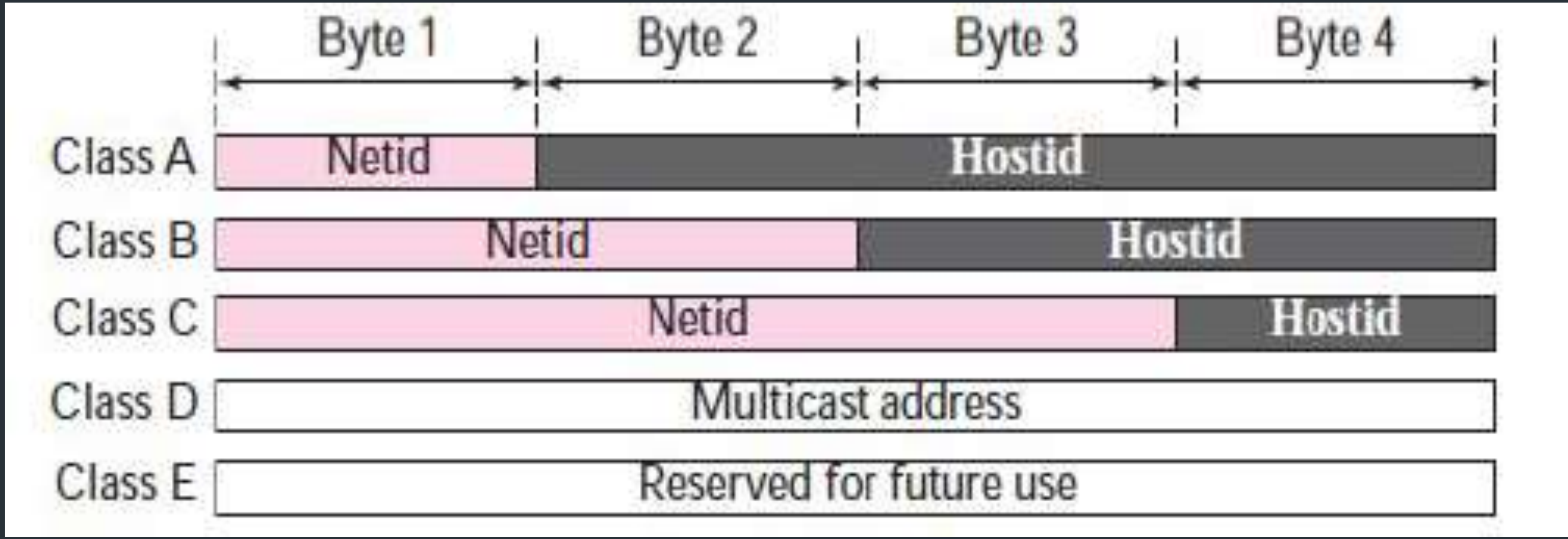
b. 193.14.56.22

c. 14.23.120.8

d. 252.5.15.111

Netid and Hostid

- In classful addressing, an IP address in classes **A, B,** and **C** is divided into **netid and hostid**



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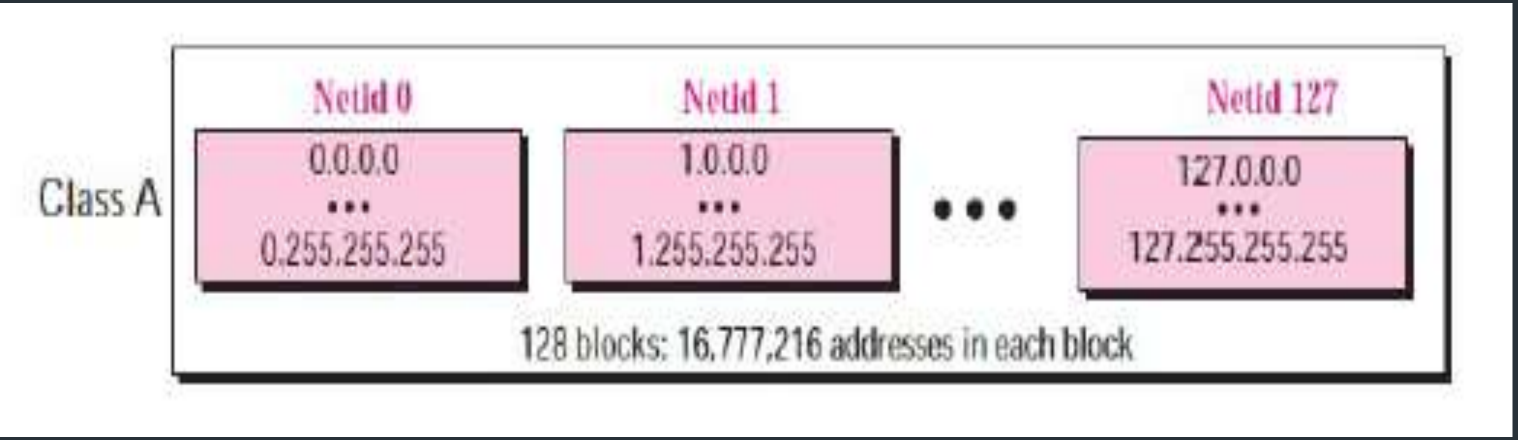
Classes and Blocks

- In classful addressing, each class is divided into a fixed number of blocks with each block having a fixed size.

Blocks in Class A

- Since only 1 byte in class A defines the netid and the leftmost bit should be 0, the next 7 bits can be changed to find the number of blocks in this class.
- Therefore, class A is divided into $2^7 = 128$ blocks



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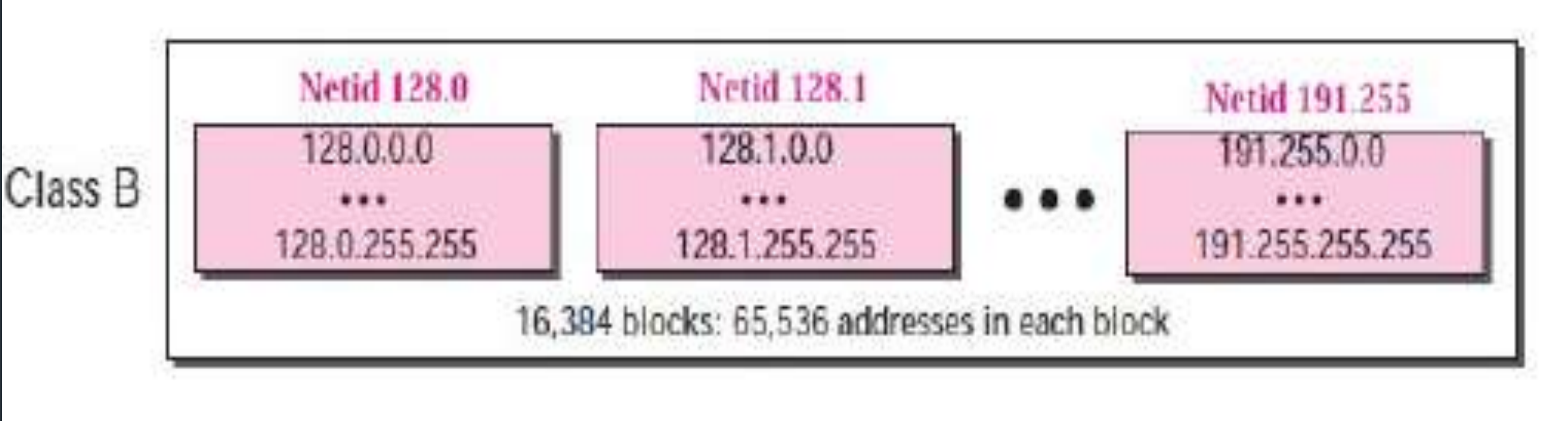
Blocks in Class B

- Since 2 bytes in class B define the class and the two leftmost bit should be 10 (fixed), the next 14 bits can be changed to find the number of blocks in this class.
- Therefore, class B is divided into 2^{14} = 16,384 blocks



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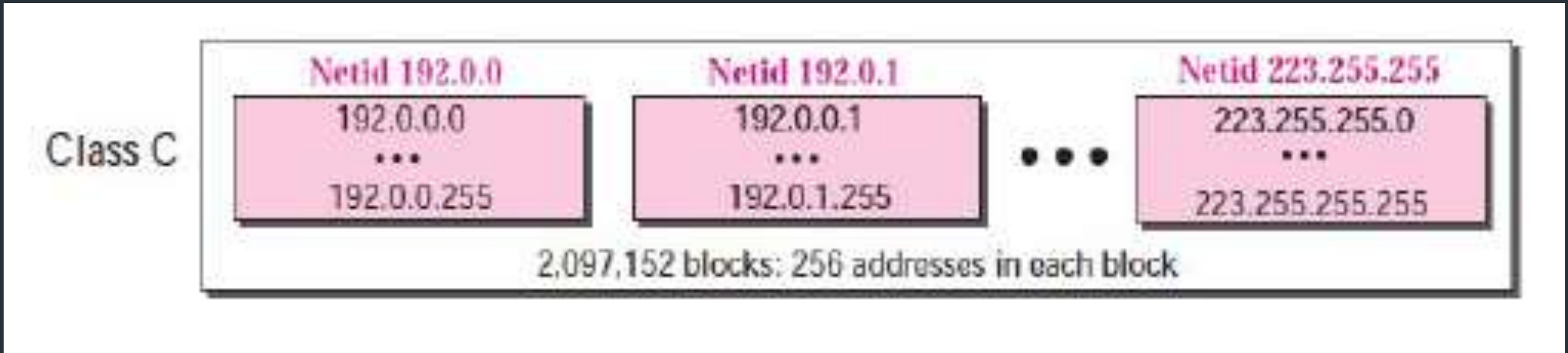
Blocks in Class C

- Since 3 bytes in class C define the class and the three leftmost bits should be 110 (fixed), the next 21 bits can be changed to find the number of blocks in this class.
- Therefore, class C is divided into 2^{21} = 2,097,152 blocks



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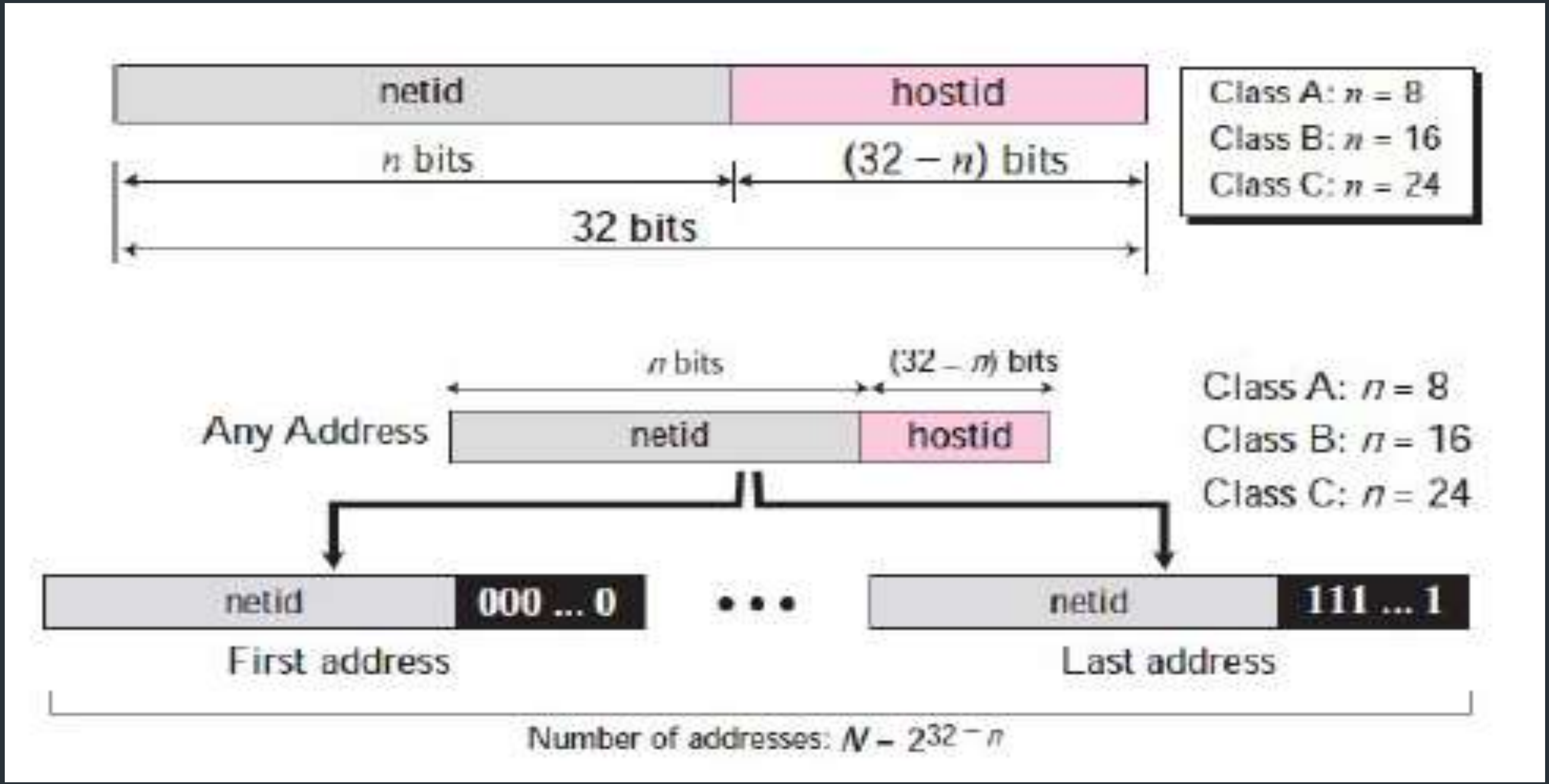
Two – Level Addressing



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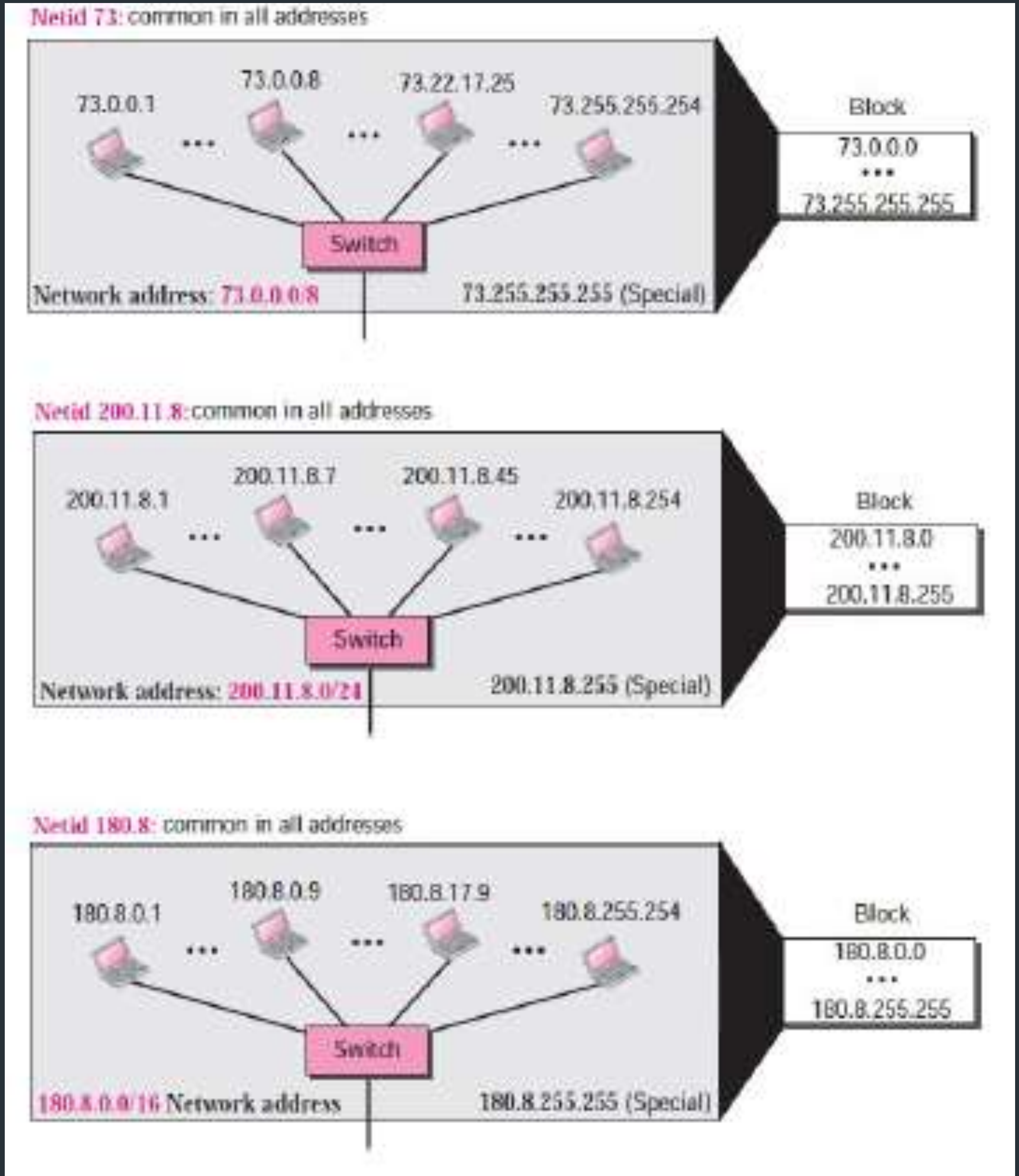
Information Extraction (Classful addressing)

- The number of addresses in the block, N, can be found using $N = 2^{32-n}$.
- To find the first address, we keep the n leftmost bits and set the (32 - n) rightmost bits all to Os.
- To find the last address, we keep the n leftmost bits and set the (32 - n) rightmost bits all to ls.

Simple Task 5

- An address in a block is given as 73.22.17.25. Find the number of addresses in the block, the first address, and the last address.
- An address in a block is given as 200.11.8.45. Find the number of addresses in the block, the first address, and the last address.
- An address in a block is given as 180.8.17.9. Find the number of addresses in the block, the first address, and the last address



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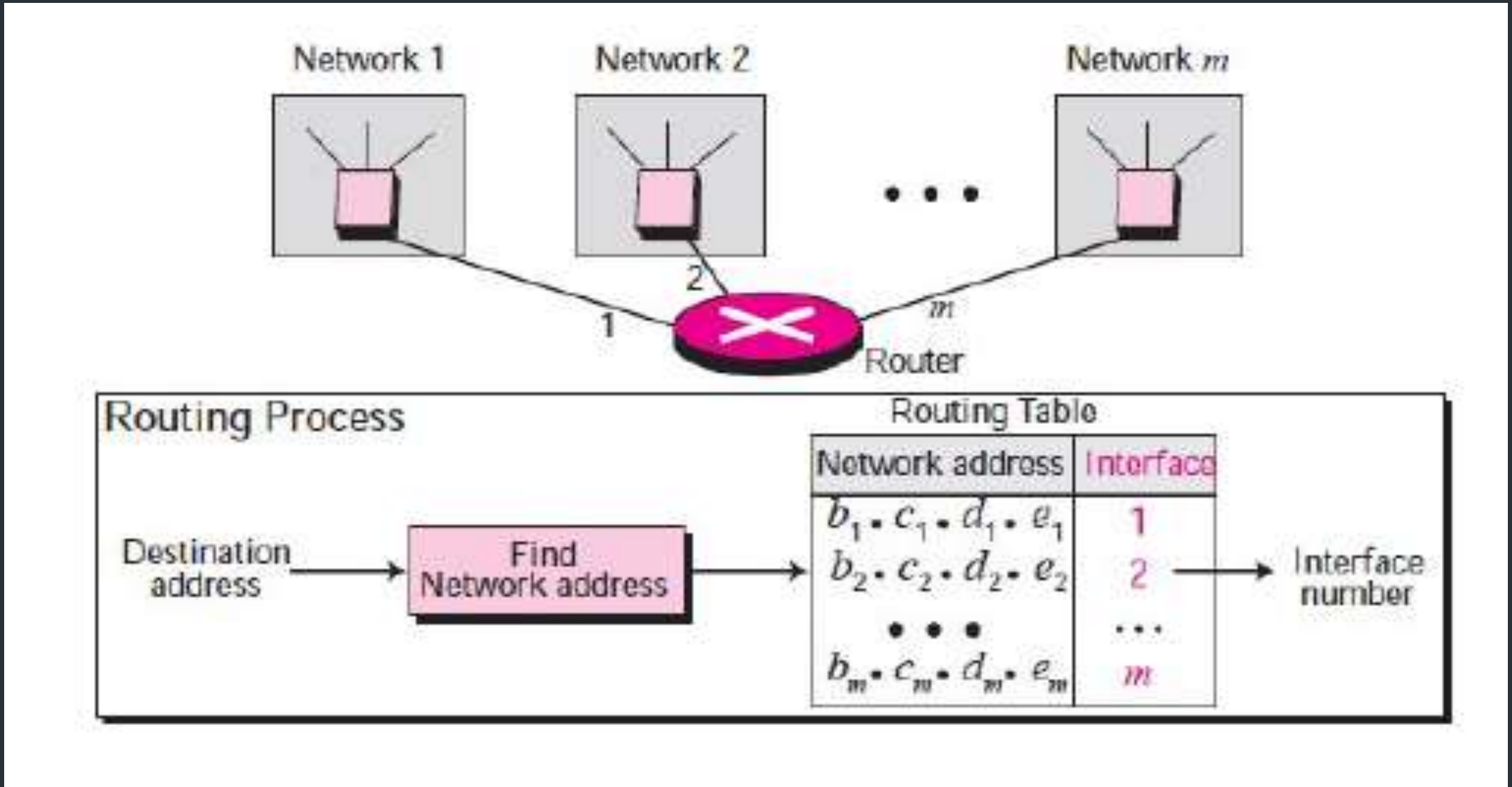
Network Address

- Network address is used in routing a packet to its destination network.
- Assume that an internet is made of m networks and a router with m interfaces.
- When a packet arrives at the router from any source host, the router needs to know to which network the packet should be sent;
- The router needs to know from which interface the packet should be sent out.

Network Address (Contd…)



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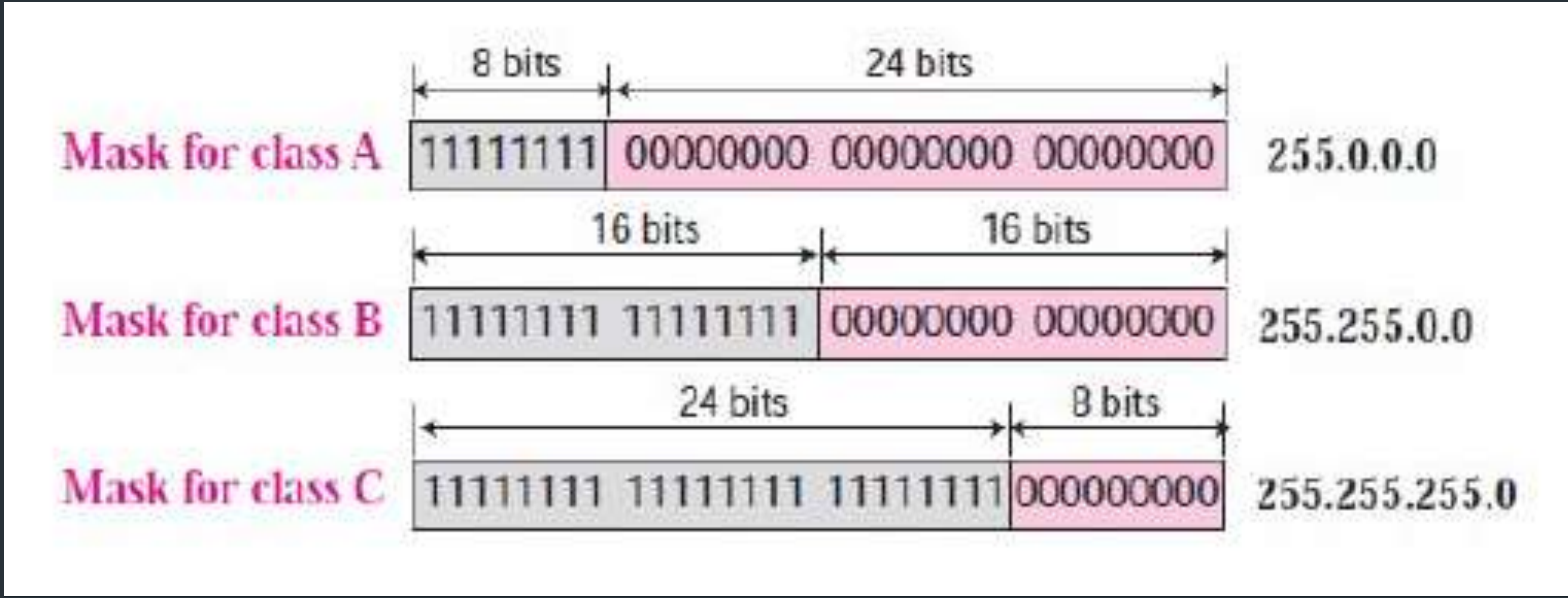
Network Mask

- Network Mask - To extract the network address from the destination address of a packet.
- A network mask or a default mask in classful addressing is a 32-bit number with n leftmost bits all set to ls and (32 - n) rightmost bits all set to Os.

Network Mask (Contd..)



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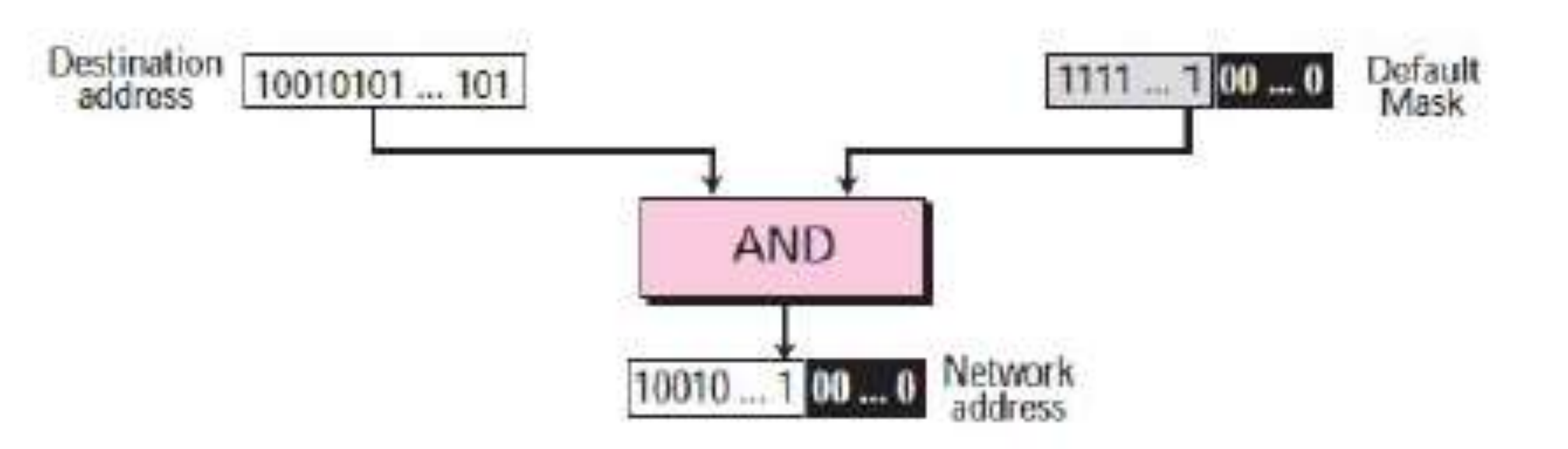
Network Mask (Contd..)

- When the destination address (or any address in the block)is ANDed with the default mask, the result is the network address



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Simple Task 6

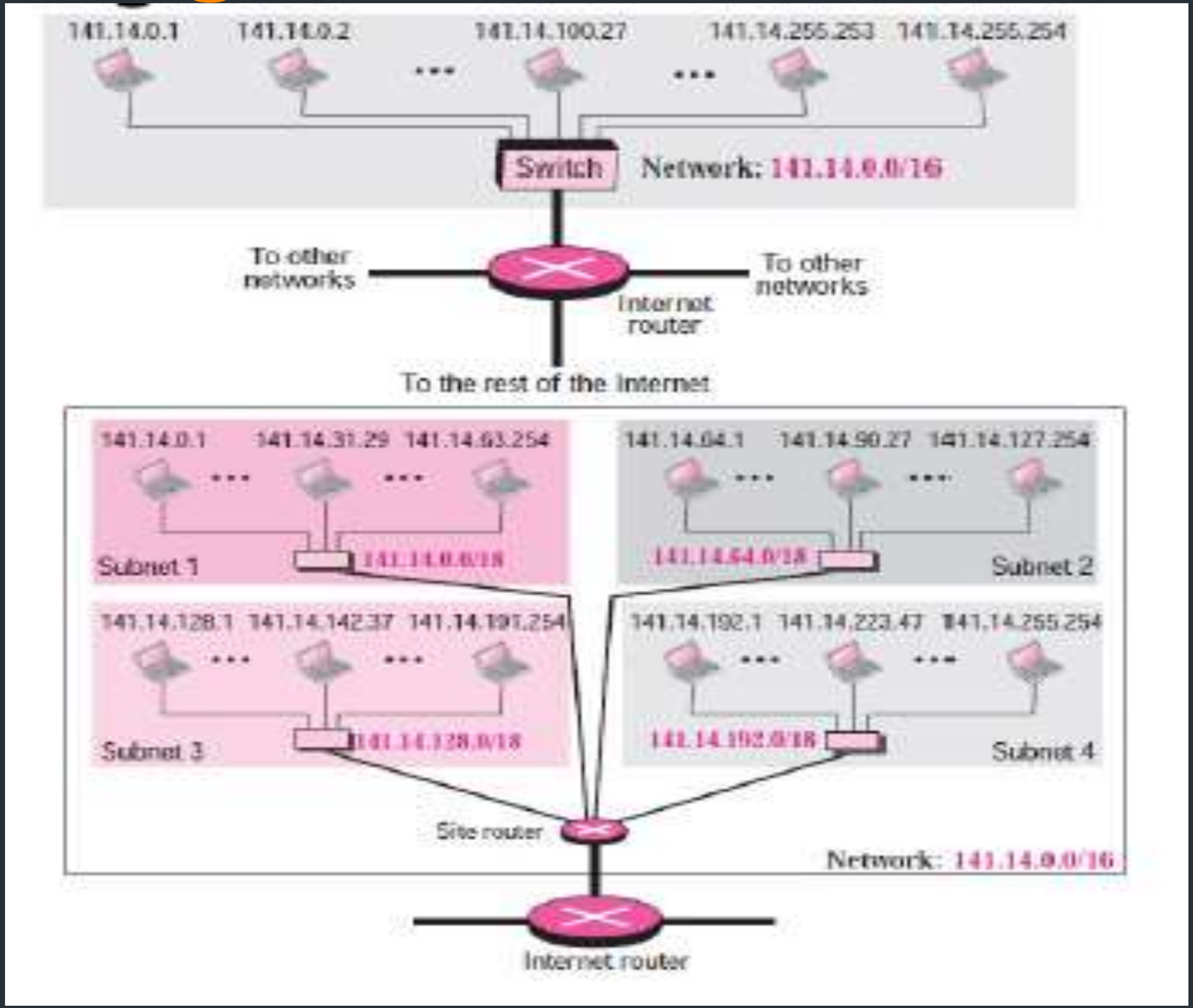
- A router receives a packet with the destination address 201.24.67.32. Show how the router finds the network address of the packet.

Classful Addressing & subnetting

Three – Level Addressing : Subnetting

- First, an organization that was granted a block in class A or B needed to divide its large network into several subnetworks for better security and management.
- Second, since the blocks in class A and B were almost depleted and the blocks in class C were smaller than the needs of most organizations, an organization that has been granted a block in class A or B could divide the block into smaller subblocks and share them with other organizations.
- In subnetting, a network is divided into several smaller subnetworks (subnets) with each subnetwork having its own subnetwork address.

Subnetting



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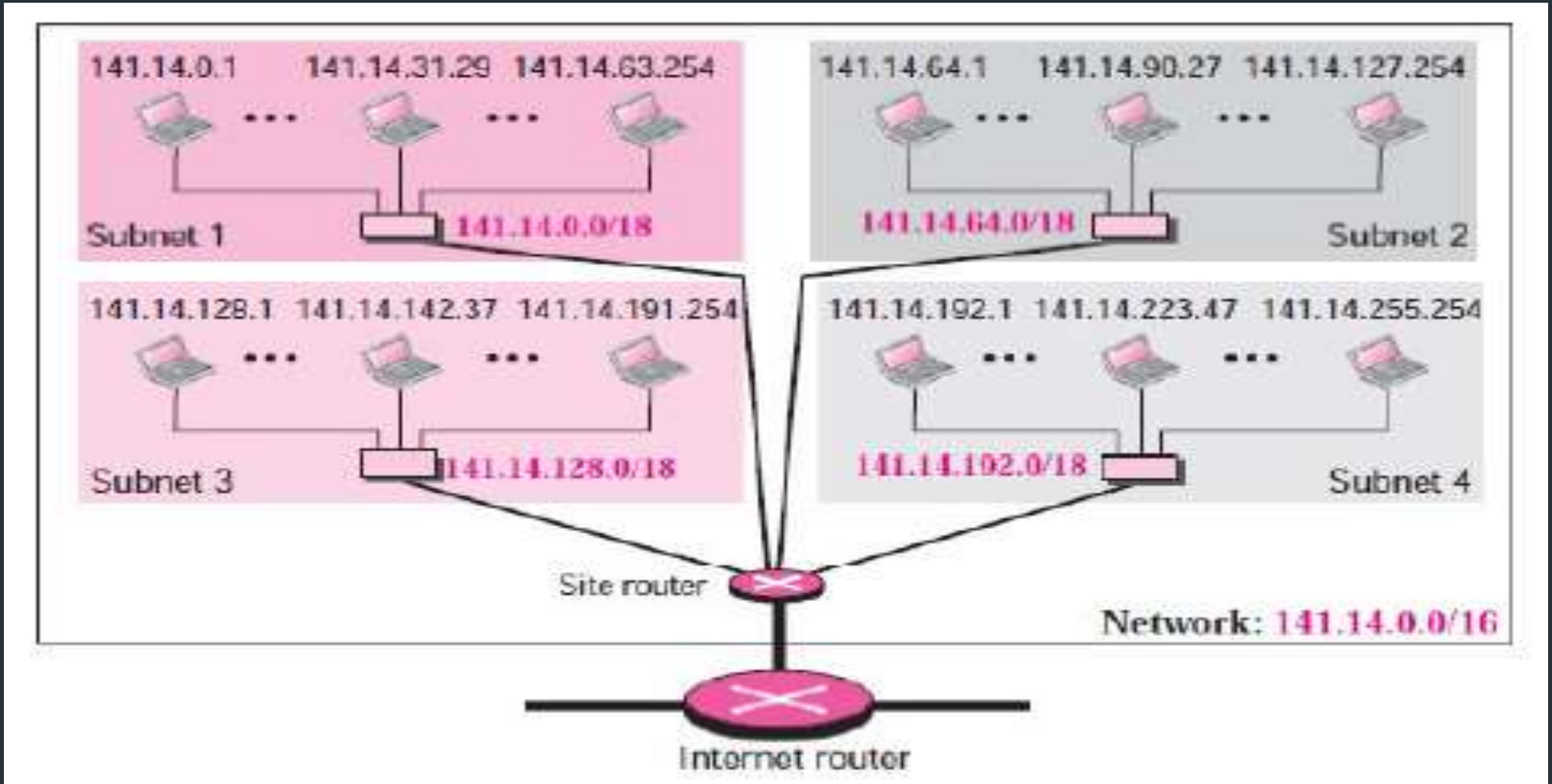
Subnetting



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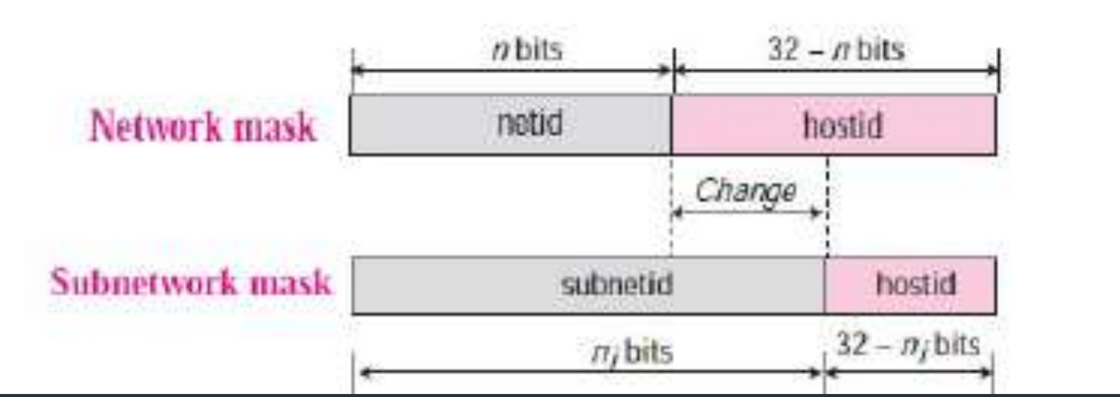
Subnetid

- Subnetting increases the length of the netid and decreases the length of hostid.
- When we divide a network to s number of subnetworks, each of equal numbers of hosts, we can calculate the subnetid for each subnetwork as

$$n_{sub} = n + \log_2 s$$

- n is the length of netid, n_{sub} is the length of each subnetid, and s is the number of subnets which must be a power of 2.



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Subnetid (Contd..)

- Class B network into four subnetworks.
- The value of n = 16
- Calculate the subnet mask

Subnetid (Contd..)

- This means that the subnet mask has eighteen Is and fourteen Os.
- In other words, the subnet mask is 255.255.192.0 which is different from the network mask for class B (255.255.0.0).

Subnetid (Contd..)

- we show that a network is divided into four subnets, one of the addresses in subnet 2 is 141.14.120.77
- Calculate the subnet address.

Subnetid (Contd..)

Address	→	141	.	14	.	120	.	77
Mask	→	255	.	255	.	192	.	0
Subnet Address	→	141	.	14	.	64	.	0

Address (120)	0	+	64	+	32	+	16	+	8	+	0	+	0	+	0
Mask (192)	128	+	64	+	0	+	0	+	0	+	0	+	0	+	0
Result (64)	0	+	64	+	0	+	0	+	0	+	0	+	0	+	0

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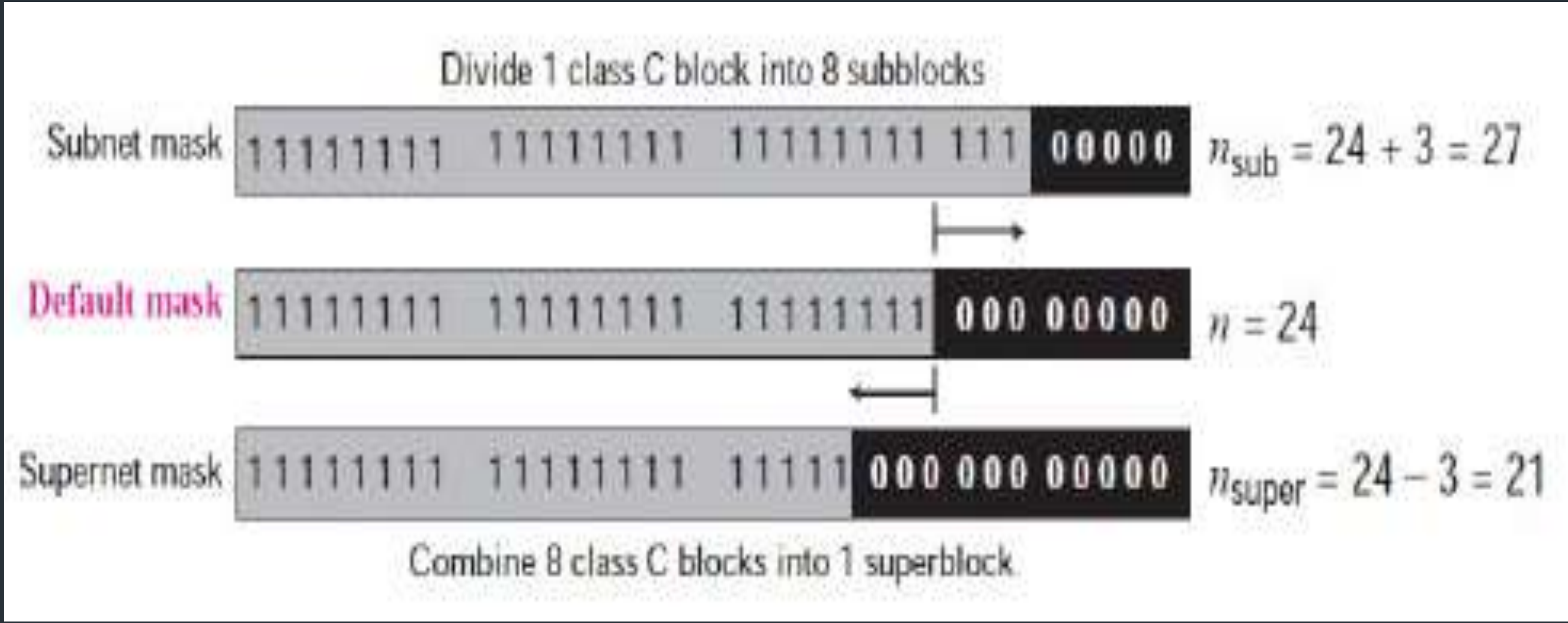
Supernetting

- Since class C blocks were still available but the size of the block did not meet the requirement of new organizations that wanted to join the Internet, one solution was supernetting.
- In supernetting, an organization can combine several class C blocks to create a larger range of addresses

Supernet Mask

- A supernet mask is the reverse of a subnet mask.
- A subnet mask for class C has more Is than the default mask for this class.
- A supernet mask for class C has less Is than the default mask for this class.

Supernet Mask (Contd..)



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Example 19.1

Change the following IPv4 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 (see Appendix B) and add dots for separation.

a. 129.11.11.239

b. 193.131.27.255

Example 19.2

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

a. 111.56.45.78

b. 221.34.7.82

Solution

We replace each decimal number with its binary equivalent (see Appendix B).

a. 01101111 00111000 00101101 01001110

b. 11011101 00100010 00000111 01010010

Example 19.3

Find the error, if any, in the following IPv4 addresses.

a. 111.56.045.78
b. 221.34.7.8.20
c. 75.45.301.14
d. 11100010.23.14.67

Solution

a. ***There must be no leading zero (045).***

b. ***There can be no more than four numbers.***

c. ***Each number needs to be less than or equal to 255.***

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

Example 19.4

Find the class of each address.

a. 00000001 00001011 00001011 11101111

b. 11000001 10000011 00011011 11111111

c. 14.23.120.8

d. 252.5.15.111

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 byte is 14; the class is A.***

d. ***The first byte is 252; the class is E.***

NOTE:

In classful addressing, the address space is divided into five classes: A, B, C, D, and E.

NOTE:

In classful addressing, a large part of the available addresses were wasted.

NOTE:

Classful addressing, which is almost obsolete, is replaced with classless addressing.

NOTE:

In IPv4 addressing, a block of addresses can be defined as

x.y.z.t */n*

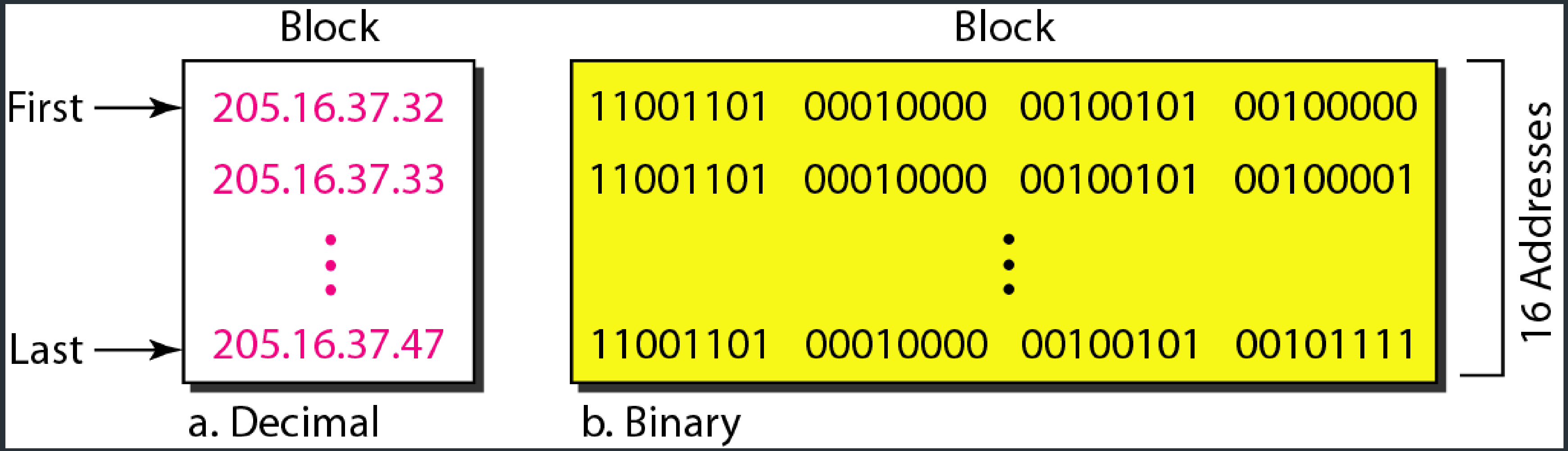
in which x.y.z.t defines one of the addresses and the */n* defines the mask.

Usually, x.y.z.t is the first address in the address block

NOTE:

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

Figure 19.3 *A block of 16 addresses granted to a small organization*



We can see that the restrictions are applied to this block. The addresses are contiguous. The number of addresses is a power of 2 ($16 = 2^4$). This block of IP addresses is represented by:

205.16.37.32/28

Example 19.6

A /28 block of addresses is granted to a small organization. We know that one of the addresses is 205.16.37.39. What is the first address in the block? What is its x.y.z.t/n representation?

Solution

- *The binary representation of the given address is*
  - *11001101 00010000 00100101 00100111*
- *If we set 32−28 rightmost bits to 0, we get*
  - *11001101 00010000 00100101 0010000 0*
    - *or*

205.16.37.32

  - *The block representation is 205.16.37.32/28*

NOTES:

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

Example 19.7

Find the last address for the block in Example 19.6.

Solution

- *The binary representation of the given address is*
  - *11001101 00010000 00100101 00100111*
- *If we set 32 − 28 rightmost bits to 1, we get*
  - *11001101 00010000 00100101 00101111*
  - *or*
  - *205.16.37.47*
- *This is actually the block shown in Figure 19.3.*

NOTE:

The number of addresses in the block can be found by using the formula 2^{32-n}.

Example 19.9

Another way to find the first address, the last address, and the number of addresses is to represent the mask as a 32-bit binary (or 8-digit hexadecimal) number. This is particularly useful when we are writing a program to find these pieces of information. In Example 19.5 the /28 can be represented as

11111111 11111111 11111111 11110000

(twenty-eight 1s and four 0s).

Find

a. The first address
b. The last address

Example 19.9 (continued)

Solution

a. The first address can be found by ANDing the given addresses with the mask. ANDing here is done bit by bit. The result of ANDing 2 bits is 1 if both bits are 1s; the result is 0 otherwise.

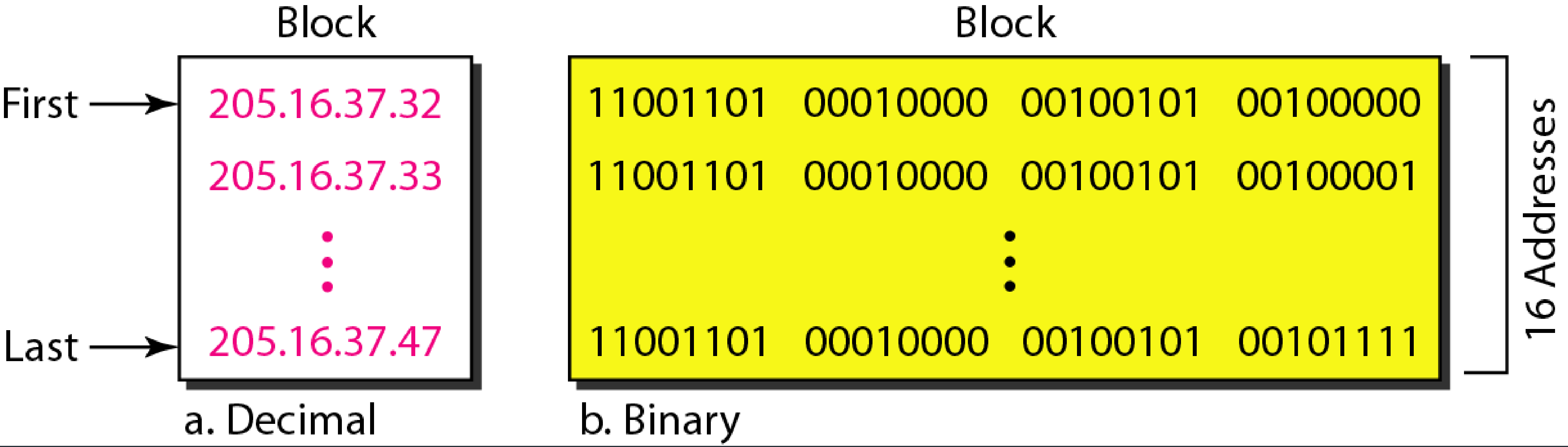
Address:	11001101	00010000	00100101	00100111
Mask:	11111111	11111111	11111111	11110000
First address:	11001101	00010000	00100101	00100000

Example 19.9 (continued)

b. ***The last address can be found by ORing the given addresses with the complement of the mask. ORing here is done bit by bit. The result of ORing 2 bits is 0 if both bits are 0s; the result is 1 otherwise. The complement of a number is found by changing each 1 to 0 and each 0 to 1.***

Address:	11001101	00010000	00100101	00100111
Mask complement:	**00000000**	**00000000**	**00000000**	**00001111**
Last address:	11001101	00010000	00100101	00101111

Figure 19.4 *A network configuration for the block 205.16.37.32/28*



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NOTE:

The first address in a block is normally not assigned to any device; it is used as the network address that represents the organization to the rest of the world.

Figure 19.5 *hierarchy in telephone numbers*

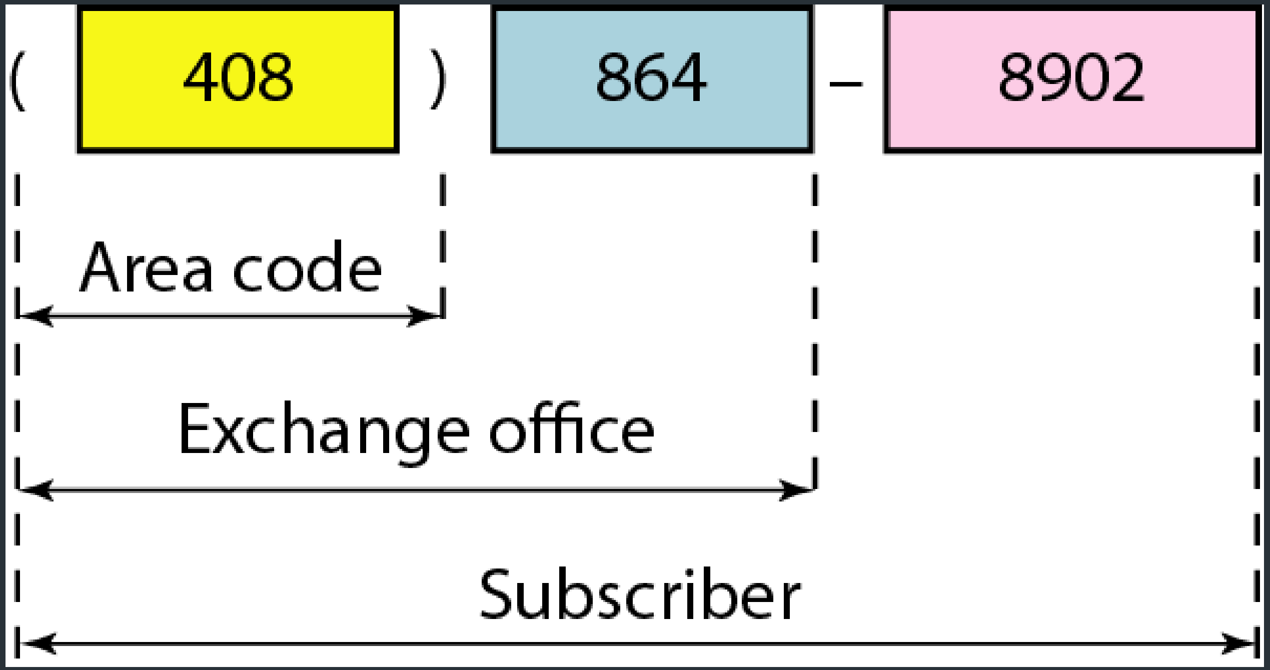

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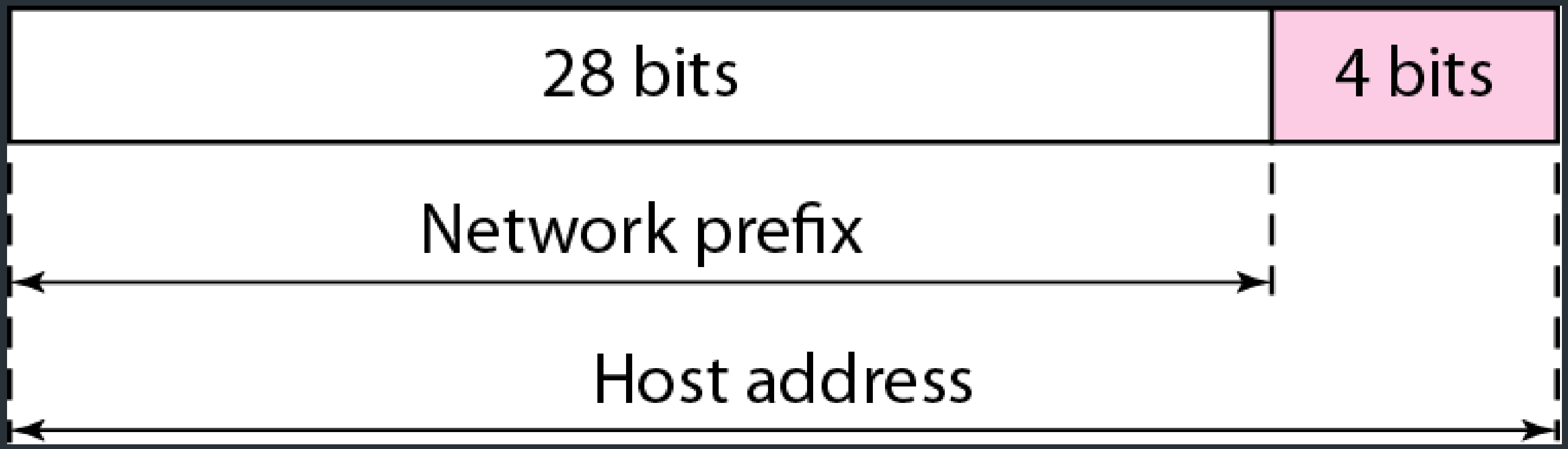
Figure 19.6 ***hierarchy in IP addressing***



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NOTE:

Each address in the block can be considered as a two-level hierarchical structure:
the leftmost *n* bits (prefix) define the network;
the rightmost 32 − n bits define the host.

Figure 19.7 *Configuration and addresses in a subnetted network*

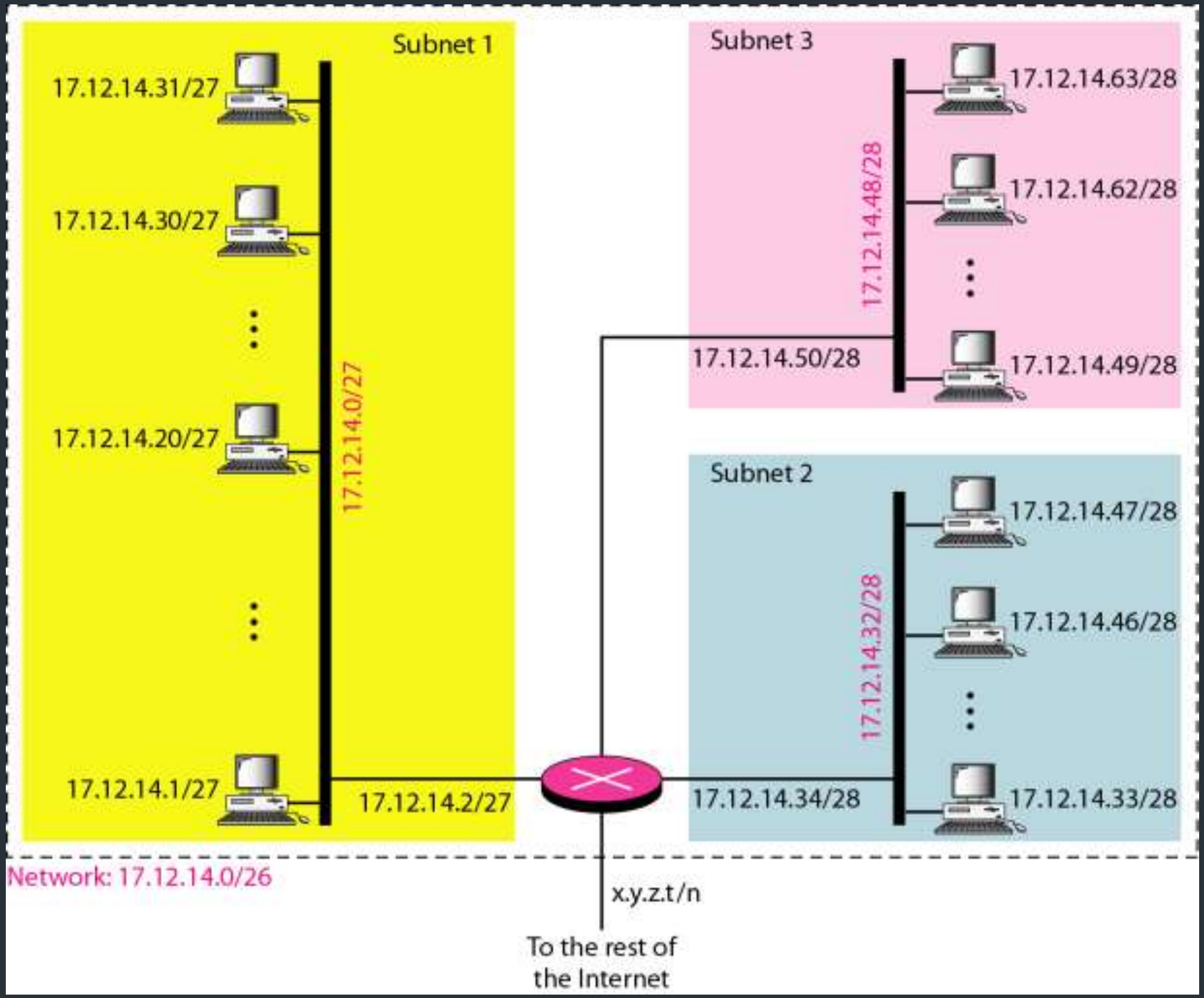

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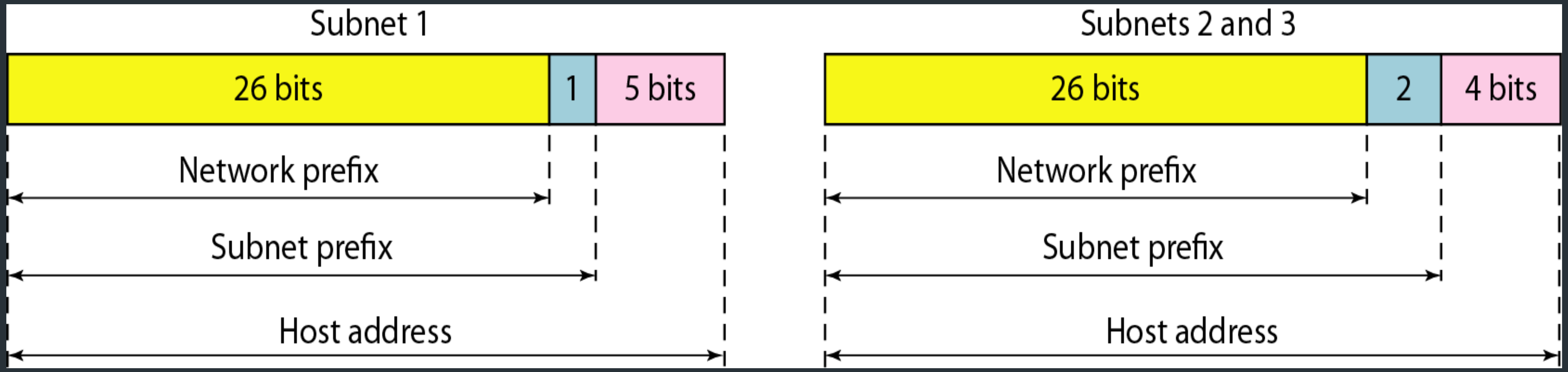
Figure 19.8 *Three-level hierarchy in an IPv4 address*



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Example 19.10

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.

Assume the blocks of IPs are sequentially assigned. Design the subblocks and find out how many addresses are still available after these allocations.

Example 19.10 (continued)

Solution

Figure 19.9 shows the situation.

Group 1

For this group, each customer needs 256 addresses. This means that 8 (log2 256) bits are needed to define each host. The prefix length is then 32 − 8 = 24. The addresses are

1st Customer:	190.100.0.0/24	190.100.0.255/24
2nd Customer:	190.100.1.0/24	190.100.1.255/24
. . .		
64th Customer:	190.100.63.0/24	190.100.63.255/24

Total = $64 \times 256 = 16,384$

Example 19.10 (continued)

Group 2

For this group, each customer needs 128 addresses. This means that 7 (log2 128) bits are needed to define each host. The prefix length is then 32 − 7 = 25. The addresses are

1st Customer:	190.100.64.0/25	190.100.64.127/25
2nd Customer:	190.100.64.128/25	190.100.64.255/25
. . .		
128th Customer:	190.100.127.128/25	190.100.127.255/25

Total = 128 × 128 = 16,384

Example 19.10 (continued)

Group 3

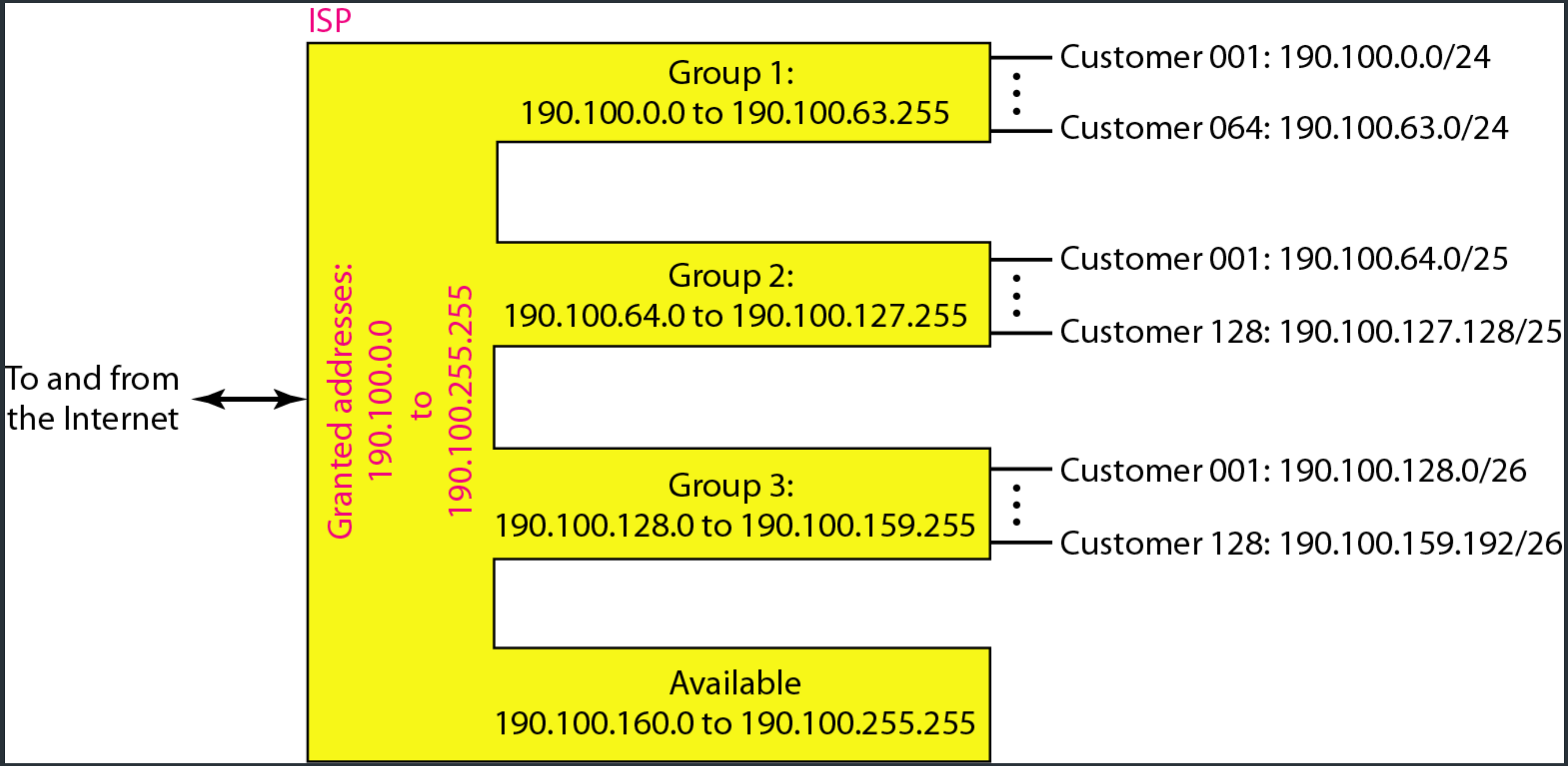
For this group, each customer needs 64 addresses. This means that 6 ($\log_2 64$) bits are needed to each host. The prefix length is then 32 − 6 = 26. The addresses are

1st Customer:	*190.100.128.0/26*	*190.100.128.63/26*
2nd Customer:	*190.100.128.64/26*	*190.100.128.127/26*
. . .		
128th Customer:	*190.100.159.192/26*	*190.100.159.255/26*

Total = 128 × 64 = 8192

Number of granted addresses to the ISP: 65,536
Number of allocated addresses by the ISP: 40,960
Number of available addresses: 24,576

Figure 19.9 *An example of address allocation and distribution by an ISP*



Source: Data Communications and Networking – Behrouz A. Forouzan

Another Example on Subnetting

An ISP needs to allocate three subnets: Subnet 1, Subnet 2, and Subnet 3 with its acquired IP block of 223.1.17.0/24. Subnet 1 is required to support 63 interfaces, Subnet 2 is to support at least 40 interfaces, and Subnet 3 is to support at least 95 interfaces. In addition, values of IP addresses have the relationship: Subnet 1 $<$ Subnet 2 $<$ Subnet 3.

Provide three network addresses (of the form a.b.c.d/x) that satisfy these constraints.

Subnetting

223.1.17.0/24, ip addresses are 2^(32-24) = 256

Subnet 1 needs 2^6=64, 223.1.17.0/26

last address: 223.1.17.63

Subnet 2 needs 2^6=64, 223.1.17.64/26

last address: 223.1.17.127

Subnet 3 needs 2^7 = 128, 223.1.17.128/25

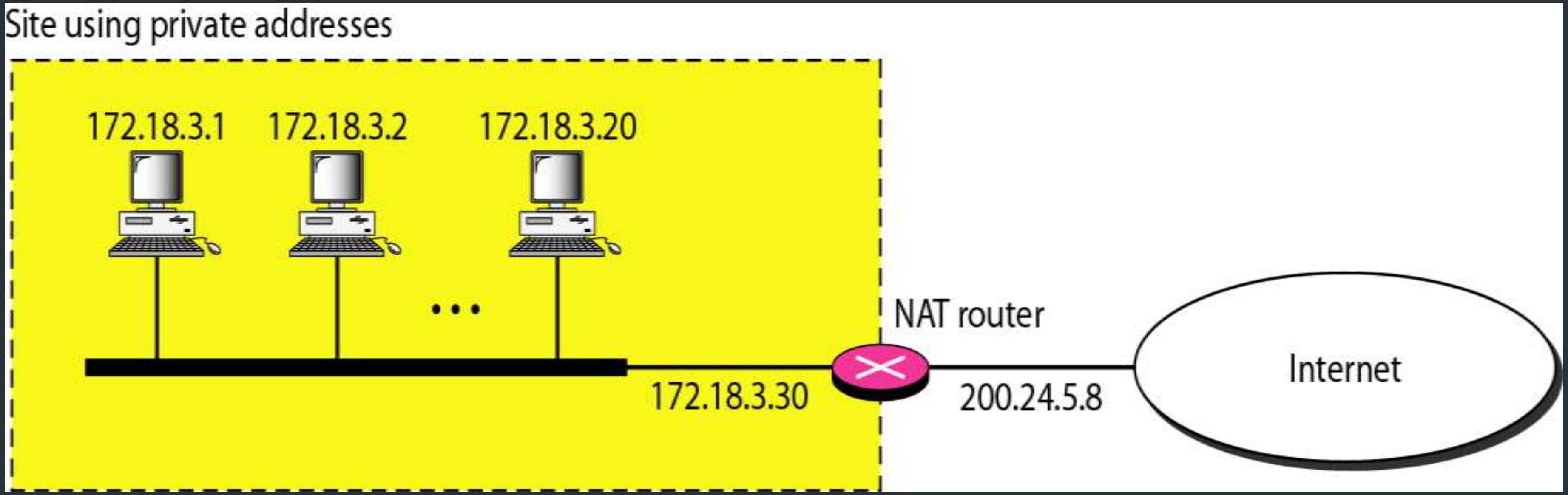
Table 19.3 *Addresses for private networks*

Range			*Total*
10.0.0.0	to	10.255.255.255	2^{24}
172.16.0.0	to	172.31.255.255	2^{20}
192.168.0.0	to	192.168.255.255	2^{16}

Source: Data Communications and Networking – Behrouz A. Forouzan

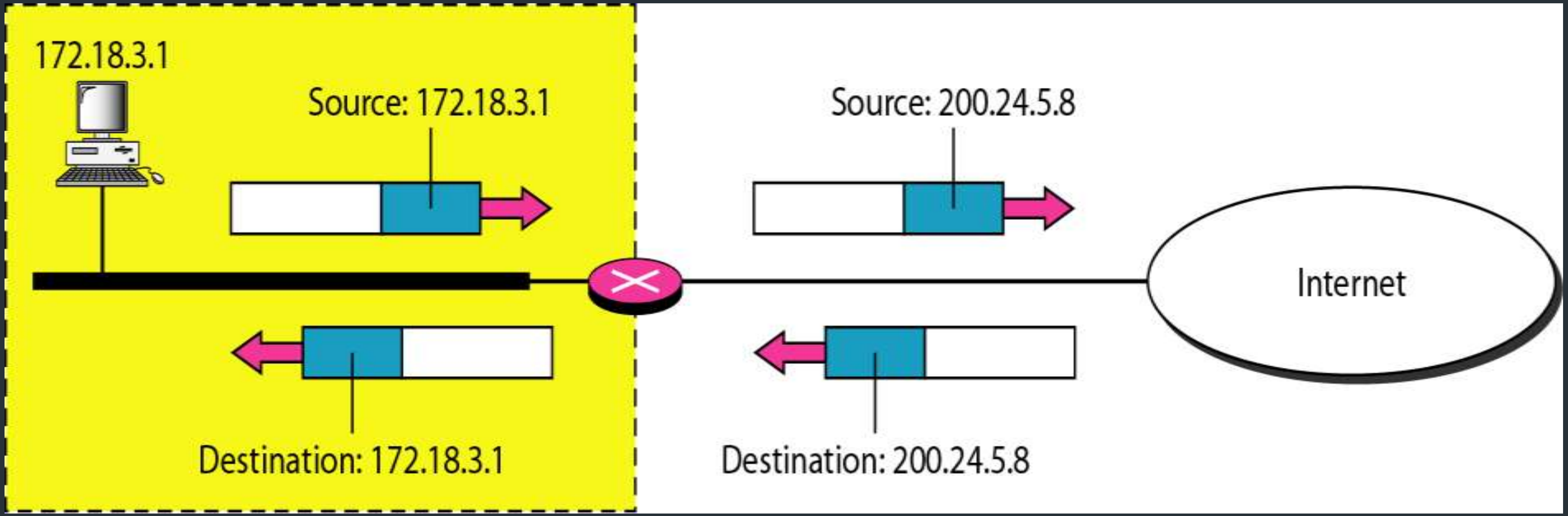
Home used wireless router usually uses 192.168.1.0/24 or 192.168.0.0/24 IP block

Figure 19.10 *A NAT implementation*



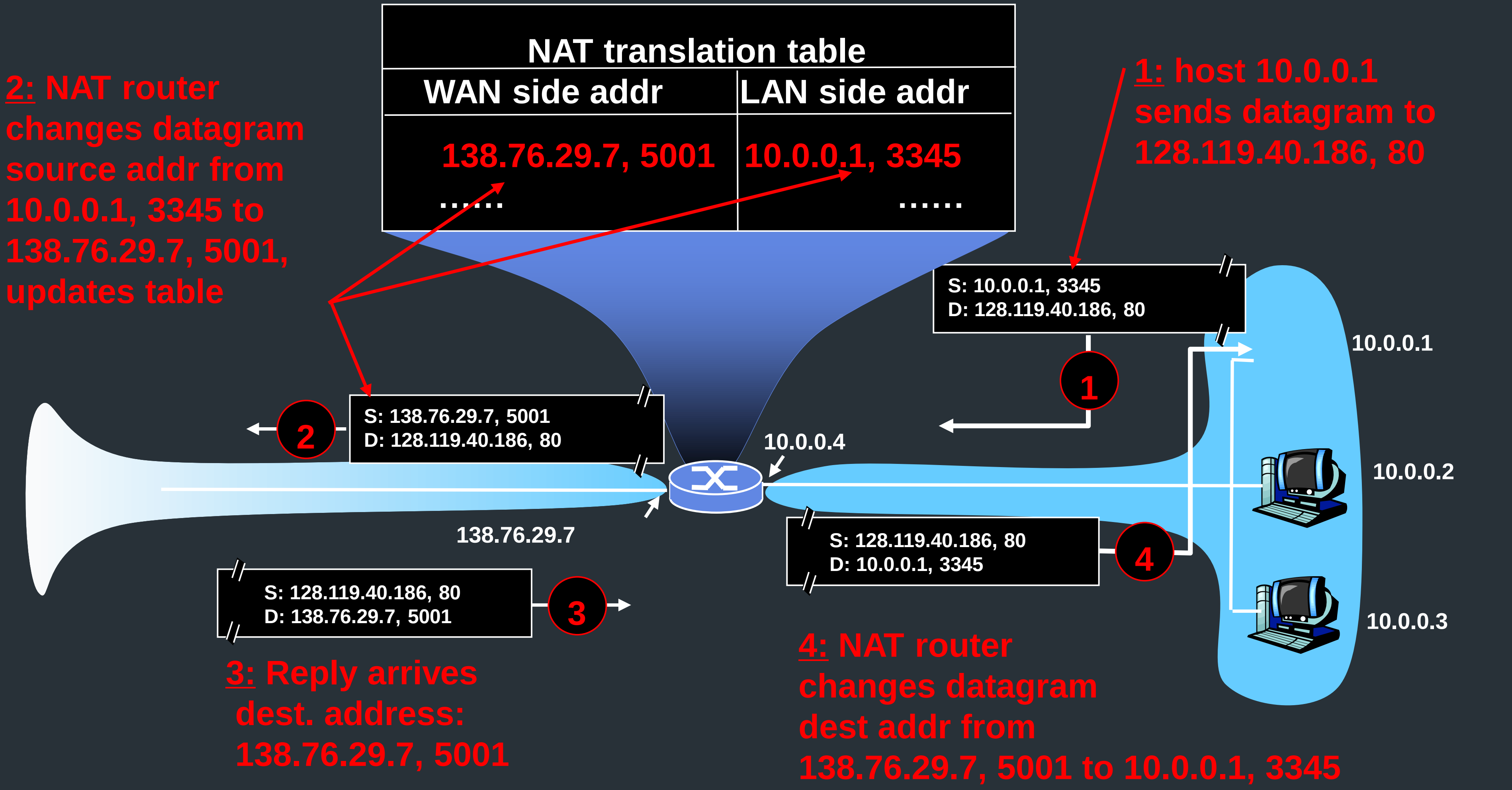
Source: Data Communications and Networking – Behrouz A. Forouzan

Figure 19.11 *Addresses in a NAT*



Source: Data Communications and Networking – Behrouz A. Forouzan

NAT: Network Address Translation



Source: Data Communications and Networking – Behrouz A. Forouzan

NAT: Network Address Translation

- 16-bit port-number field:
  - 60,000 simultaneous connections with a single LAN-side address!
- NAT is controversial:
  - violates end-to-end argument
    - Internal computers not visible to outside
    - Outside hosts have trouble to request service from local computers, e.g., P2P, video conference, web hosting.
  - address shortage should instead be solved by IPv6

Table 19.4 *Five-column translation table*

Private Address	*Private Port*	*External Address*	*External Port*	*Transport Protocol*
172.18.3.1	1400	25.8.3.2	80	TCP
172.18.3.2	1401	25.8.3.2	80	TCP
...	...	...	...	...

Source: Data Communications and Networking – Behrouz A. Forouzan

19-2 IPv6 ADDRESSES

Despite all short-term solutions, address depletion is still a long-term problem for the Internet. This and other problems in the IP protocol itself have been the motivation for IPv6.

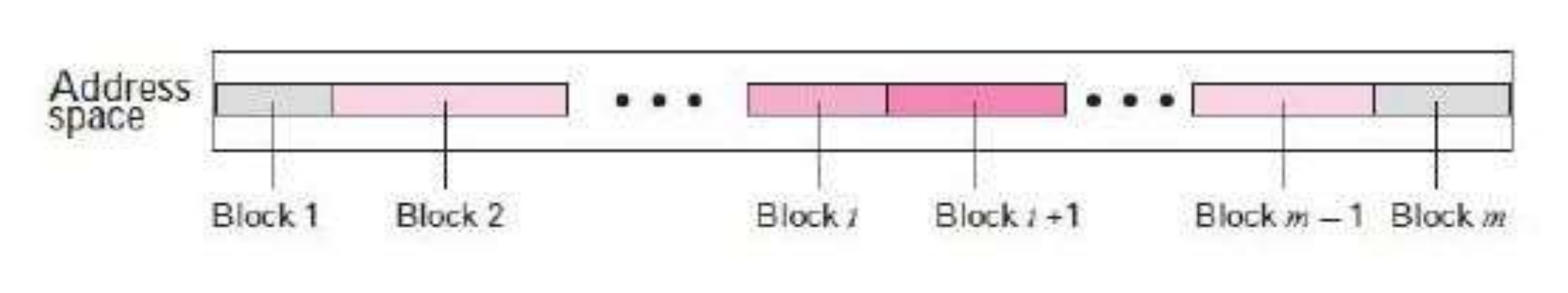
NOTE:

An IPv6 address is 128 bits long.

Classless addressing

Classless addressing

- Variable-length blocks are used that belong to no classes.
- Block of 1 address, 2 addresses, 4 addresses, 128 addresses, and so on.



Source: Data Communications and Networking – Behrouz A. Forouzan

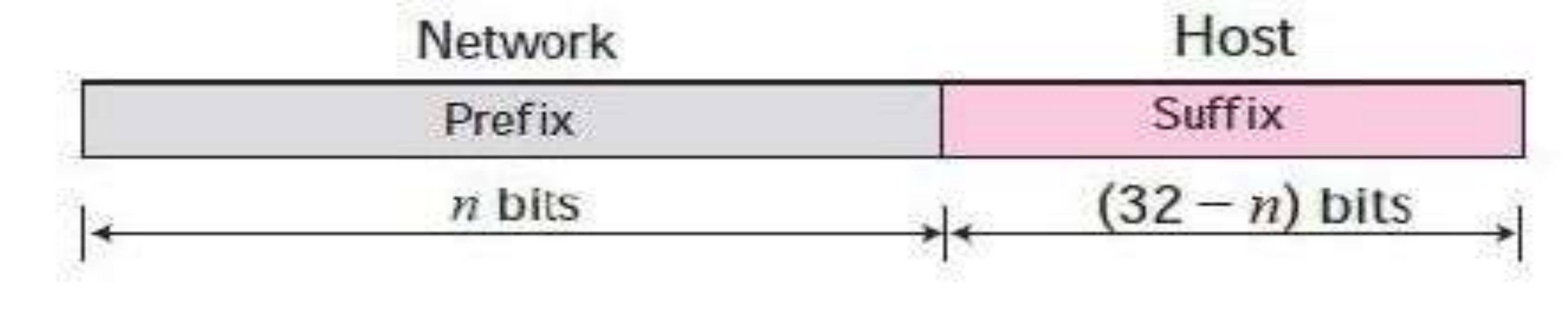
Variable-length Blocks

- The whole address space is divided into variable length blocks.
- Block of 20, 21, 22, . . . , 232 addresses.
- The number of addresses in a block needs to be a power of 2.
- An organization can be granted one block of addresses.

Two-level Addressing

- When an organization is granted a block of addresses, the block is actually divided into two parts, the prefix and the suffix.
- The prefix plays the same role as the netid
- The suffix plays the same role as the hostid.
- All addresses in the block have the same prefix
- Each address has a different suffix.

Two-level Addressing



Source: Data Communications and Networking – Behrouz A. Forouzan

- The length of the prefix, *n,* depends on the size of the block
- The value of *n is referred to as prefix length;*
- *The value of 32 – n is referred to as suffix* length.
- The prefix length in classless addressing can be 1 to 32.

Simple Task 1

- What is the prefix length and suffix length if the whole Internet is considered as one single block with 4,294,967,296 addresses?
- 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?

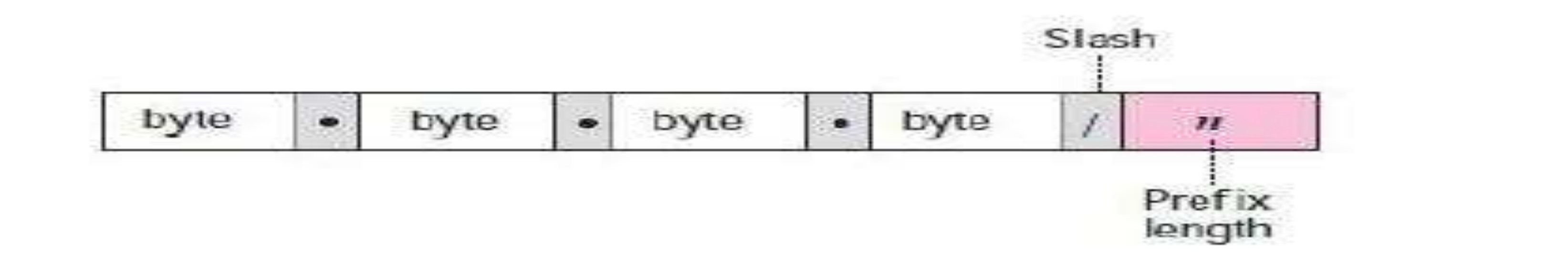
"The number of addresses in a block is inversely related to the value of the prefix length, *n. A* small *n means a larger block; a large n means a small block*"

Slash Notation

- The prefix length in classless addressing play a very important role when we need to extract the information about the block from a given address in the block.
- 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).
- In classless addressing, the prefix length cannot be found if we are given only an address in the block. The given address can belong to a block with any prefix length.

Slash Notation

- In classless addressing, we need to include the prefix length to each address if we need to find the block of the address.
- In this case, the prefix length, *n, is added to the address* separated by a slash.
- The notation is informally referred to as **slash notation.**
- Classless Interdomain Routing or CIDR (pronounced cider) notation
- In classless addressing, we need to know one of the addresses in the block and the prefix length to define the block.



Source: Data Communications and Networking – Behrouz A. Forouzan

Network Mask

- A network mask is a 32-bit number with the n leftmost bits all set to 1s and the rest of the bits all set to 0s.
- 12.23.24.78/8, 130.11.232.156/16, 167.199.170.82/27

Extracting Block Information

- An address in slash notation (CIDR) contains all information: the first address (network address), the number of addresses, and the last address.
- The number of addresses in the block

$$N = 2^{32 - n}$$

- The first address (network address) in the block

First address = (any address) AND (network mask)

- The last address in the block can be found

Last address = (any address) OR [NOT (network mask)]

Simple Task 2

One of the addresses in a block is 167.199.170.82/27. Find the number of addresses in the network, the first address, and the last address.

One of the addresses in a block is 17.63.110.114/24. Find the number of addresses, the first address, and the last address in the block.

One of the addresses in a block is 110.23.120.14/20. Find the number of addresses, the first address, and the last address in the block.

Block Allocation

- The number of requested addresses, *N, needs to be a power of 2.*
- The value of prefix length can be found from the number of addresses in the block.

  N = 232 − n,

  then n = 32 − log2N.
- The beginning address needs to be divisible by the number of addresses in the block.

Subnetting

- Three levels of hierarchy can be created using subnetting.
- An organization (or an ISP) that is granted a range of addresses may divide the range into several subranges and assign each subrange to a **subnetwork (or subnet).**

Designing Subnets

- Assume

  N - the total number of addresses granted to the organization

  n - the prefix length

  Nsub - the assigned number of addresses to each subnetwork

  nsub - The prefix length for each subnetwork

  s - The total number of subnetworks

Subnetting (Contd...)

- The number of addresses in each subnetwork should be a power of 2.
- The prefix length for each subnetwork

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

- The starting address in each subnetwork should be divisible by the number of addresses in that subnetwork

Simple Task 3

- An organization is granted the block 130.34.12.64/26. The organization needs four subnetworks, each with an equal number of hosts. Design the subnetworks and find the information about each network.

Simple Task 4

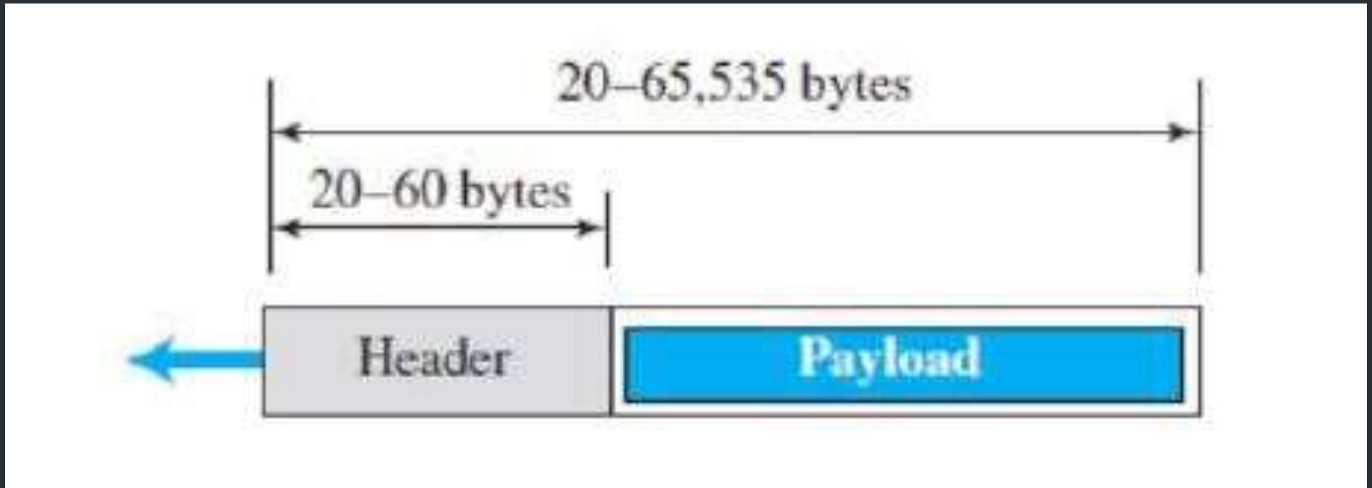
- A n organization is granted ablock of addresses with the beginning address 14.24.74.0/24. The organization needs to have 3 subblocks of addresses to use in its three subnets as shown below:
  – One subblock of 120 addresses.
  – One subblock of 60 addresses.
  – One subblock of 10 addresses.

IPv4 Header Format

IPv4 datagram

- variable-length packet
  - header and payload (data)
- The header is 20 to 60 bytes in length and contains information essential to routing and delivery.

IPv4 Packet Format



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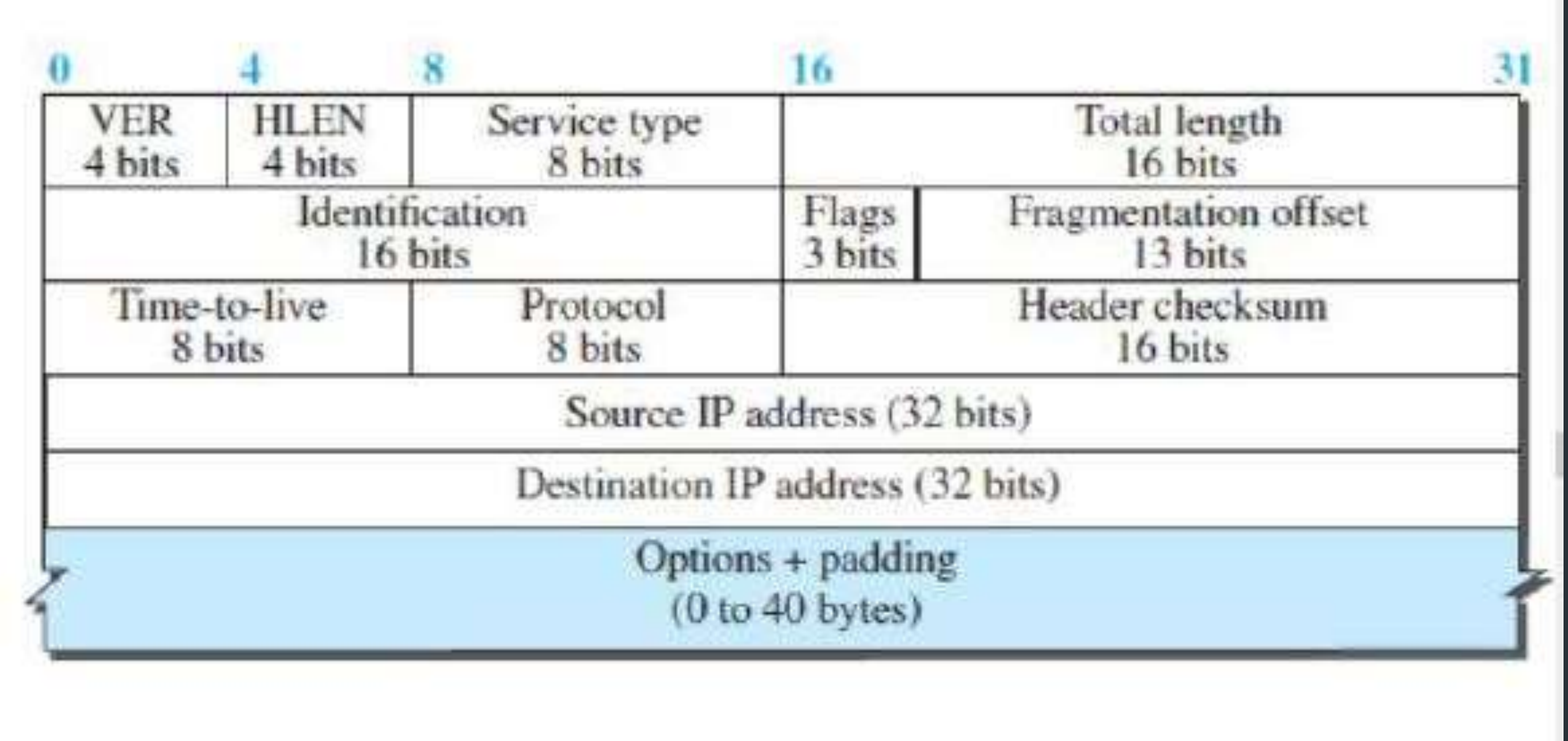
IPv4 Packet Format (Contd..)



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IPv4 Packet Format (Contd..)

- **Version Number.**

  – The 4-bit version number (VER) field defines the version of the IPv4 protocol, which, obviously, has the value of 4.

- **Header Length.**

  – The 4-bit header length (HLEN) field defines the total length of the datagram header.

  – The IPv4 datagram has a variable-length header.

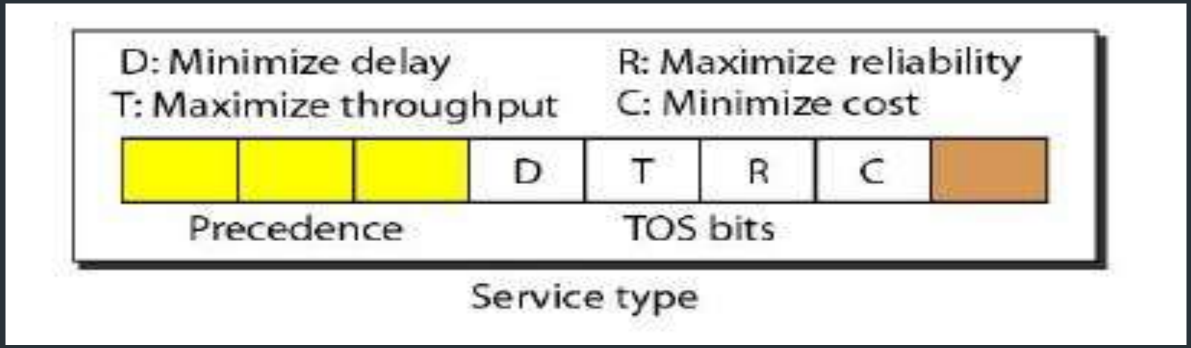
  – The total length is divided by 4 and the value is inserted in the field.

  – The receiver needs to multiply the value of this field by 4 to find the total length.

IPv4 Packet Format (Contd..)

- **Service Type**

  – In the original design of the IP header, this field was referred to as type of service (TOS), which define how the datagram should be handled.



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IPv4 Packet Format (Contd..)

- **Total Length.**

  – This 16-bit field defines the total length (header plus data) of the IP datagram in bytes.

  Length of data = total length – (HLEN) × 4

- **Identification, Flags, and Fragmentation Offset.**

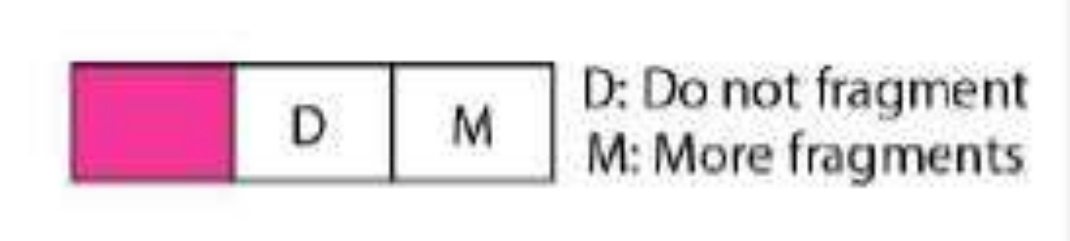
  – These three fields are related to the fragmentation of the IP datagram when the size of the datagram is larger than the underlying network can carry.

IPv4 Packet Format (Contd..)

Identification

- This 16-bit field identifies a datagram originating from the source host.
- The combination of the identification and source IP address must uniquely define a datagram as it leaves the source host.
- To guarantee uniqueness, the IP protocol uses a counter to label the datagrams.

IPv4 Packet Format (Contd..)



Flags:

- The first bit is reserved (not used).
- The second bit is called the do not fragment bit.
- If its value is 1, the machine must not fragment the datagram. If it cannot pass the datagram through any available physical network, it discards the datagram and sends an ICMP error message to the source host.
- If its value is 0, the datagram can be fragmented if necessary.
- The third bit is called the more fragment bit.
- If its value is 1, it means the datagram is not the last fragment; there are more fragments after this one.
- If its value is 0, it means this is the last or only fragment

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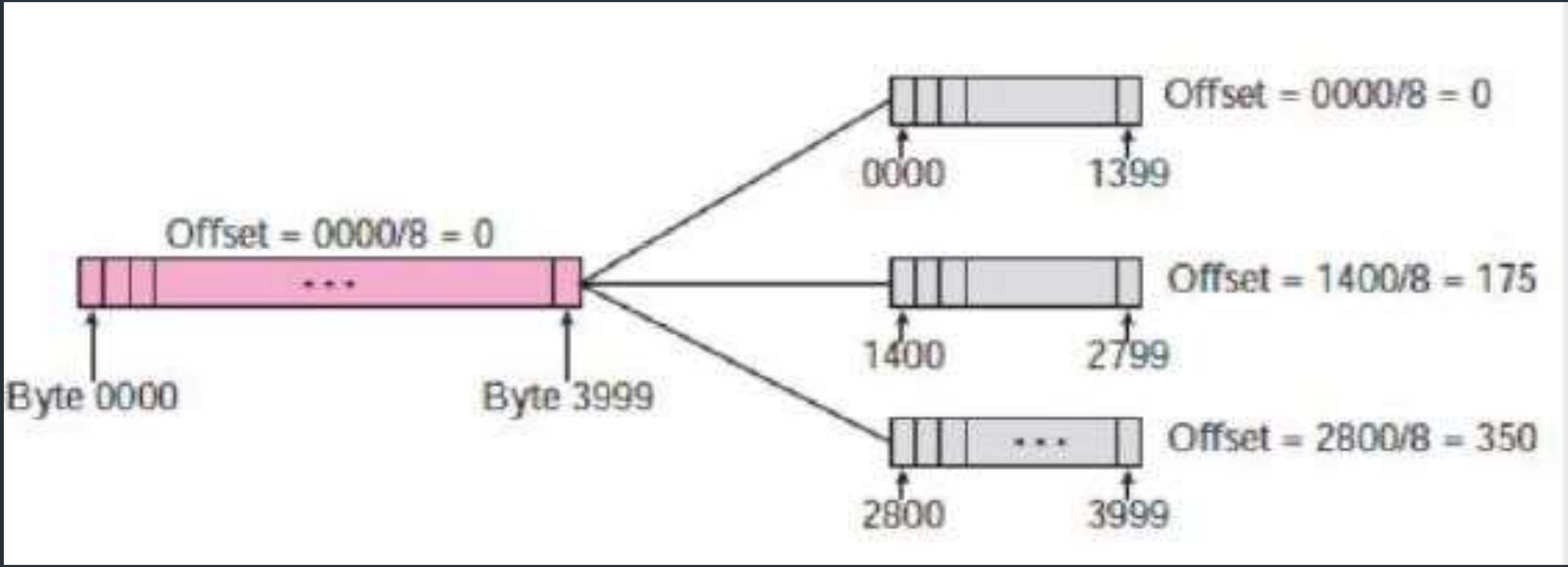
IPv4 Packet Format (Contd..)

Fragmentation offset:



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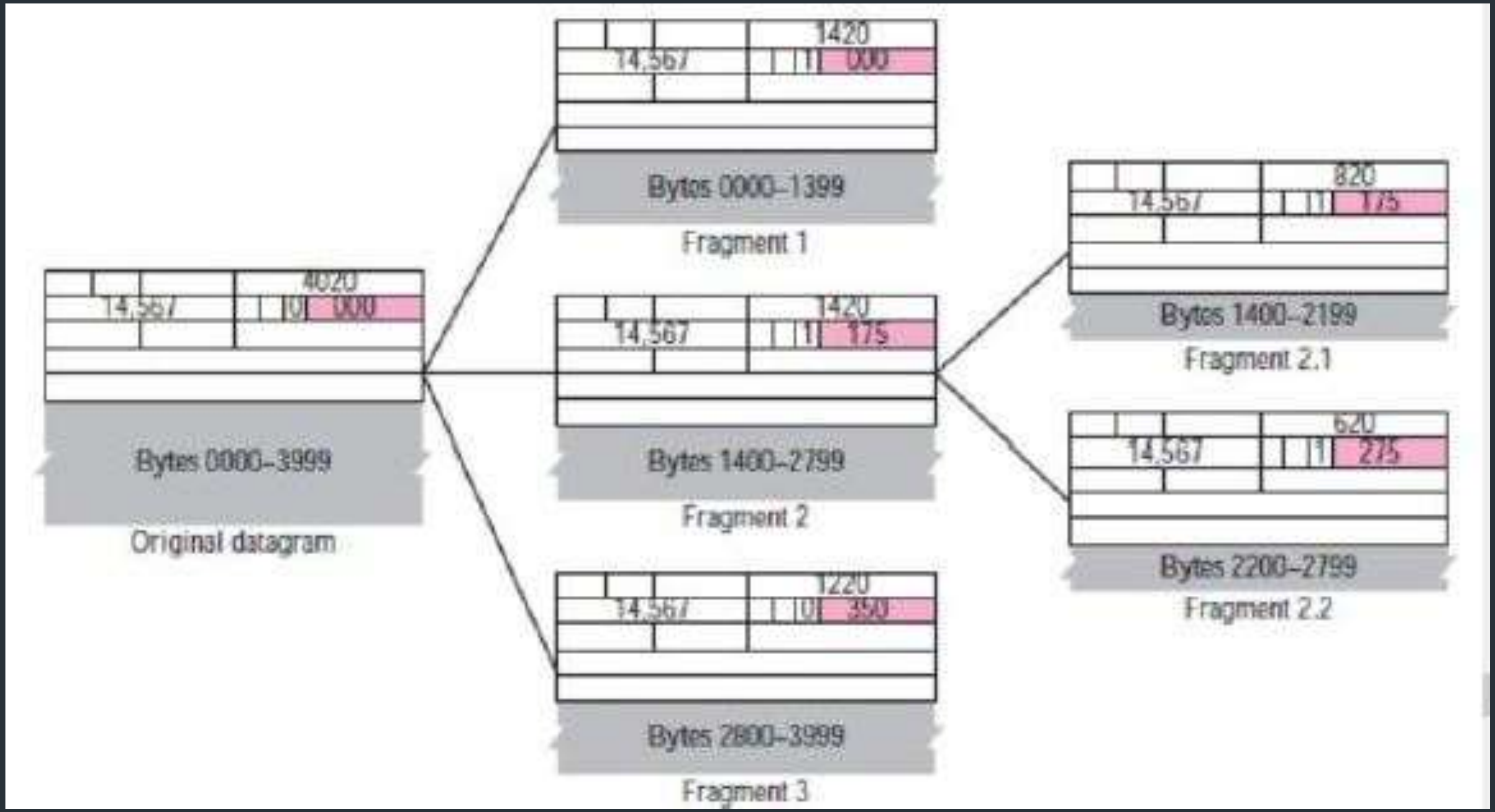
IPv4 Packet Format (Contd..)

- Fragmentation offset:



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IPv4 Packet Format (Contd..)

Time-To-Live

- (TTL) field is used to control the maximum number of hops (routers) visited by the datagram.
- When a source host sends the datagram, it stores a number in this field.
- This value is approximately two times the maximum number of routers between any two hosts.
- Each router that processes the datagram decrements this number by one.
- If this value, after being decremented, is zero, the router discards the datagram.

IPv4 Packet Format (Contd..)

Protocol

- A datagram, for example, can carry a packet belonging to any transport-layer protocol such as UDP or TCP.

Some protocol values

ICMP	01
IGMP	02
TCP	06
UDP	17
OSPF	89

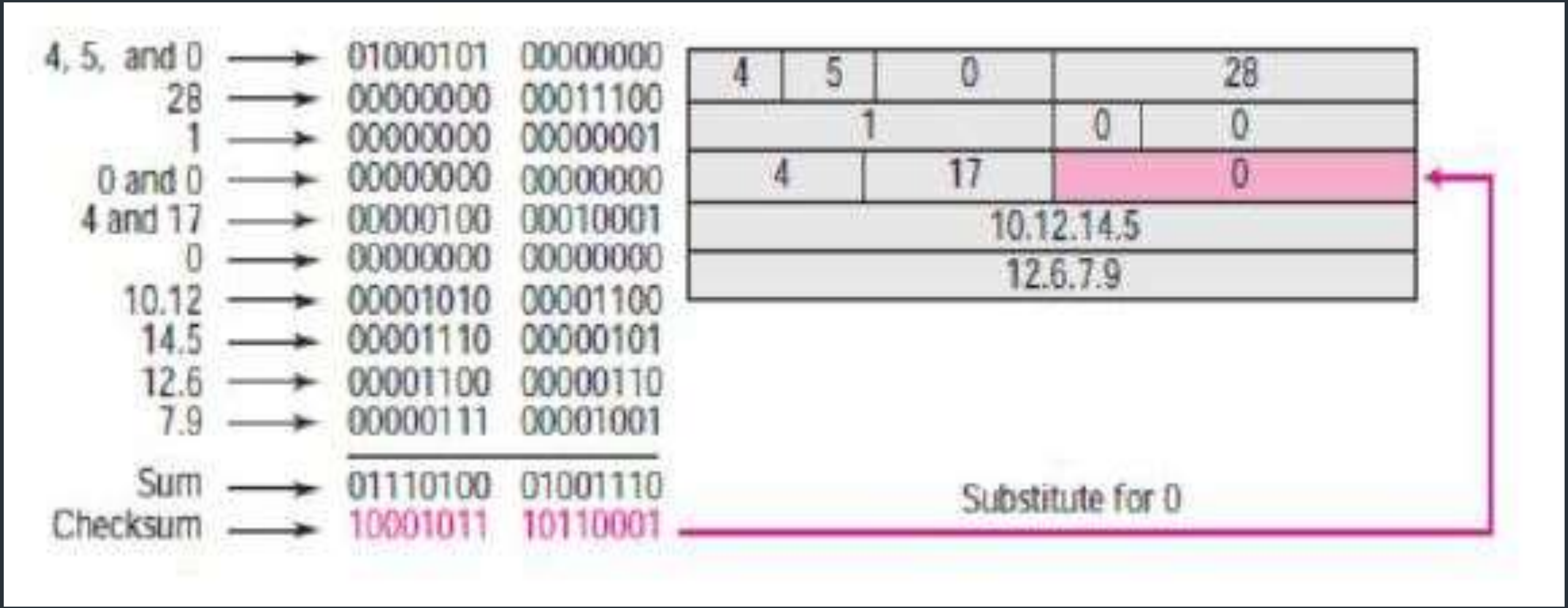
Source: Data Communications and Networking – Behrouz A. Forouzan

IPv4 Packet Format (Contd..)

Header Checksum

- Checksum in IP covers only the header not the data.
- First, the value of the checksum field is set to 0.
- The entire header is divided into 16-bit sections and added together.
- The result (sum) is complemented and inserted into the checksum field.

IPv4 Checksum Calculation at the Sender



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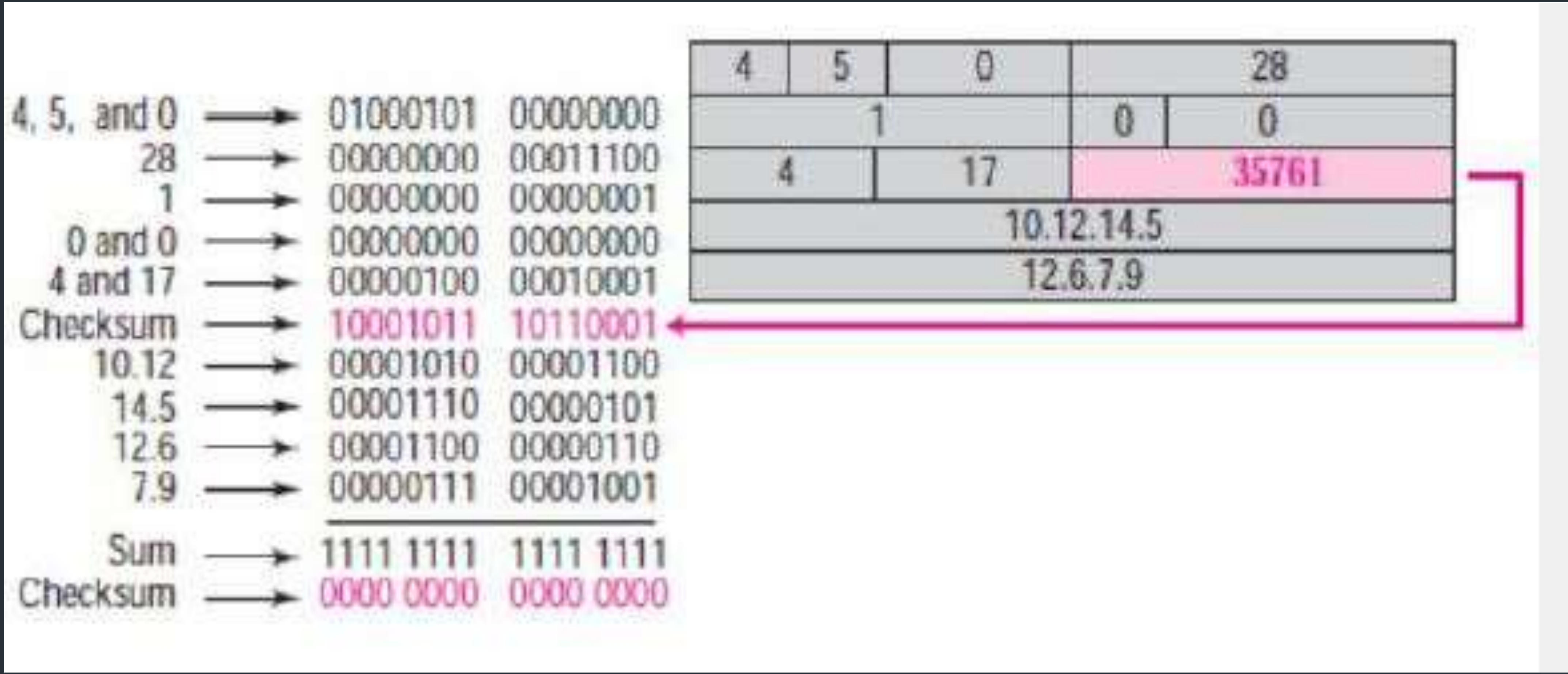
IPv4 Checksum Calculation at the Receiver



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IPv4 Packet Format (Contd..)

Source and Destination Addresses

- These 32-bit source and destination address fields define the IP address of the source and destination respectively.

IPv4 Packet Format (Contd..)

- An IPv4 packet has arrived with the first 8 bits as $(01000010)_2$ The receiver discards the packet. Why?
- In an IPv4 packet, the value of HLEN is $(1000)_2$. How many bytes of options are being carried by this packet?
- In an IPv4 packet, the value of HLEN is 5, and the value of the total length field is $(0028)_{16}$. How many bytes of data are being carried by this packet?
- An IPv4 packet has arrived with the first few hexadecimal digits as shown. How many hops can this packet travel before being dropped. The data belong to what upper layer protocol.

$(45000028000100000102...)_{16}$

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