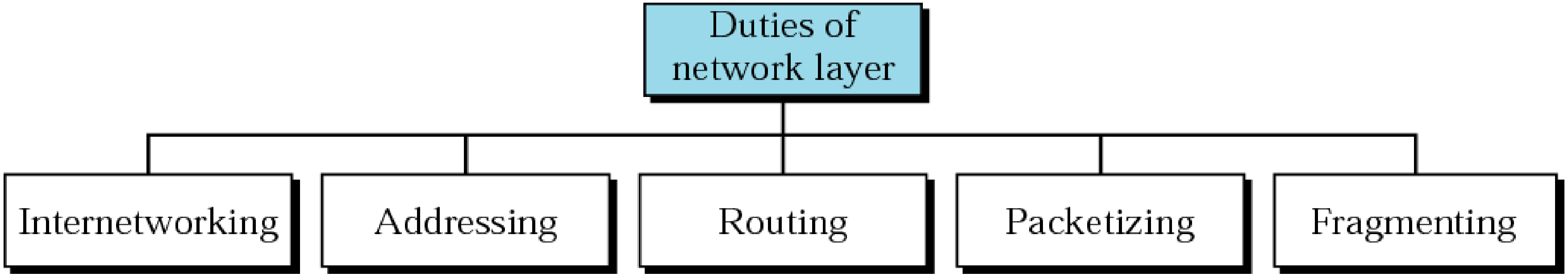
Network Layer

Network layer duties



Host-to-Host Delivery:

Internetworking, Addressing, and Routing

19.2 Addressing

Internet Address

Classful Addressing

Subnetting

Supernetting

Classless Addressing

Dynamic Address Configuration

Network Address Translation

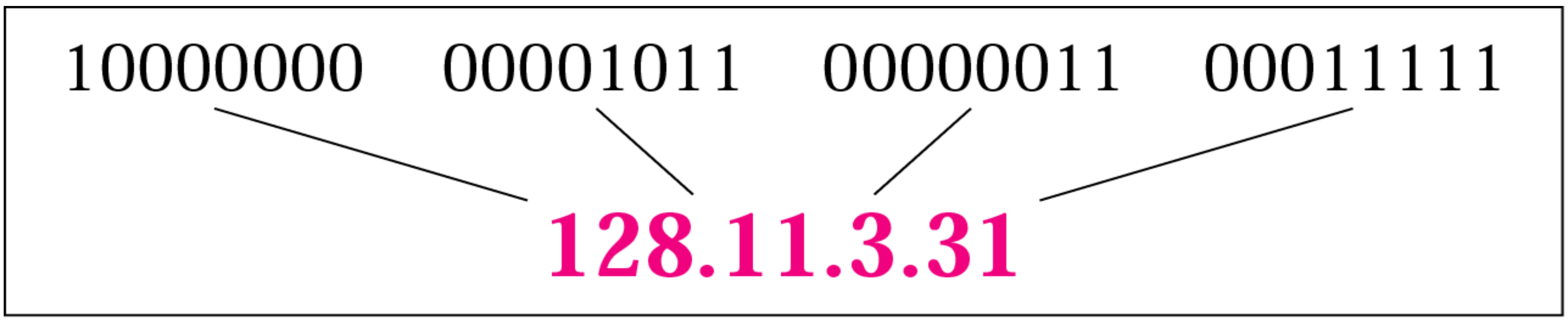
Note:

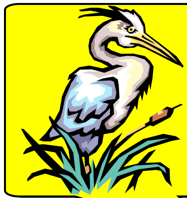
An IP address is a 32-bit address.

Note:

The IP addresses are unique and universal.

Figure 19.9 Dotted-decimal notation





Note:

The binary, decimal, and hexadecimal number systems are reviewed in Appendix B.

Example 1

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

a. 10000001 00001011 00001011 11101111

b. 11111001 10011011 11111011 00001111

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. 249.155.251.15

Example 2

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

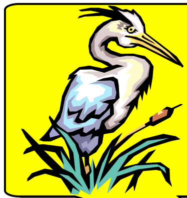
a. 111.56.45.78

b. 75.45.34.78

Solution

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

a. 01101111 00111000 00101101 01001110
b. 01001011 00101101 00100010 01001110



Note:

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

Figure 19.10 Finding the class in binary and Decimal notation

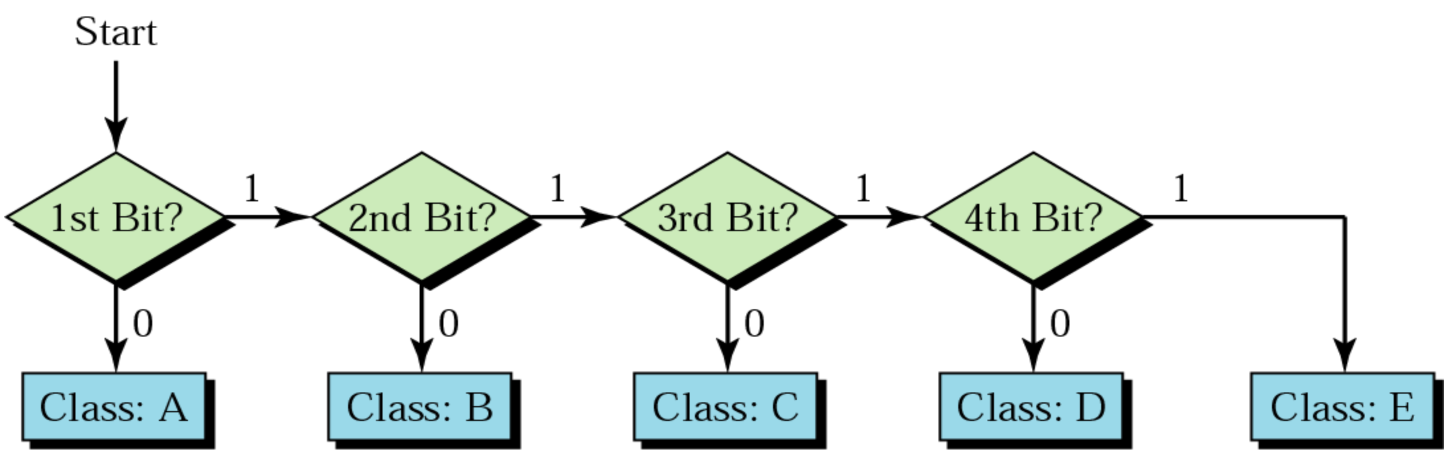
	First byte	Second byte	Third byte	Fourth byte
Class A	**0**			
Class B	**10**			
Class C	**110**			
Class D	**1110**			
Class E	**1111**			

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

CLASSES OF IPv4 ADDRESS

Address Class	1st Octet range in decimal	1st Octet bits (Blue Dots do not change)	Network (N) and Host (H) Portion
A	0–127	00000000 - 01111111	N.H.H.H
B	128–191	10000000 - 10111111	N.N.H.H
C	192–223	11000000 - 11011111	N.N.N.H
D	224–239	11100000 - 11101111	NA (Multicast)
E	240–255	11110000 - 11111111	NA (Experimental)

Figure 19.11 Finding the address class



Example 3

Find the class of each address:

a. **0**0000001 00001011 00001011 11101111

b. **1111**0011 10011011 11111011 00001111

Solution

See the procedure in Figure 19.11.

a. The first bit is 0; this is a class A address.
b. The first 4 bits are 1s; this is a class E address.

Example 4

Find the class of each address:

a. **227**.12.14.87

b. **252**.5.15.111

c. **134**.11.78.56

Solution

a. The first byte is 227 (between 224 and 239); the class is D.
b. The first byte is 252 (between 240 and 255); the class is E.
c. The first byte is 134 (between 128 and 191); the class is B.

Figure 19.13 Netid and hostid

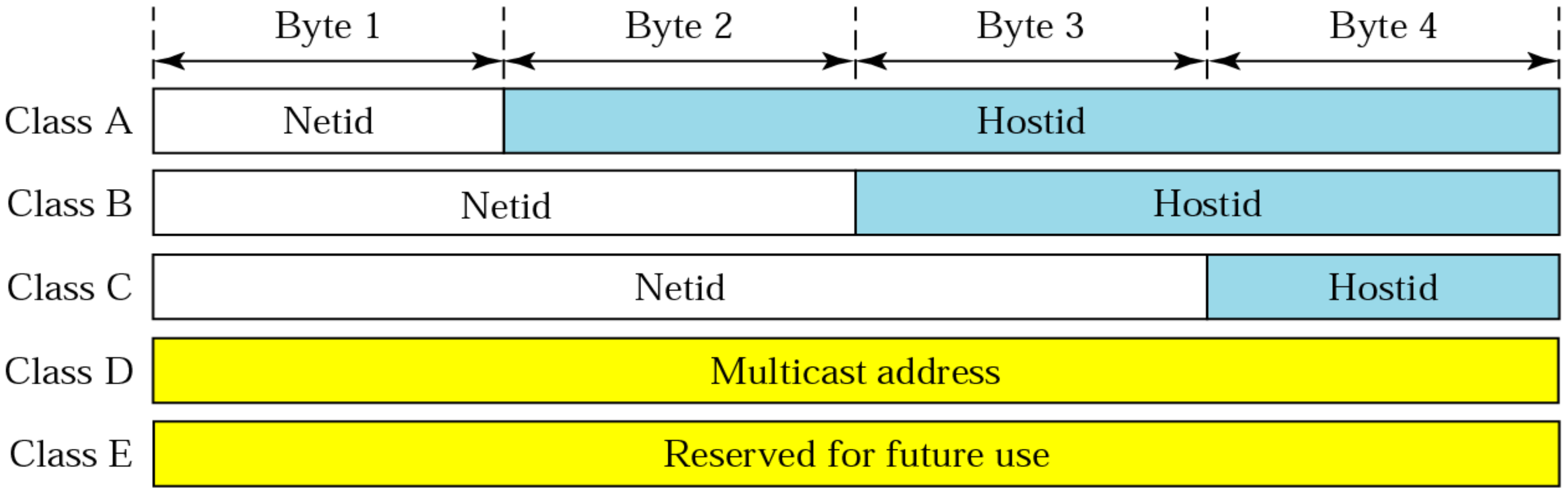
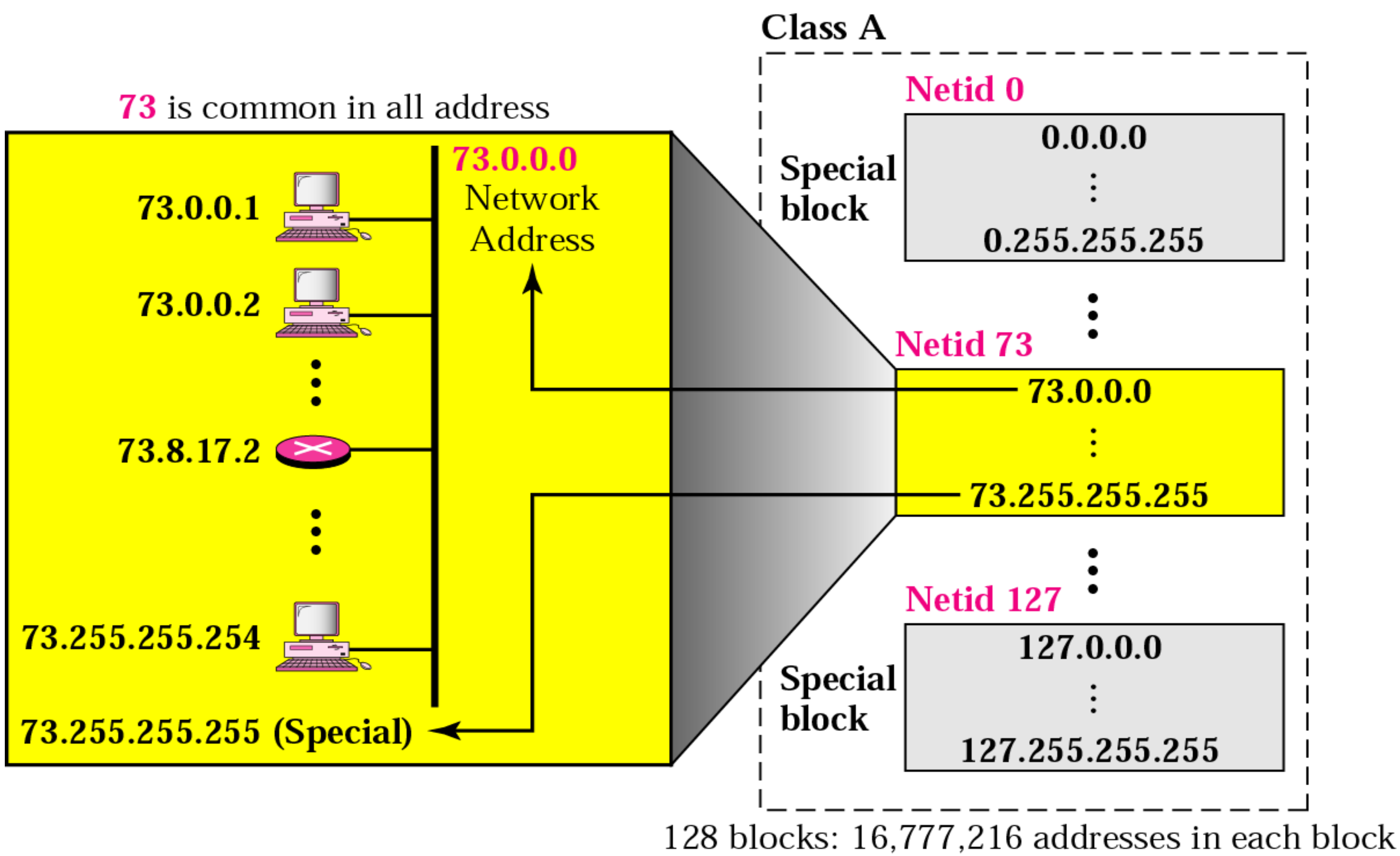


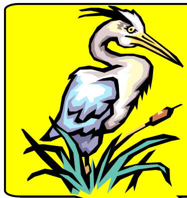
Table 19.1 Default masks

Class	*In Binary*	*In Dotted-Decimal*	*Using Slash*
A	11111111 00000000 00000000 00000000	255.0.0.0	/8
B	11111111 11111111 00000000 00000000	255.255.0.0	/16
C	11111111 111111111 11111111 00000000	255.255.255.0	/24

	Subnet Mask	# of Networks	# of Hosts per Network
Class A	255.0.0.0	126 =2^7-2	16,777,214 2^24-2
Class B	255.255.0.0	16,382 =2^14-2	65,534 =2^16-2
Class C	255.255.255.0	2,097,150 =2^21-2	254 =2^8-2

Figure 19.14 Blocks in class A

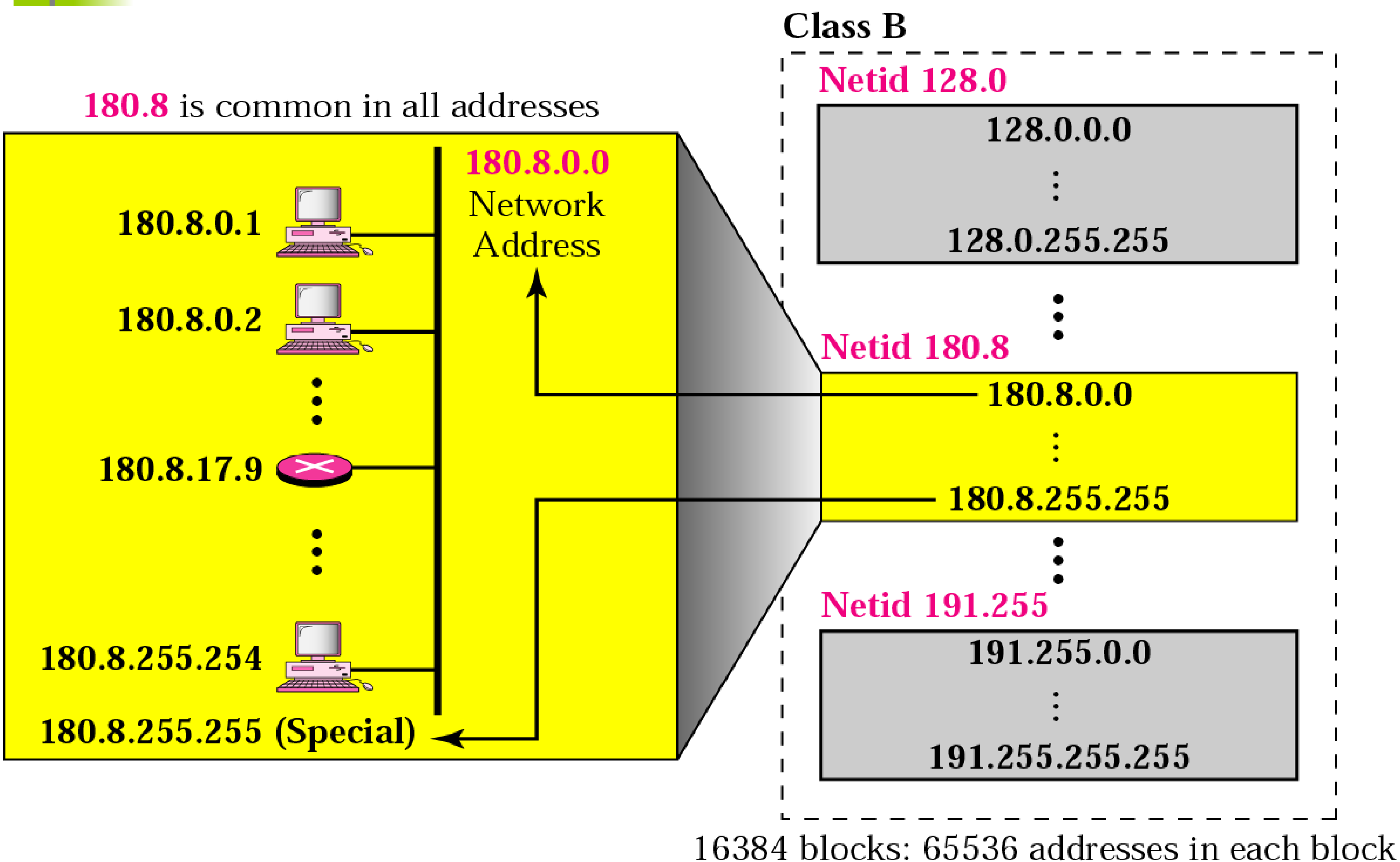


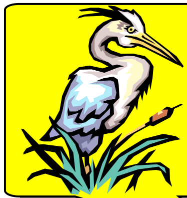


Note:

Millions of class A addresses are wasted.

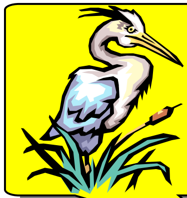
Figure 19.15 Blocks in class B





Note:

Many class B addresses are wasted.



Note:

The number of addresses in class C is smaller than the needs of most organizations.

Figure 19.16 Blocks in class C

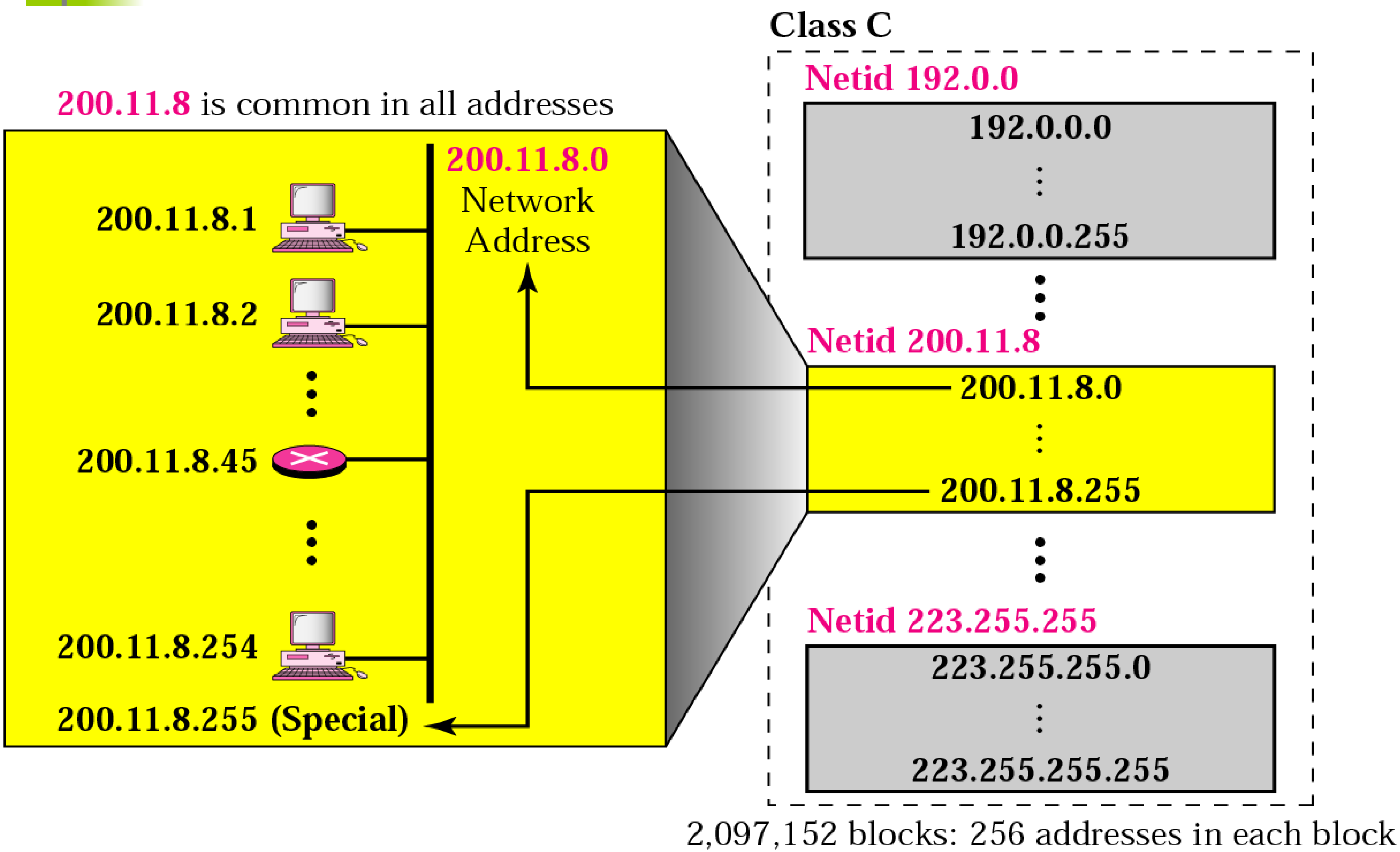
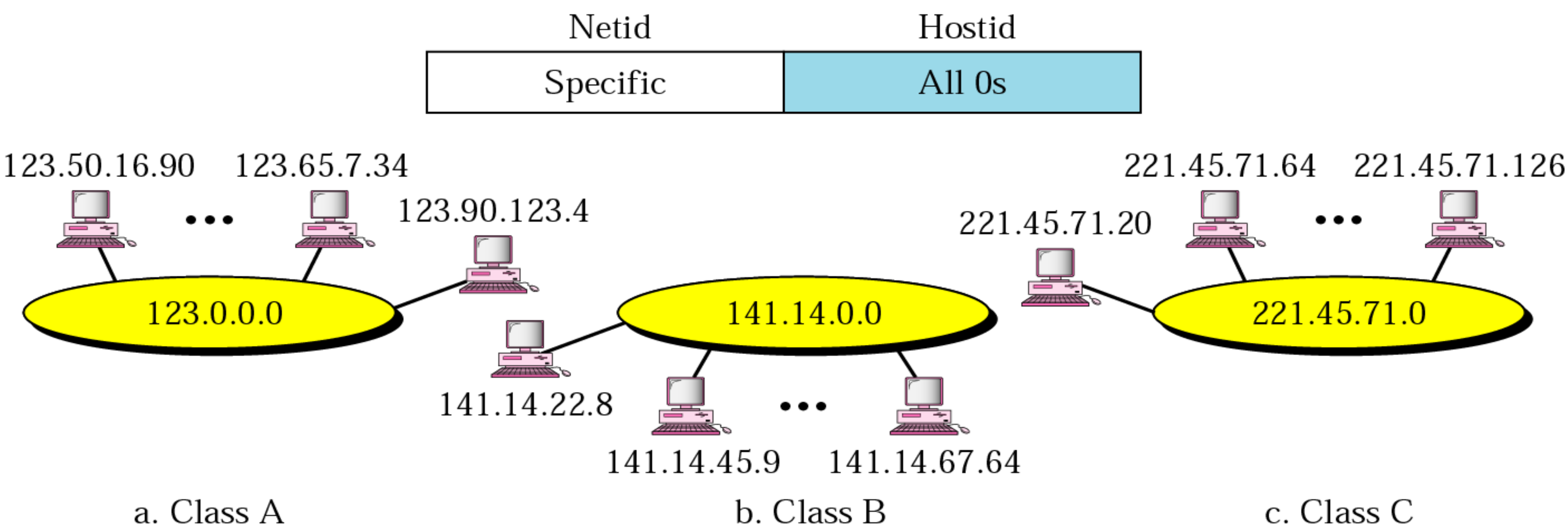


Figure 19.17 Network address



Note:

In classful addressing, the network address is the one that is assigned to the organization.

Example 5

Given the address 23.56.7.91, find the network address.

Solution

The class is A. Only the first byte defines the netid. We can find the network address by replacing the hostid bytes (56.7.91) with 0s. Therefore, the network address is 23.0.0.0.

Example 6

Given the address 132.6.17.85, find the network address.

Solution

The class is B. The first 2 bytes defines the netid. We can find the network address by replacing the hostid bytes (17.85) with 0s. Therefore, the network address is 132.6.0.0.

Example 7

Given the network address 17.0.0.0, find the class.

Solution

The class is A because the netid is only 1 byte.

Subnet Mask

10.10.10.1 10.10.20.16	255.0.0.0 ; Same N/W	10.10.10.1 10.10.20.16	255.255.255.0 ; Different N/W
172.16.200.1 172.16.165.2	255.255.0.0 ; Same N/W	172.16.200.1 172.16.165.2	255.255.255.0 ; Different N/W
10.10.36.1 10.10.12.1	255.255.0.0 ; Same N/W	10.10.36.1 10.10.12.1	255.255.255.0 ; Different N/W

A host in a class C network has been assigned an IP address 192.168.17.9. Find the number of addresses in the block, the first address, and the last address.

SOLUTION:

Class C Network

N.N.N.H (255.255.255.0 or /24)

192.168.17.9

This network: 192.168.17.0 – 192.168.17.255

Number of addresses: $2^8 = 256$

Number of usable addresses: $256 - 2 = 254$

First Address: 192.168.17.0 (Network Address)

Last Address: 192.168.17.255 (Broadcast Address)

Note:

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

Classes of IPv4 address

Address Class	1st Octet range in decimal	1st Octet bits (Blue Dots do not change)	Network (N) and Host (H) Portion	Default mask (Decimal)	Number of possible networks and hosts per network
A	0–127	00000000 - 01111111	N.H.H.H	255.0.0.0	128 Nets (2^7) 16,777,214 hosts (2^{24}–2)
B	128–191	10000000 - 10111111	N.N.H.H	255.255.0.0	16,384 Nets (2^{14}) 65,534 hosts (2^{16}–2)
C	192–223	11000000 - 11011111	N.N.N.H	255.255.255.0	2,09,150 Nets (2^{21}) 254 hosts (2^8–2)
D	224–239	11100000 - 11101111	NA (Multicast)	-	-
E	240–255	11110000 - 11111111	NA (Experimental)	-	-

Drawbacks of classful addressing

- ★ **Lack of Internal Address Flexibility:** Big organizations are assigned large, "monolithic" blocks of addresses that don't match well the structure of their underlying internal networks.
- ★ **Inefficient Use of Address Space:** The existence of only three block sizes (classes A, B and C) leads to waste of limited IP address space.
- ★ **Proliferation of Router Table Entries:** As the Internet grows, more and more entries are required for routers to handle the routing of IP datagrams, which causes performance problems for routers. Attempting to reduce inefficient address space allocation leads to even more router table entries.

Classless Addressing

- Formal name is Classless Inter-Domain Routing (CIDR).
- Created a new set of standards that allowed service providers to allocate IPv4 addresses on any address bit boundary (prefix length) instead of only by a class A, B, or C address.
- Classless addressing is possible with the help of subnetting.

Classless addressing

Classless Inter-Domain Routing (CIDR)

- a method of IP address allocation and IP routing
- IP addresses can be allocated and routed based on their network prefix rather than their class,
- which was the traditional way of IP address allocation.
- represented using a slash notation, which specifies the number of bits in the network prefix.
- For example, an IP address of 192.168.1.0 with a prefix length of 24 would be represented as 192.168.1.0/24.

Valid Subnet masks

Valid Subnet Masks

Subnet Value	Bit Value							
	128	64	32	16	8	4	2	1
255	1	1	1	1	1	1	1	1
254	1	1	1	1	1	1	1	0
252	1	1	1	1	1	1	0	0
248	1	1	1	1	1	0	0	0
240	1	1	1	1	0	0	0	0
224	1	1	1	0	0	0	0	0
192	1	1	0	0	0	0	0	0
128	1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0

Valid Subnet masks

/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

/1: 10000000.00000000.00000000.00000000

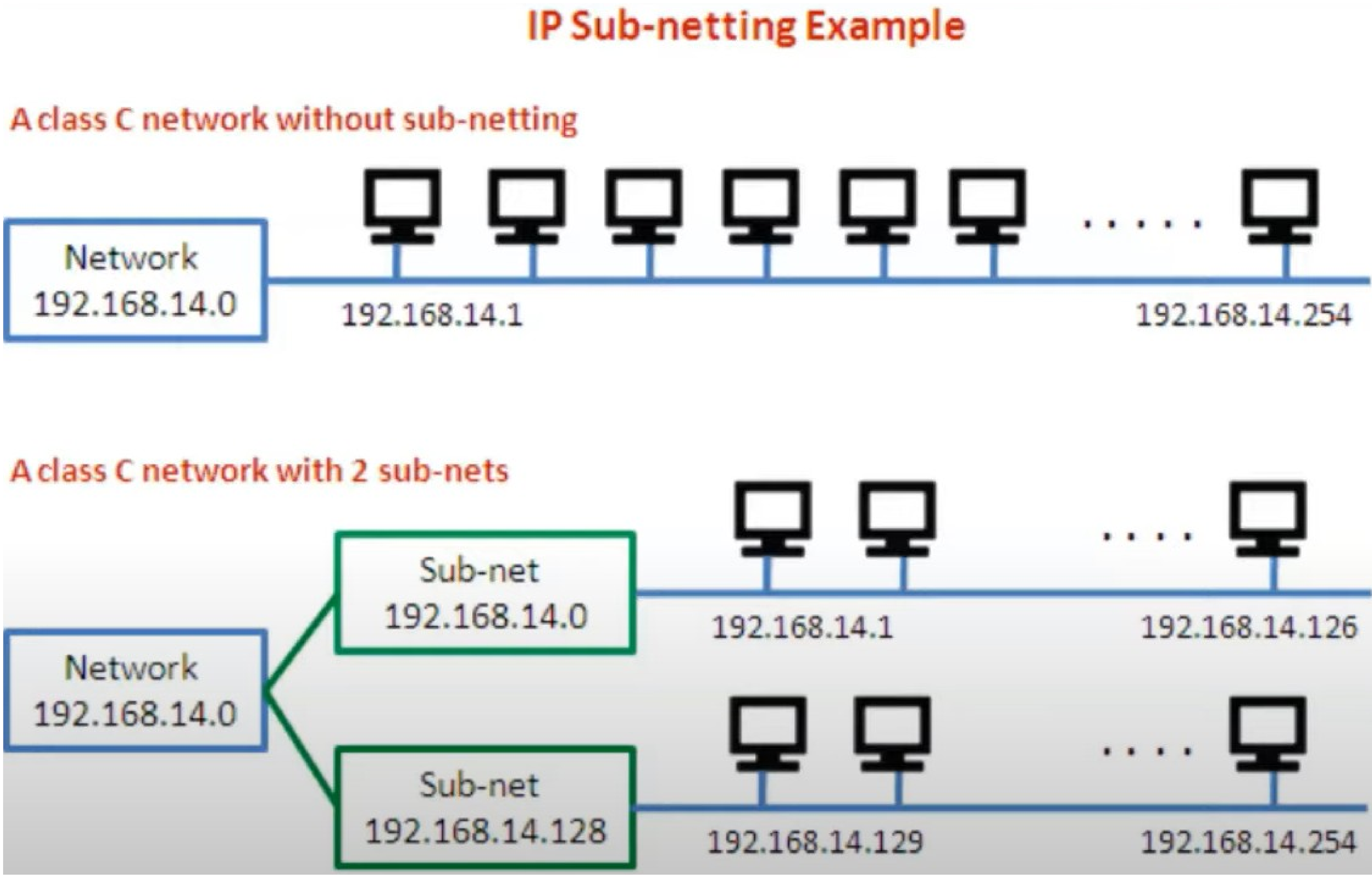
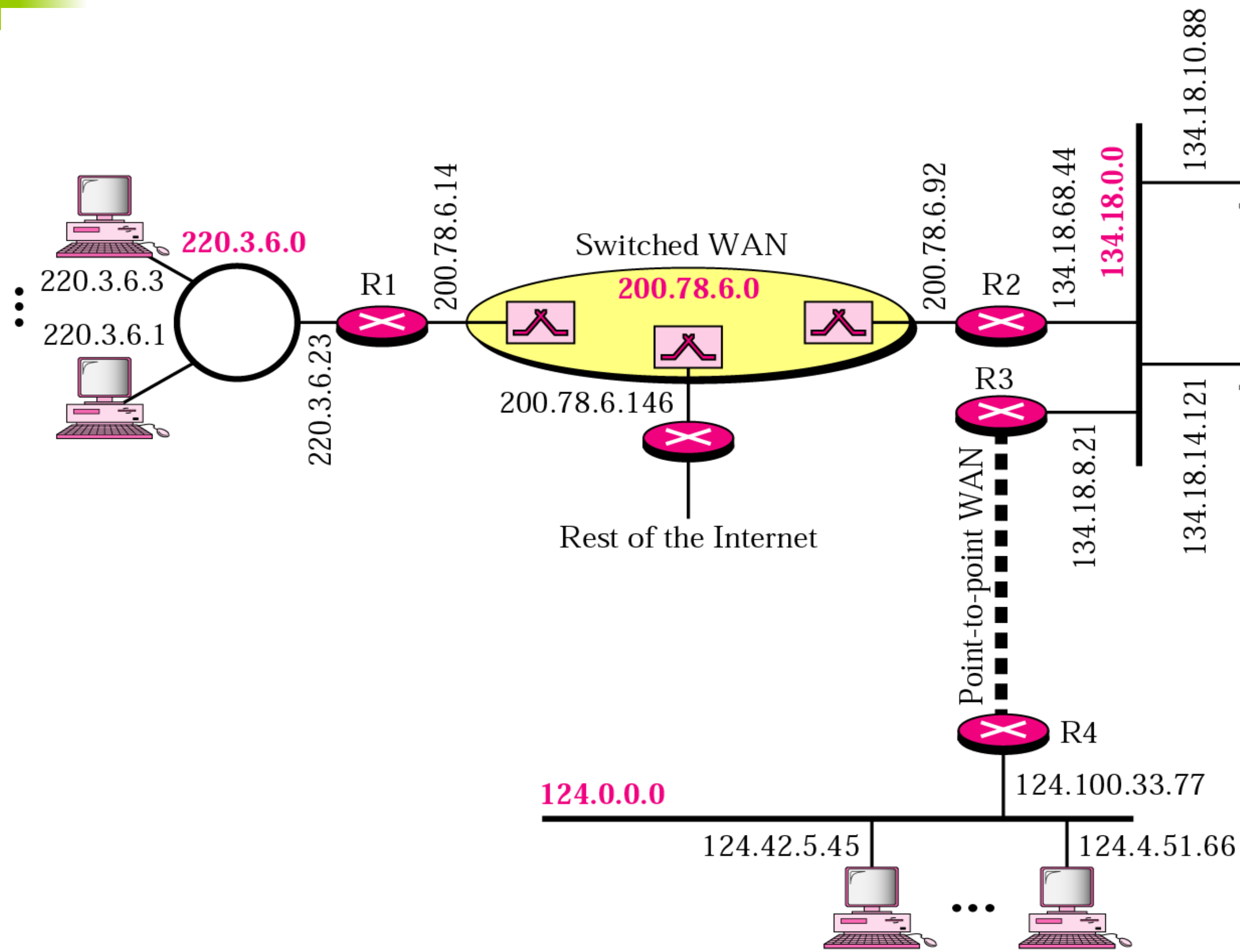
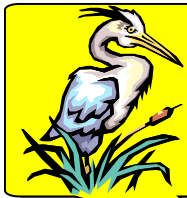

IP Sub-netting Example
A class C network without sub-netting
Network
192.168.14.0
192.168.14.1
192.168.14.254
A class C network with 2 sub-nets
Sub-net
192.168.14.0
192.168.14.1
192.168.14.126
Network
192.168.14.0
Sub-net
192.168.14.128
192.168.14.129
192.168.14.254

Figure 19.18 Sample internet





Note:

IP addresses are designed with two levels of hierarchy.

Figure 19.19 A network with two levels of hierarchy

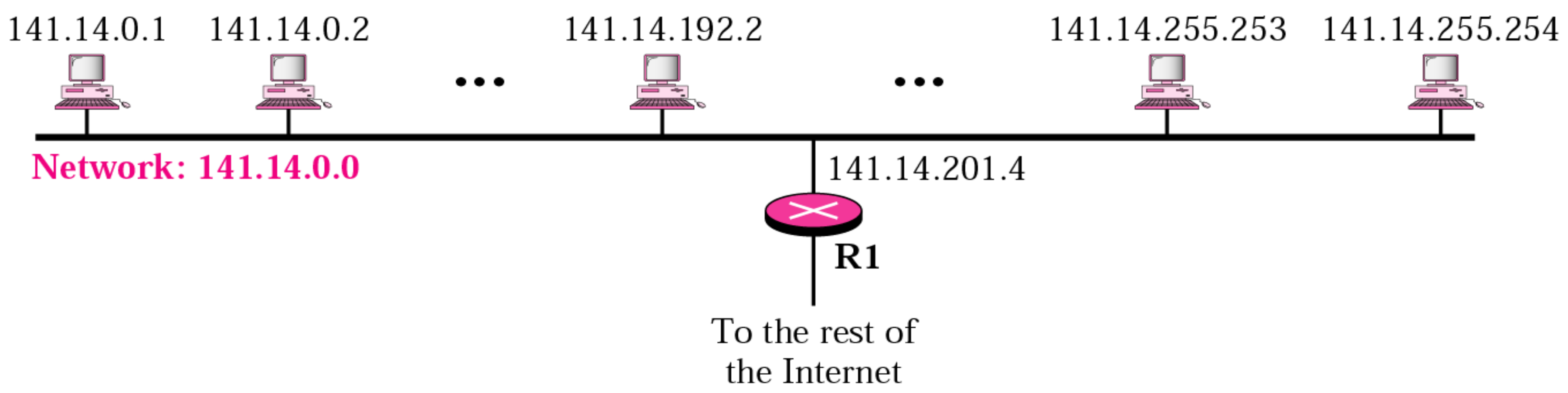


Figure 19.20 A network with three levels of hierarchy (subnetted)

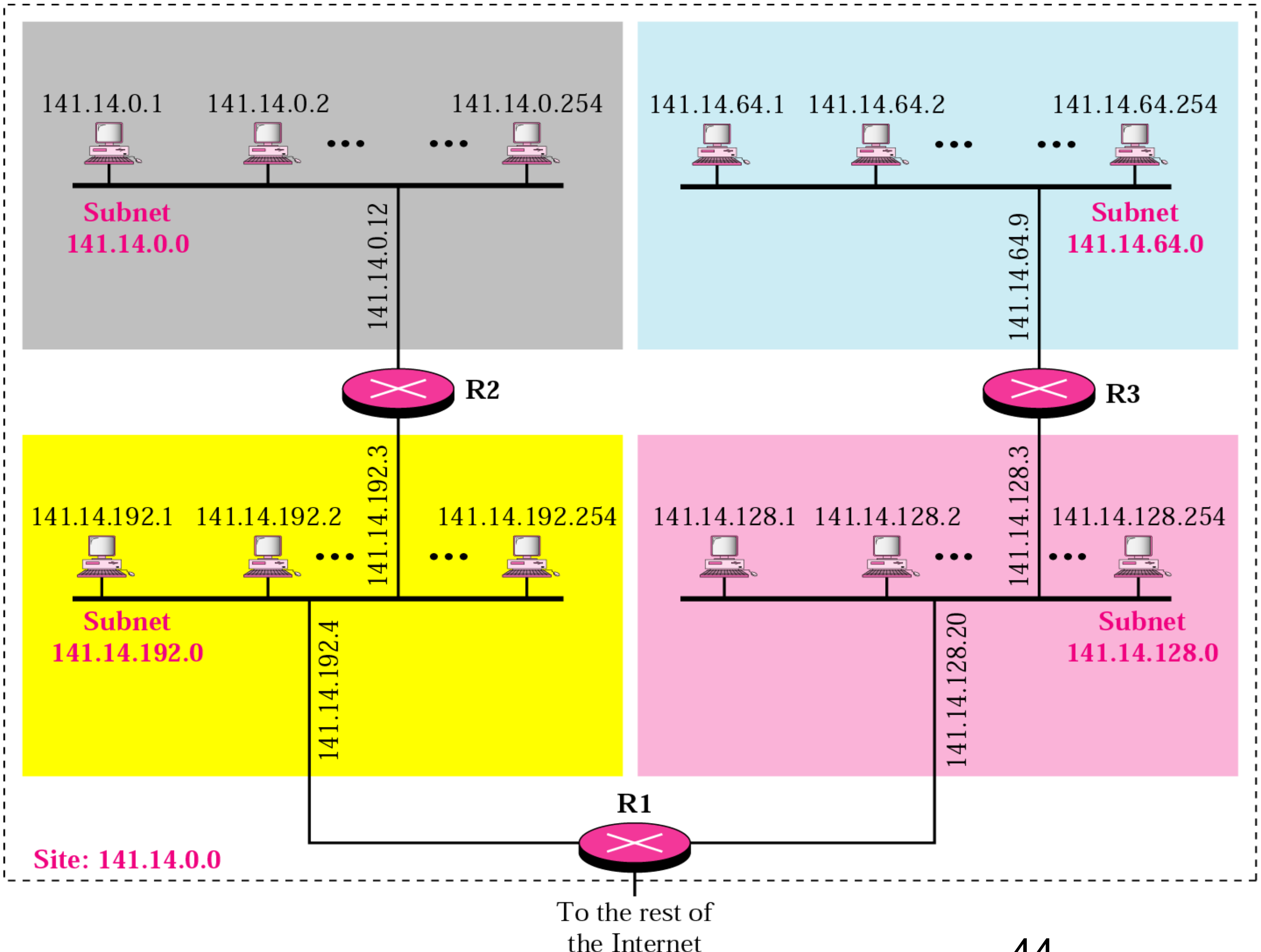
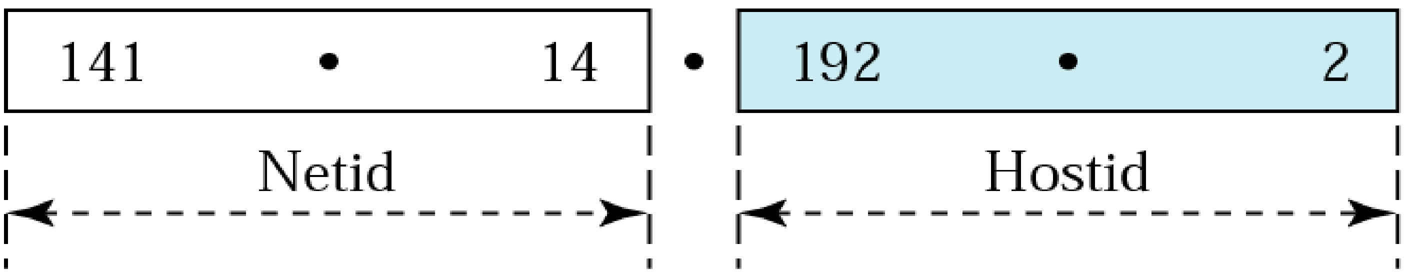
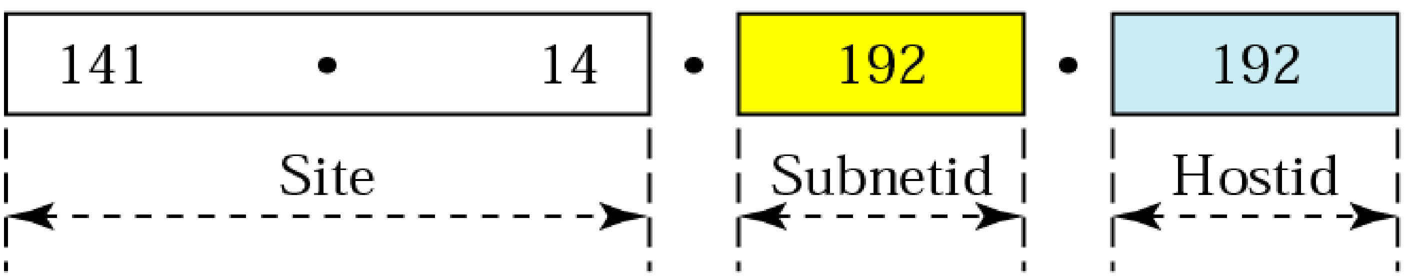


Figure 19.21 Addresses in a network with and without subnetting

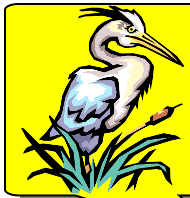


a. Without subnetting



b. With subnetting

Figure 19.22 Hierarchy concept in a telephone number



Note:

The network address can be found by applying the default mask to any address in the block (including itself). It retains the netid of the block and sets the hostid to 0s.

Example 8

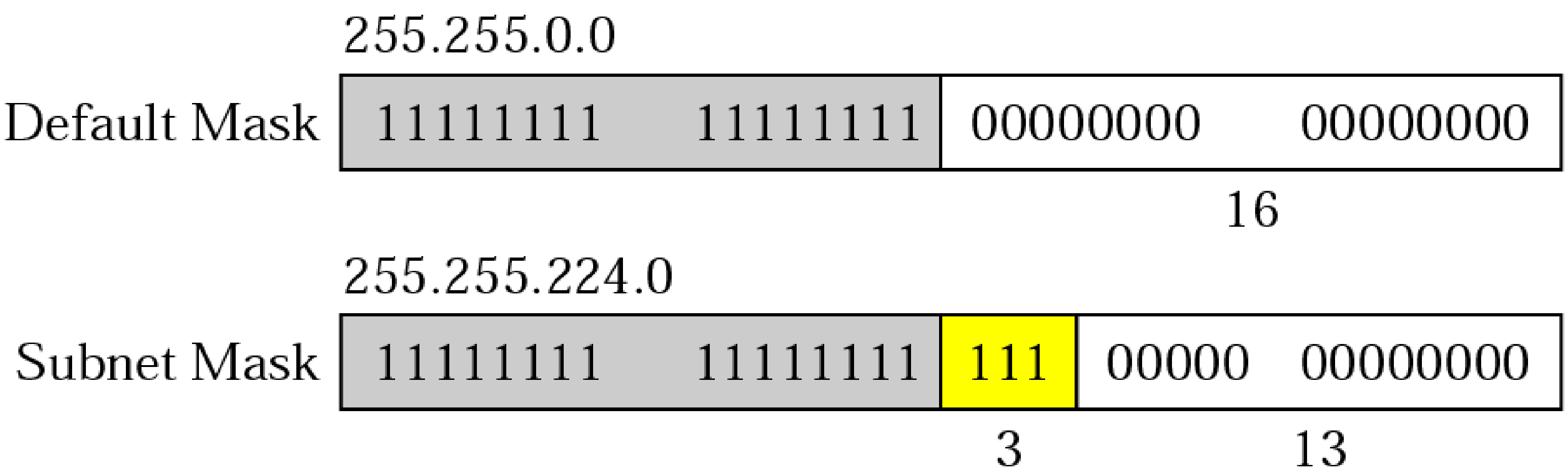
A router outside the organization receives a packet with destination address 190.240.7.91. Show how it finds the network address to route the packet.

Solution

The router follows three steps:

1. The router looks at the first byte of the address to find the class. It is class B.
2. The default mask for class B is 255.255.0.0. The router ANDs this mask with the address to get 190.240.0.0.
3. The router looks in its routing table to find out how to route the packet to this destination. Later, we will see what happens if this destination does not exist.

Figure 19.23 Subnet mask



Example 9

A router inside the organization receives the same packet with destination address 190.240.33.91. Show how it finds the subnetwork address to route the packet.

Solution

The router follows three steps:

1. **The router must know the mask. We assume it is /19, as shown in Figure 19.23.**
2. **The router applies the mask to the address, 190.240.33.91. The subnet address is 190.240.32.0.**
3. **The router looks in its routing table to find how to route the packet to this destination. Later, we will see what happens if this destination does not exist.**

Figure 19.24 DHCP transition diagram

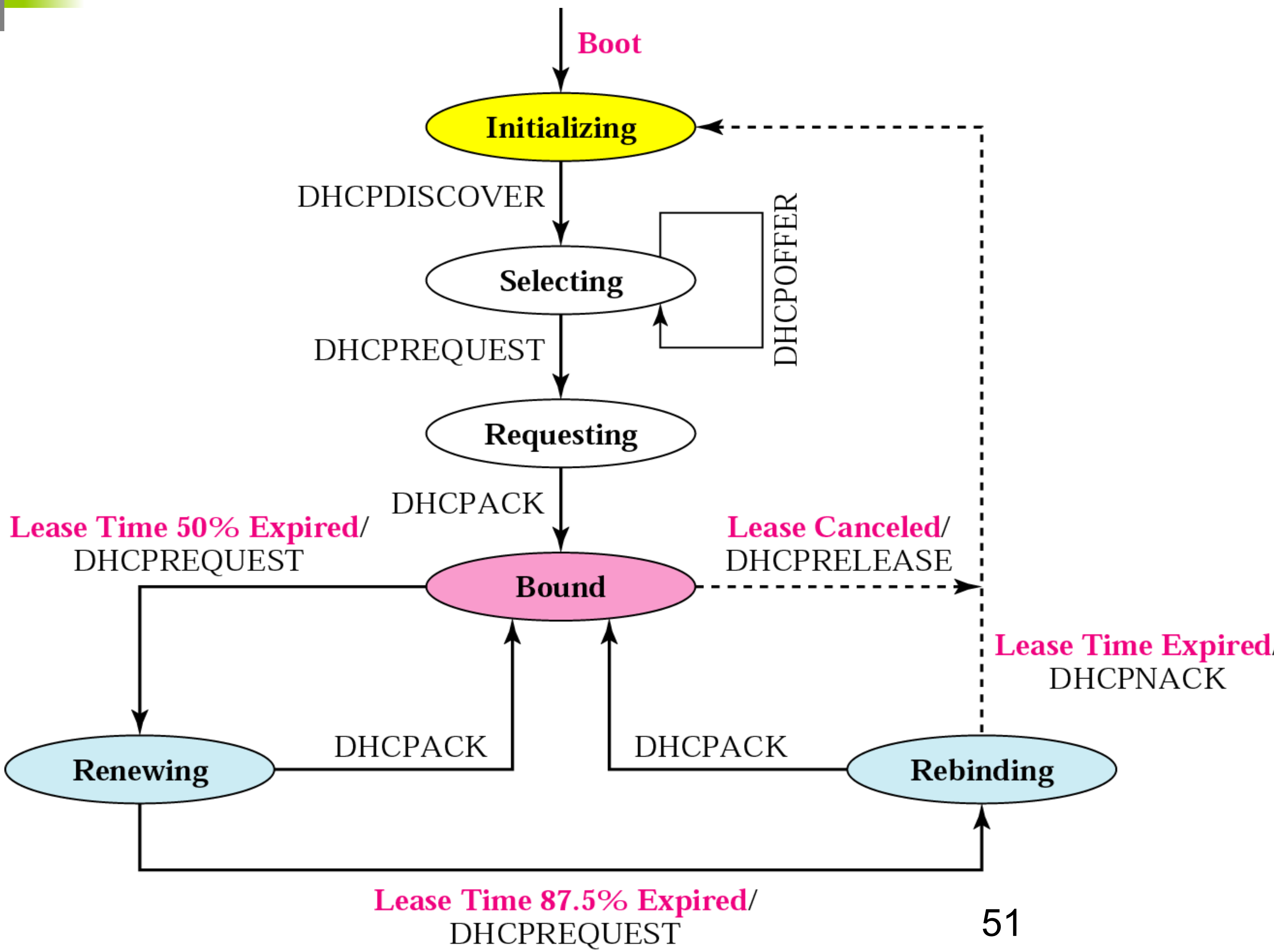


Table 19.2 Default masks

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}

Figure 19.25 NAT

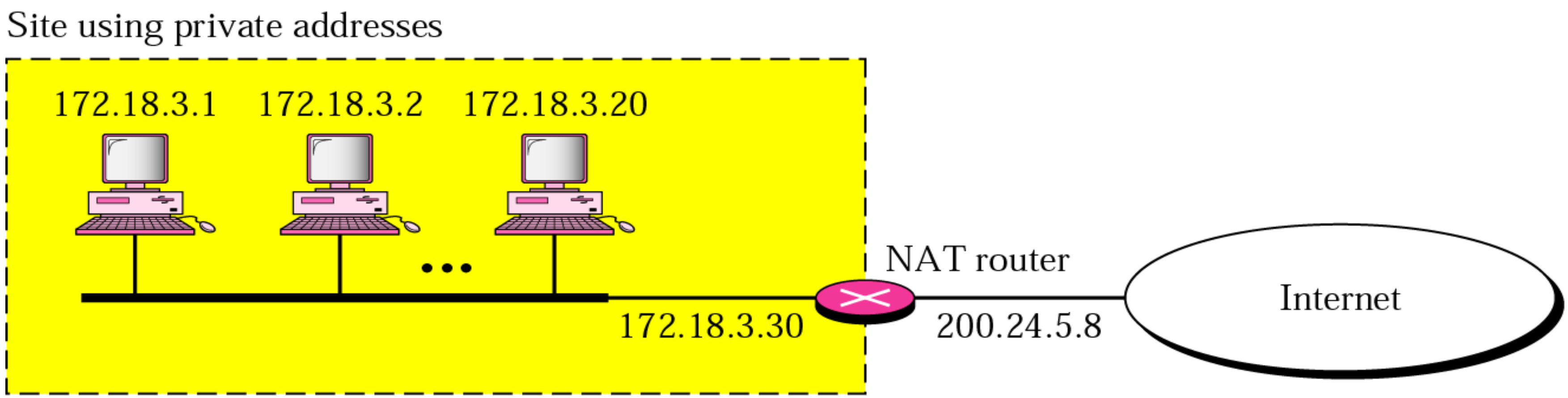


Figure 19.26 Address translation

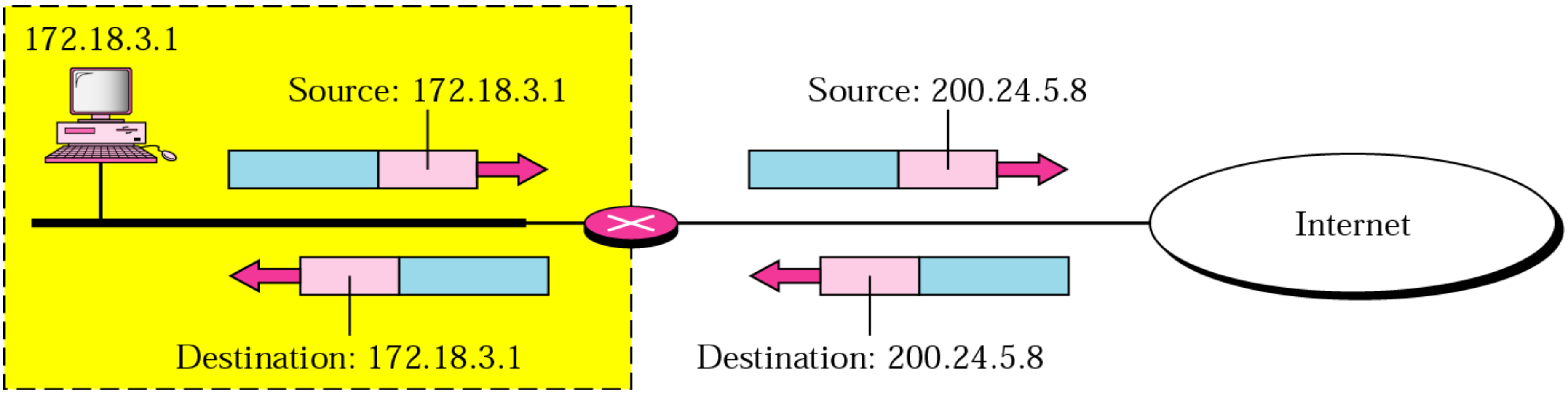


Figure 19.27 Translation

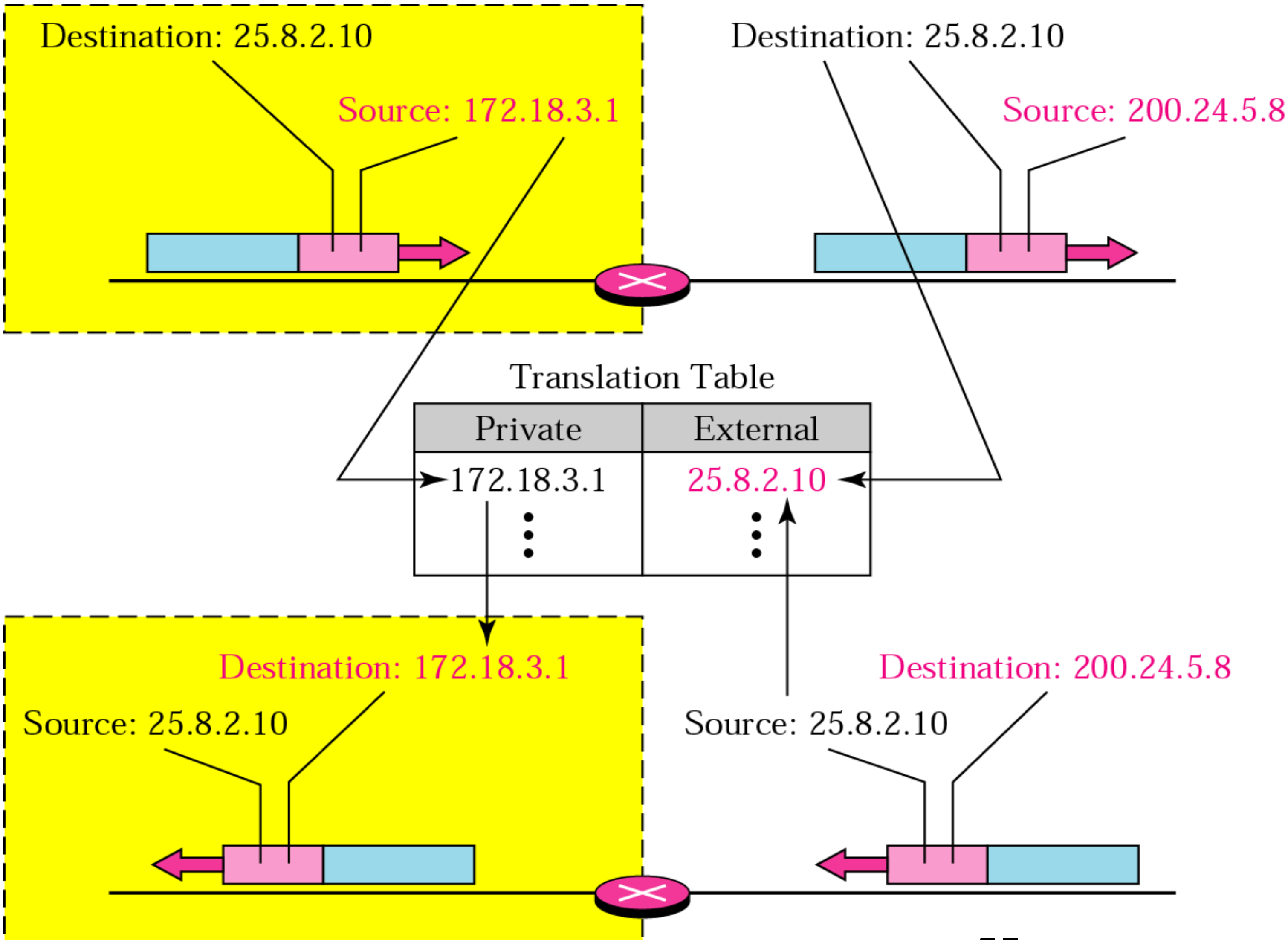


Table 19.3 Five-column translation table

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

19.3 Routing

Routing Techniques

Static Versus Dynamic Routing

Routing Table for Classful Addressing

Routing Table for Classless Addressing

Figure 19.28 Next-hop routing

Routing table for host A

Destination	Route
Host B	R1, R2, Host B

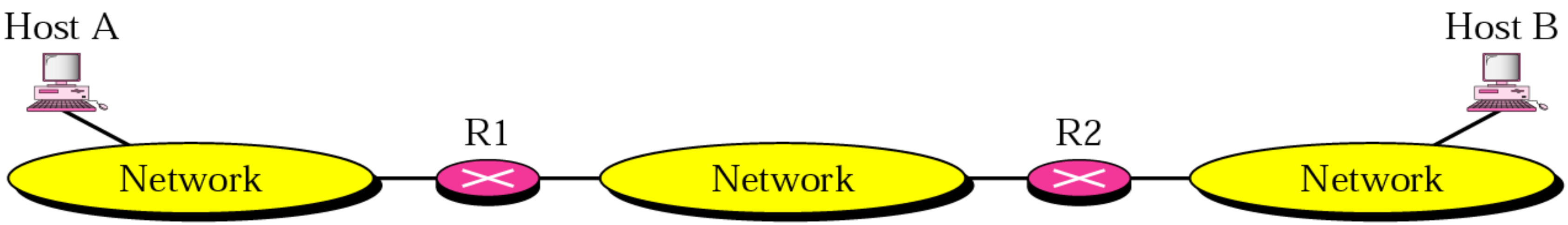
Routing table for R1

Destination	Route
Host B	R2, Host B

Routing table for R2

Destination	Route
Host B	Host B

a. Routing tables based on route



Routing table for host A

Destination	Next Hop
Host B	R1

Routing table for R1

Destination	Next Hop
Host B	R2

Routing table for R2

Destination	Next Hop
Host B	—

b. Routing tables based on next hop

Figure 19.29 Network-specific routing

Routing table for host S based on host-specific routing

Destination	Next Hop
A	R1
B	R1
C	R1
D	R1

Routing table for host S based on network-specific routing

Destination	Next Hop
N2	R1

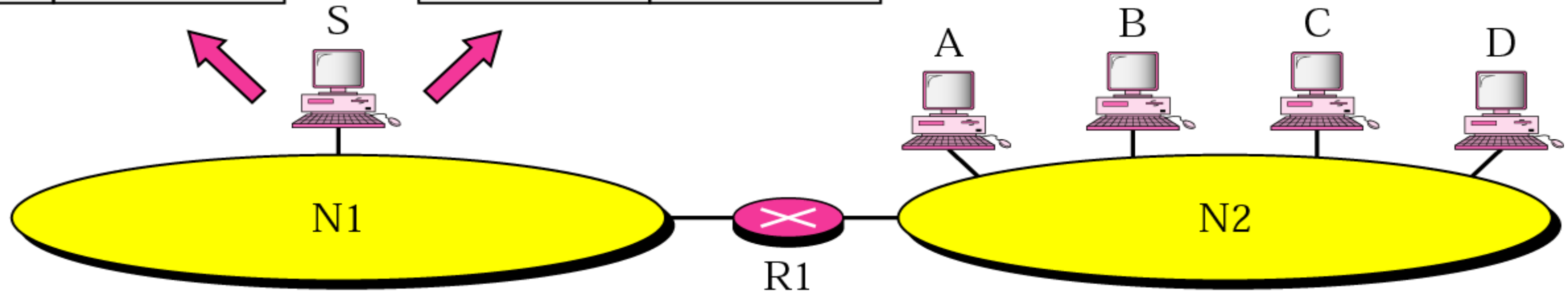


Figure 19.30 Host-specific routing

Routing table for host A

Destination	Next Hop
Host B	R3
N2	R1
N3	R3
......	......

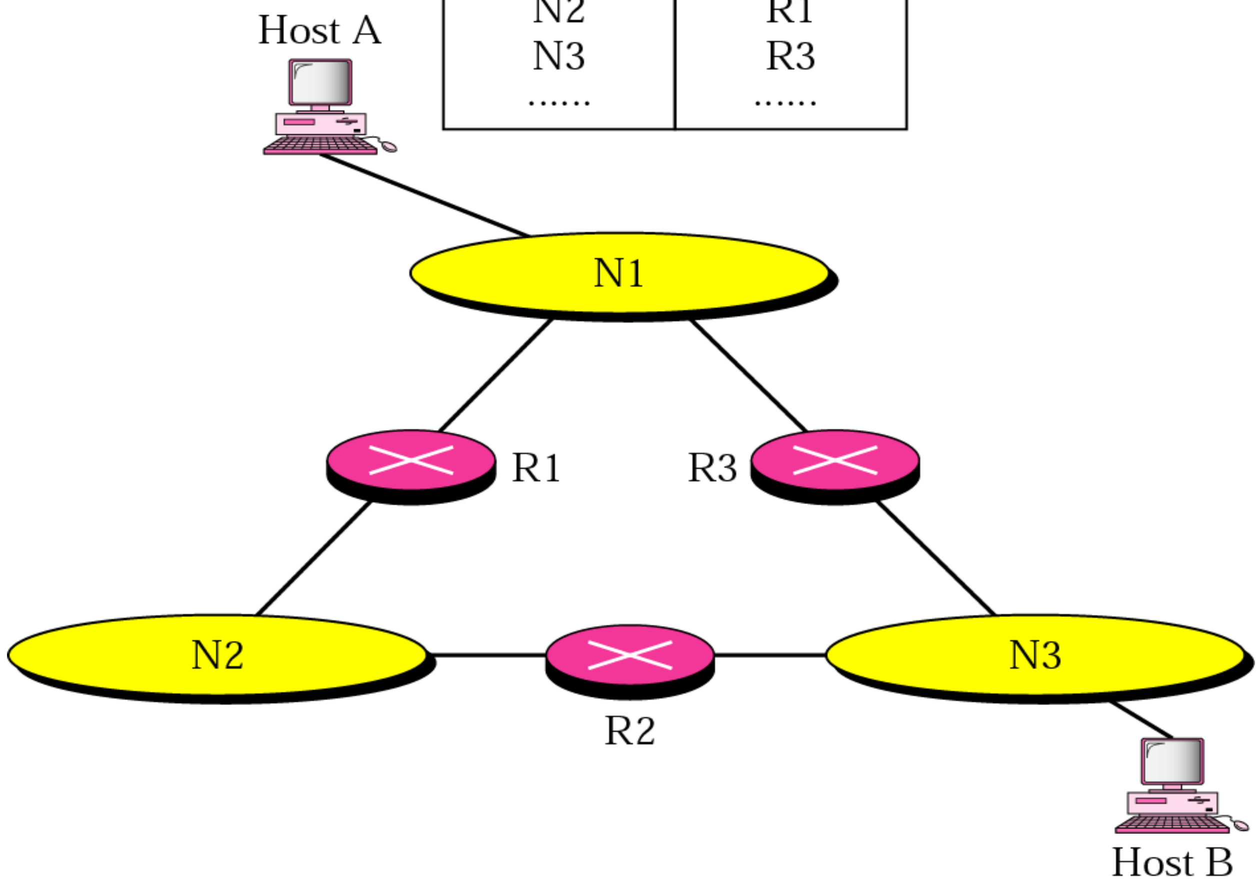


Figure 19.31 Default routing

Routing table for host A

Destination	Next Hop
N2	R1
……	……
Default	R2

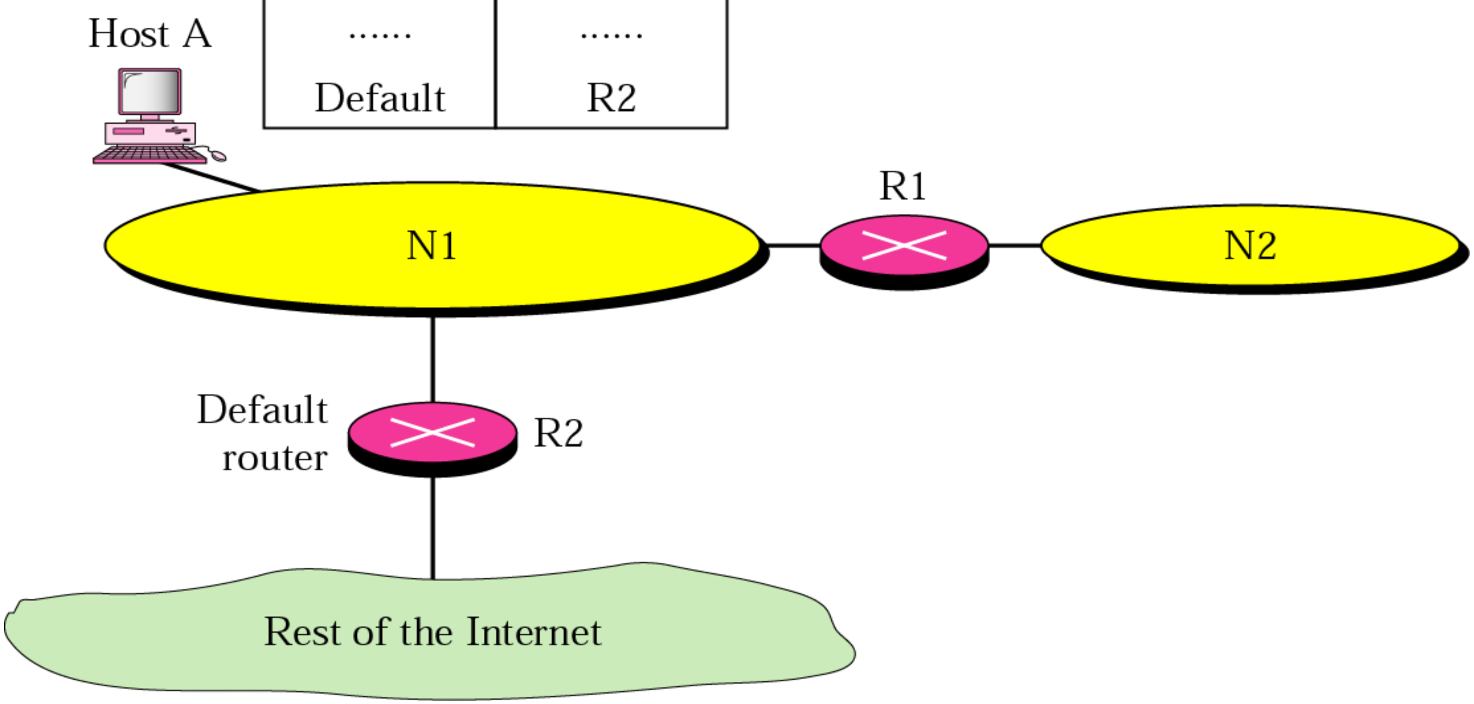


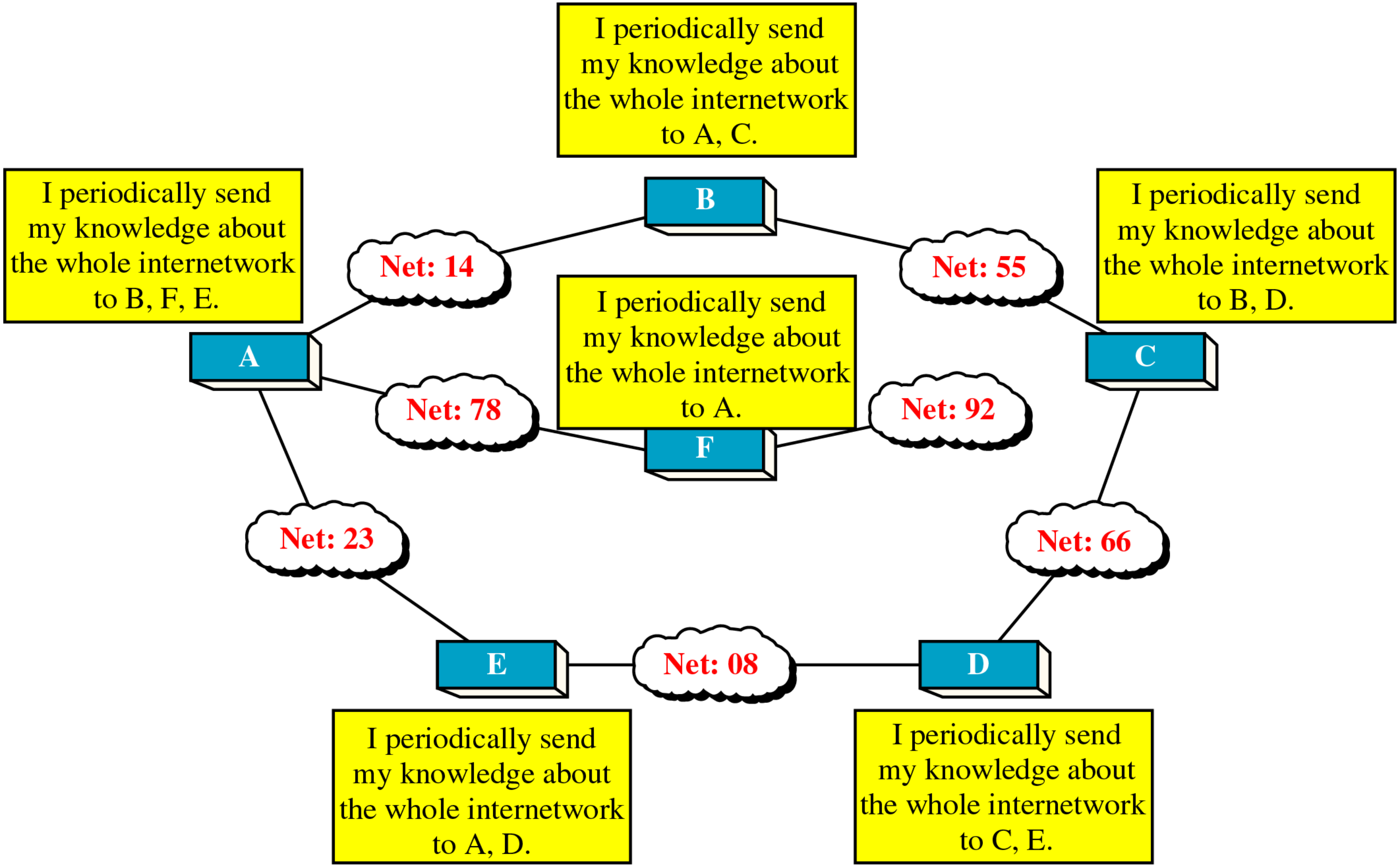
Figure 19.32 Classful addressing routing table

	Mask	Destination address	Next-hop address	Interface
	/8	14.0.0.0	118.45.23.8	m1
Host-specific	/32	192.16.7.1	202.45.9.3	m0
	/24	193.14.5.0	84.78.4.12	m2
Default	/0	/0	145.11.10.6	m0

Routing Algorithms

1. Distance Vector Routing
2. Link State Routing

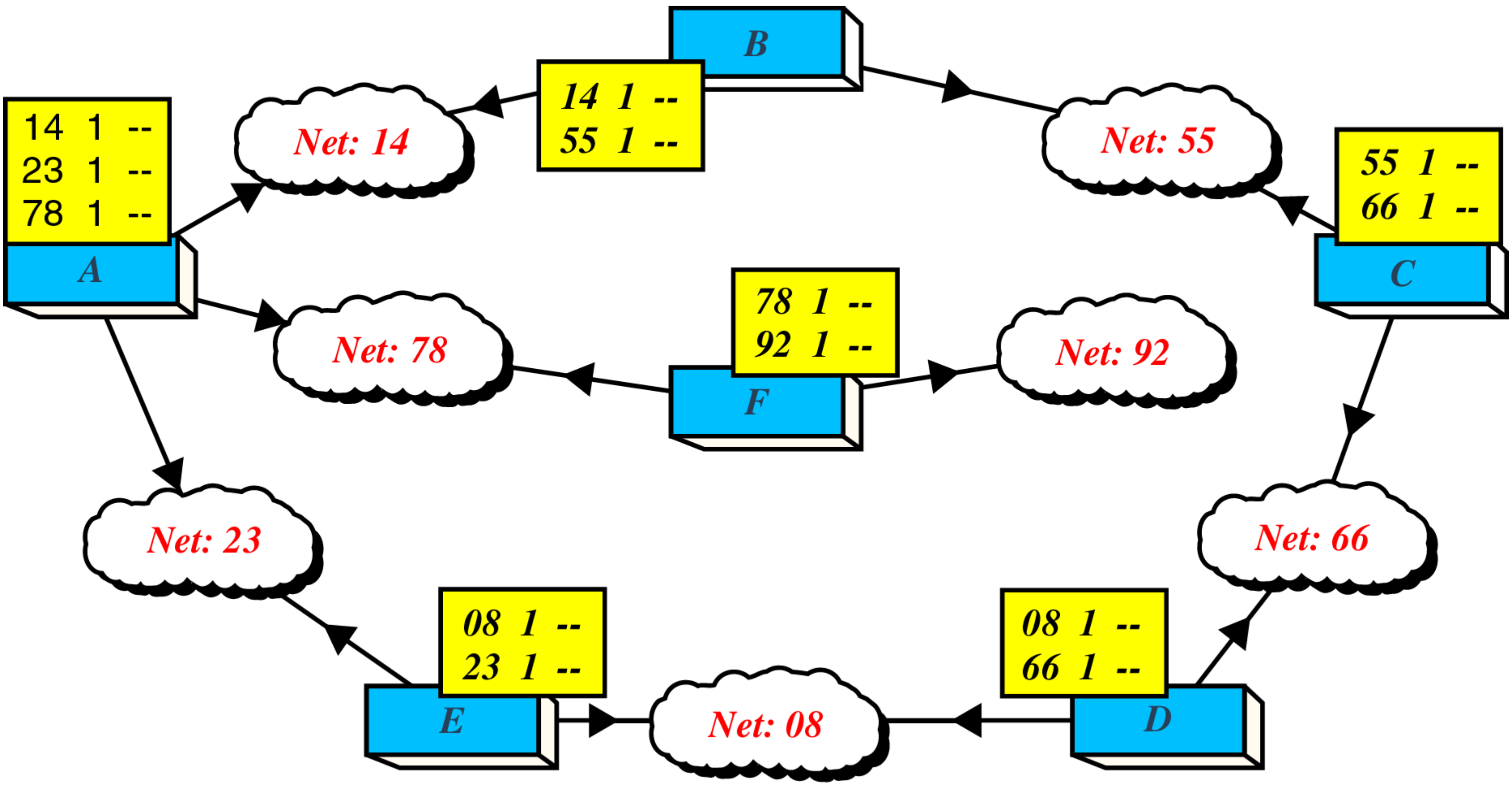
The Concept of Distance Vector Routing



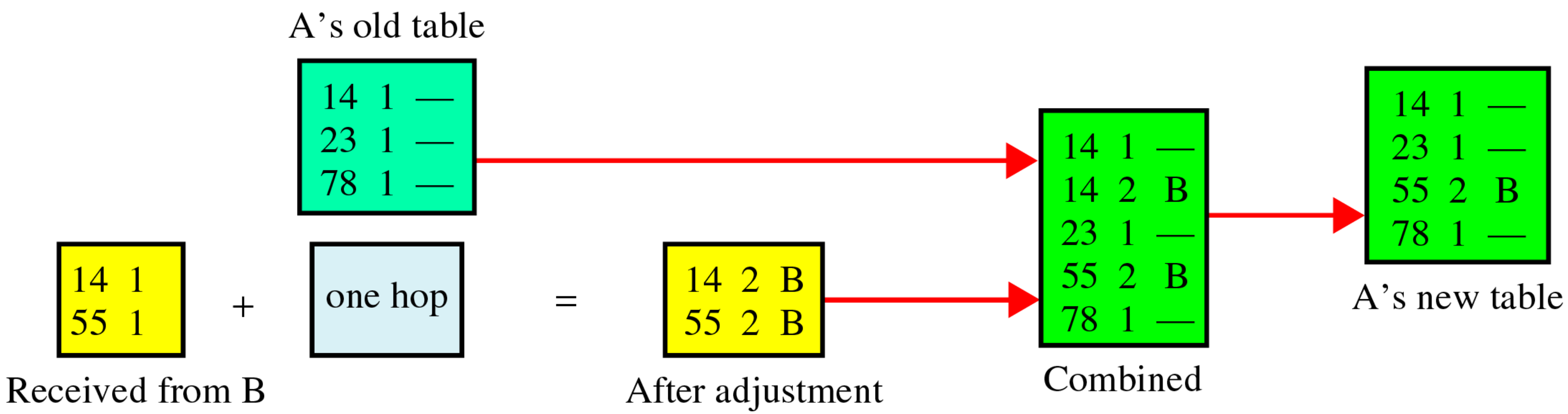
Distance Vector Routing Table

Network ID	Cost	Next Hop
. . . .	. . . .	. . . .
. . . .	. . . .	. . . .
. . . .	. . . .	. . . .
. . . .	. . . .	. . . .
. . . .	. . . .	. . . .

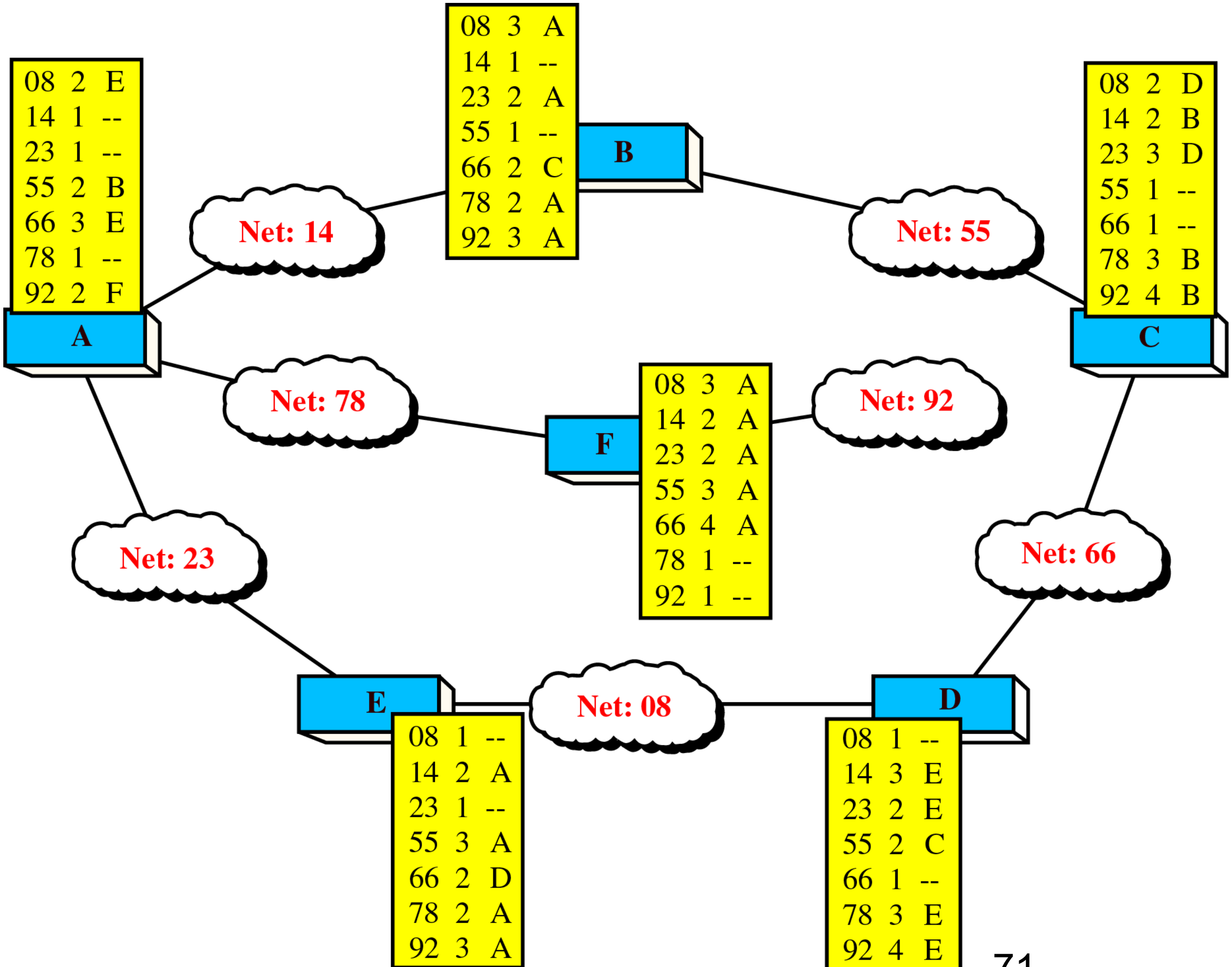
Routing Table Distribution

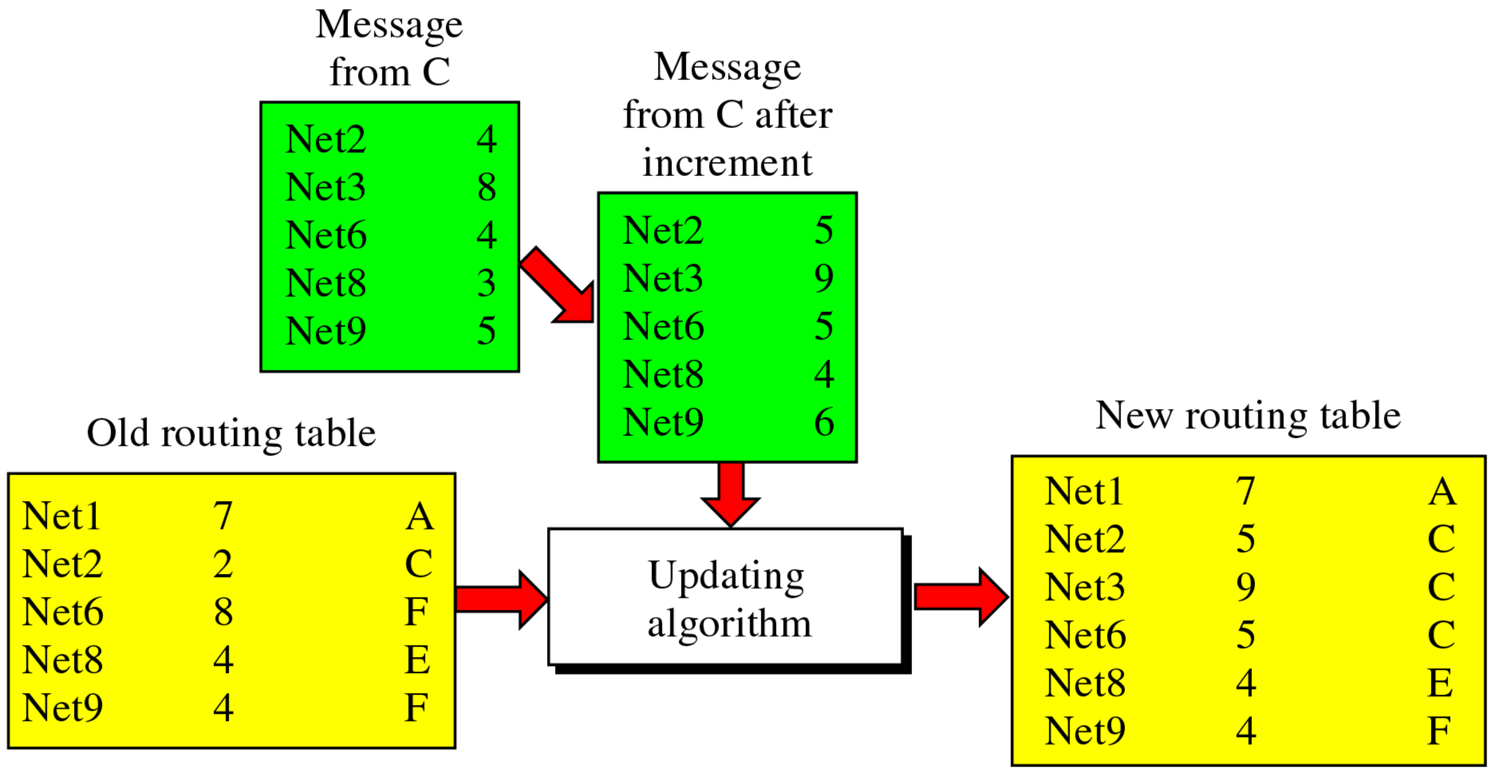


Updating Routing Table for Router A



Final Routing Tables





Rules

Net2: Replace **(Rule 2.a)**
Net3: Add **(Rule 1)**
Net6: Replace **(Rule 2.b.i)**
Net8: No change **(Rule 2.b.ii)**
Net9: No change **(Rule 2.b.ii)**

Note that there is no news about Net1 in the advertised message, so none of the rules apply to this entry.

Figure 21-24

Concept of Link State Routing

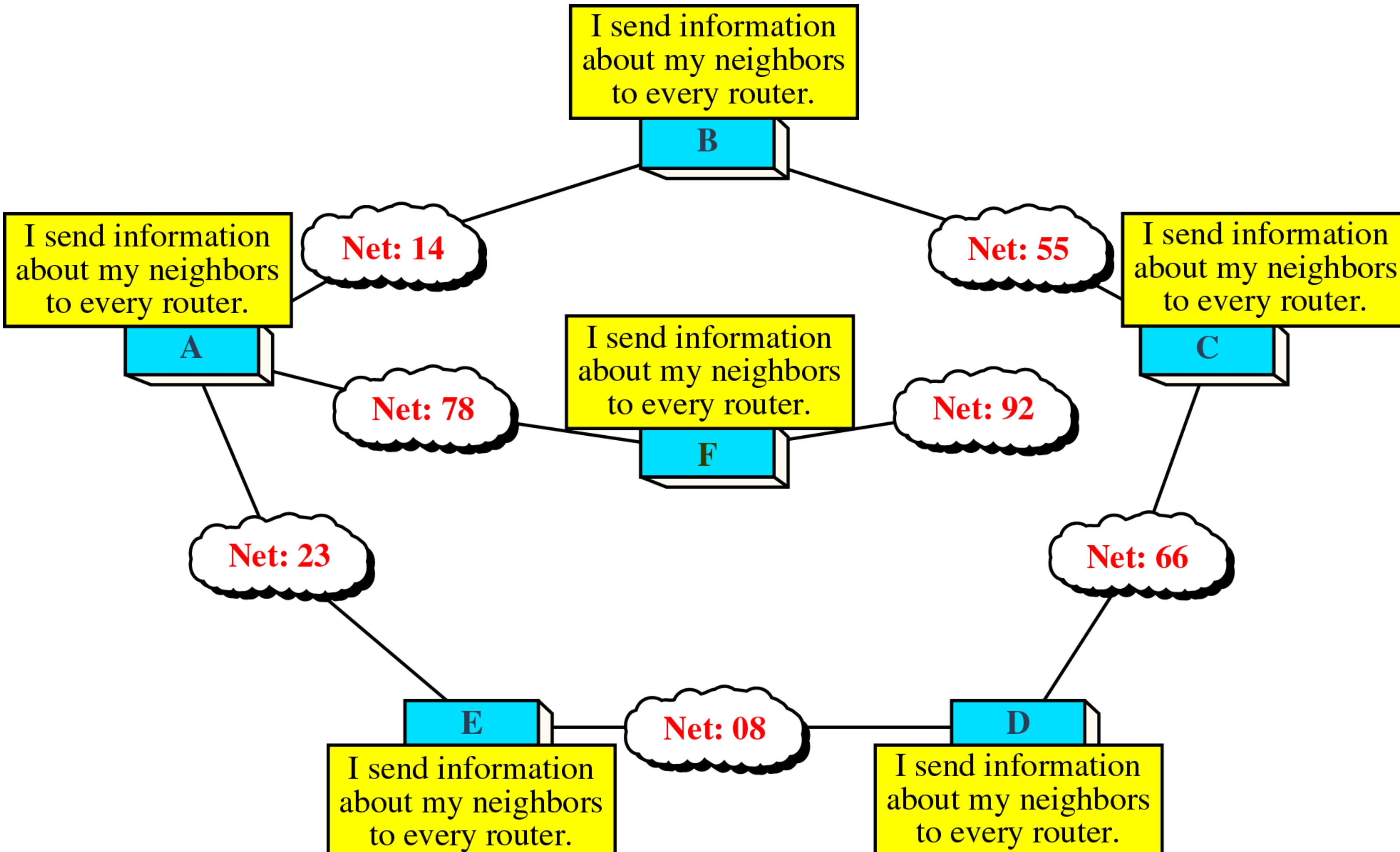


Figure 21-25

Cost in Link State Routing

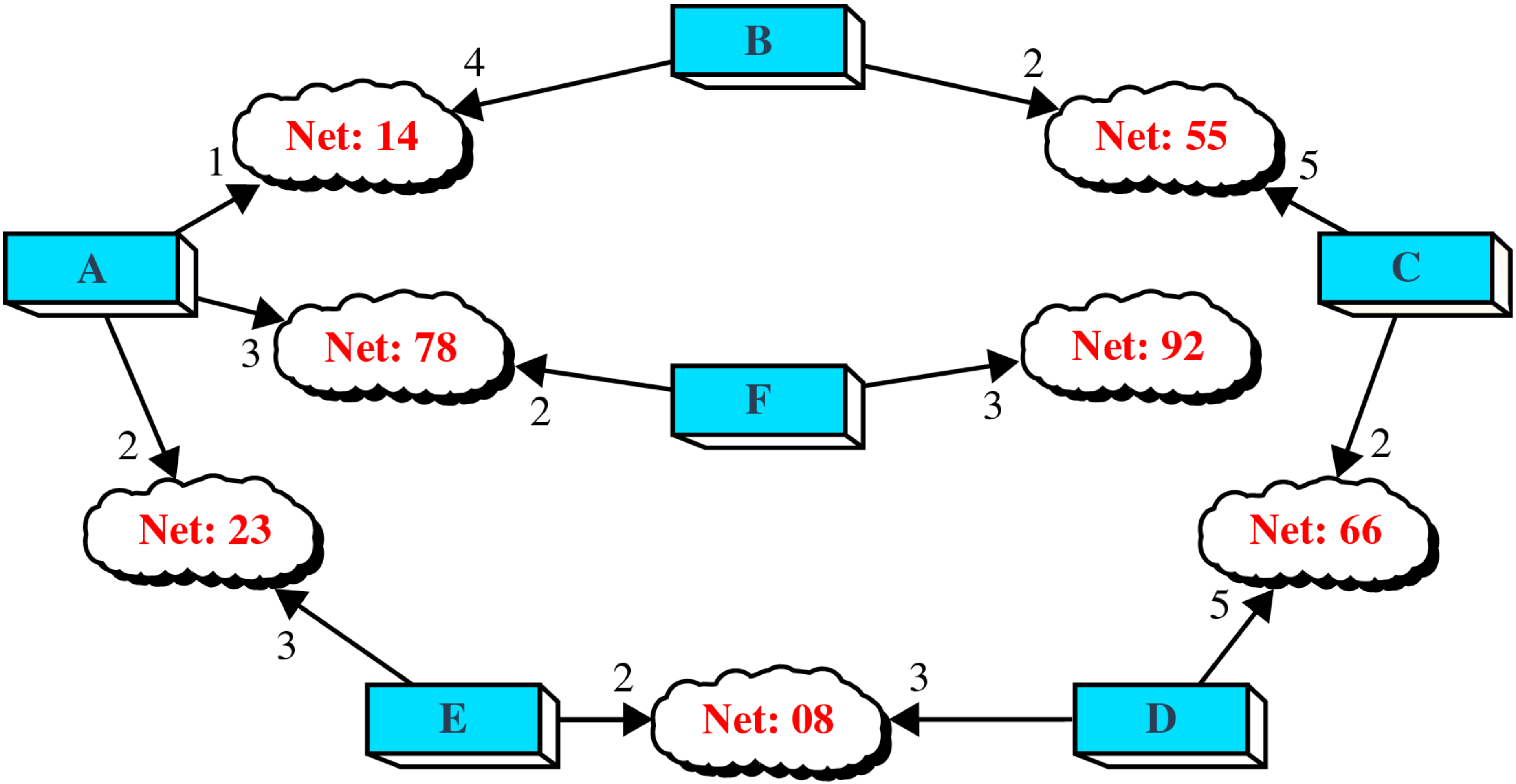


Figure 21-26

Link State Packet

Advertiser	Network	Cost	Neighbor
. . . .	. . . . . .	. . . .	. . . .
. . . .	. . . . . .	. . . .	. . . .
. . . .	. . . . . .	. . . .	. . . .

Figure 21-27

Flooding of A's LSP

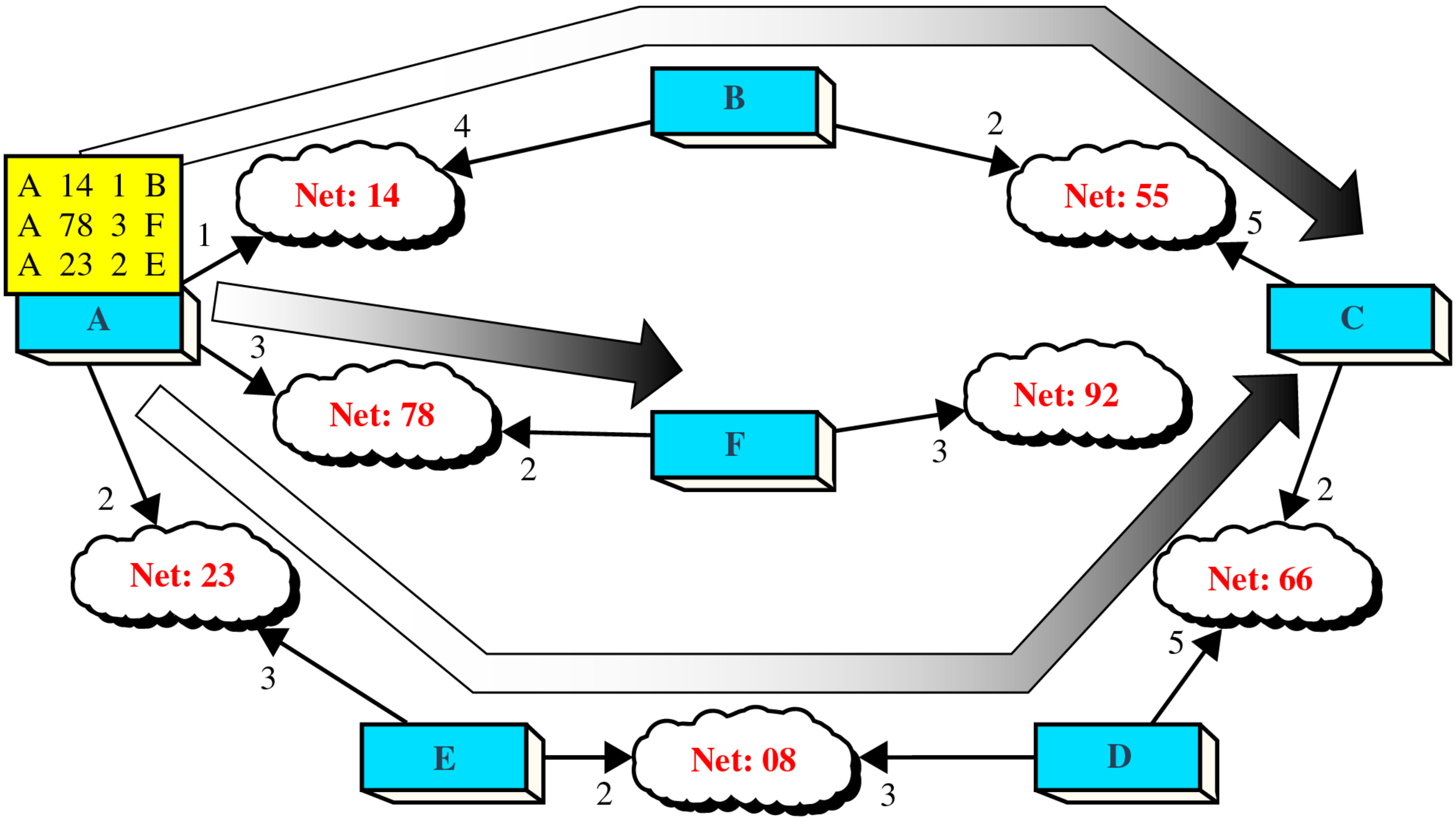


Figure 21-28

Link State Database

Advertiser	Network	Cost	Neighbor
A	14	1	B
A	78	3	F
A	23	2	E
B	14	4	A
B	55	2	C
C	55	5	B
C	66	2	D
D	66	5	C
D	08	3	E
E	23	3	A
E	08	2	D
F	78	2	A
F	92	3	—