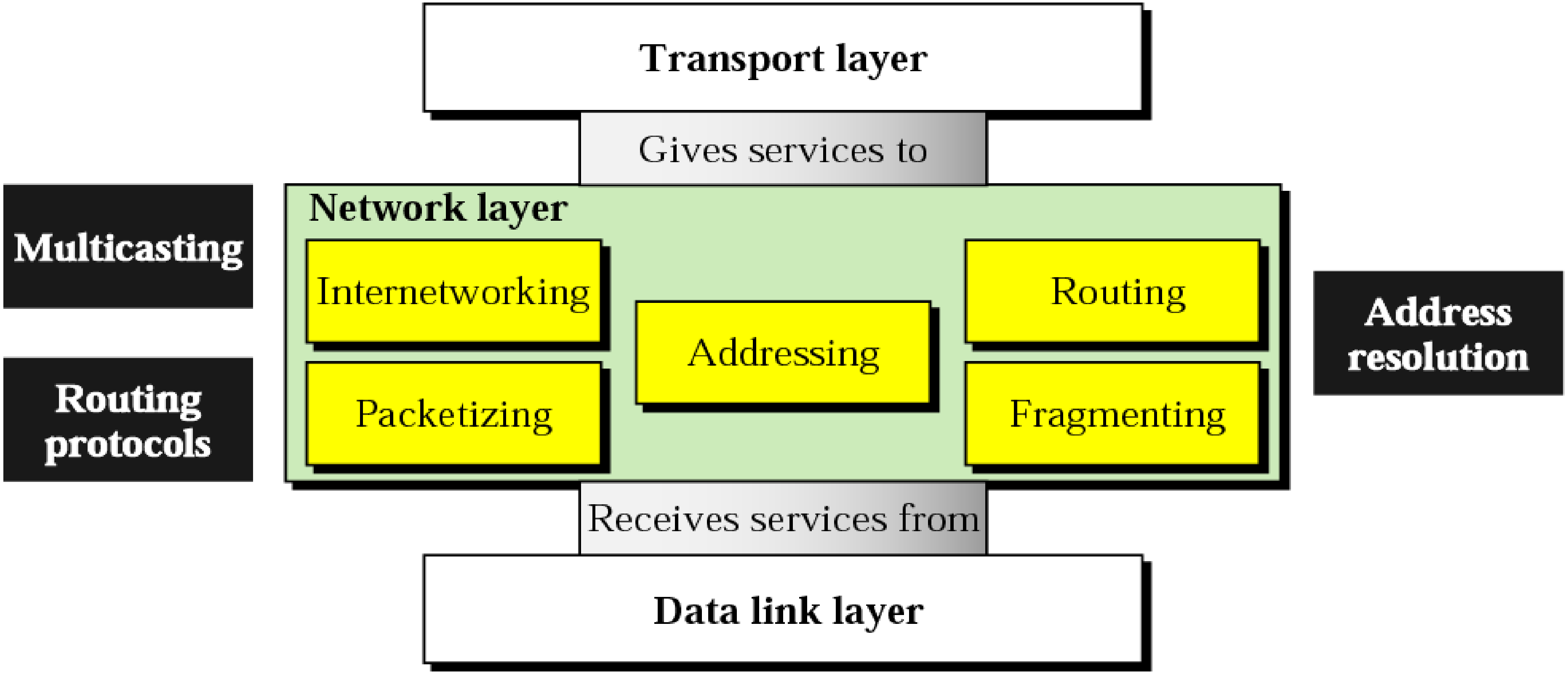
# Computer Networks

## — Unit - 3 —

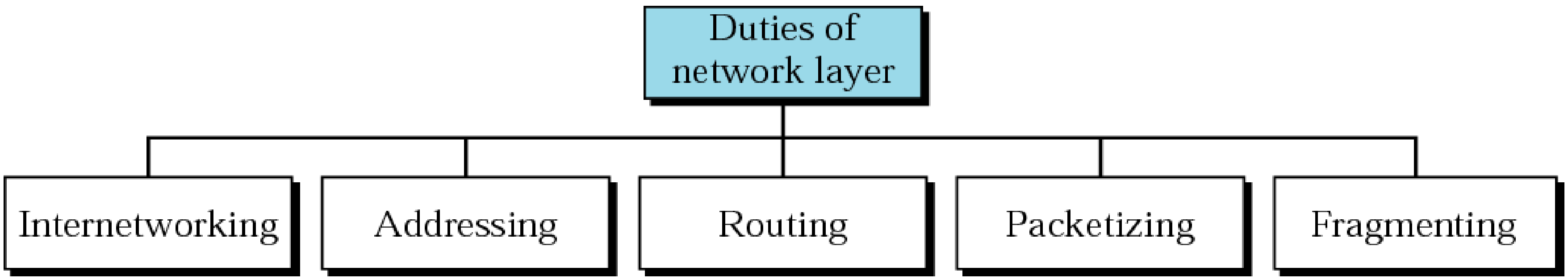
## — Network Layer —

# *Network Layer*

# Position of network layer



# Network layer duties



# ***Host-to-Host Delivery:***

## ***Internetworking, Addressing, and Routing***

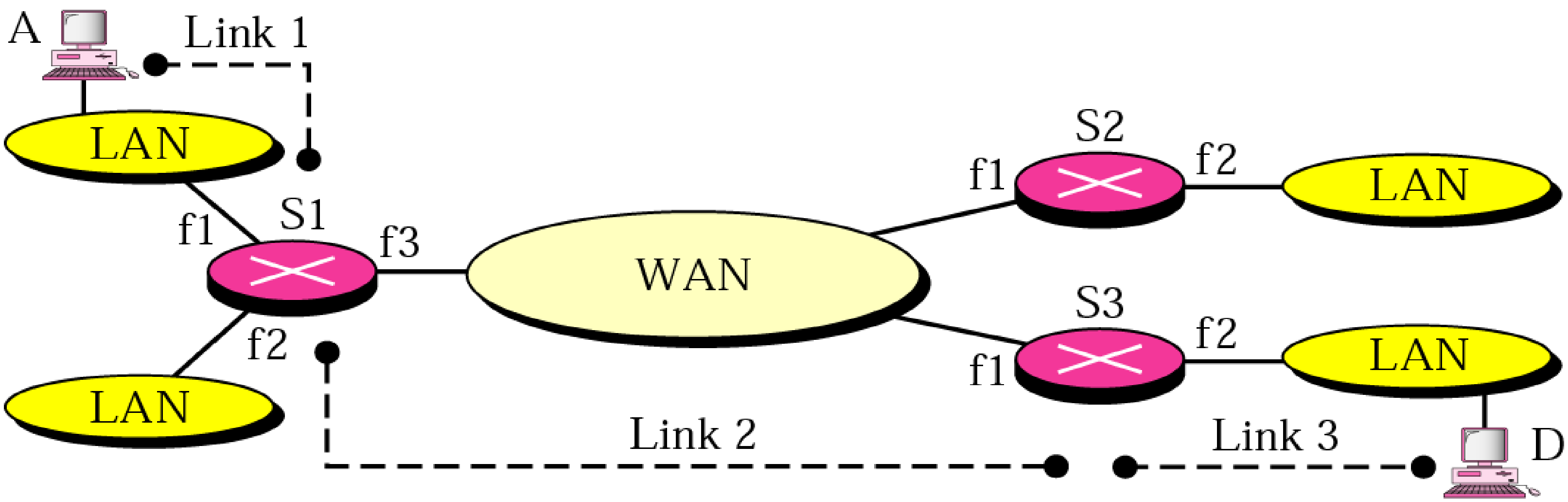
# 19.1 Internetworks

***Need For Network Layer***

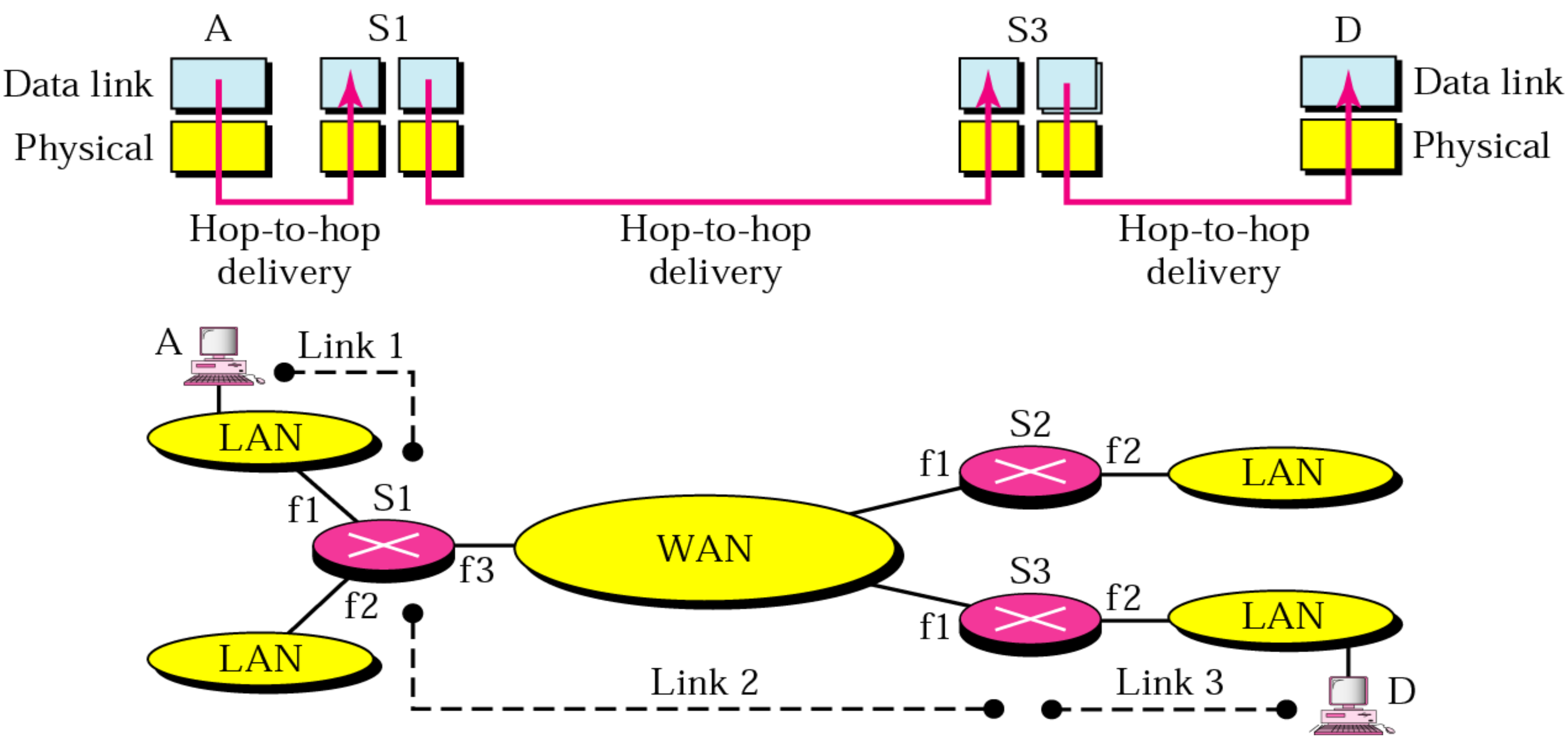
***Internet As A Packet-Switched Network***

***Internet As A Connectionless Network***

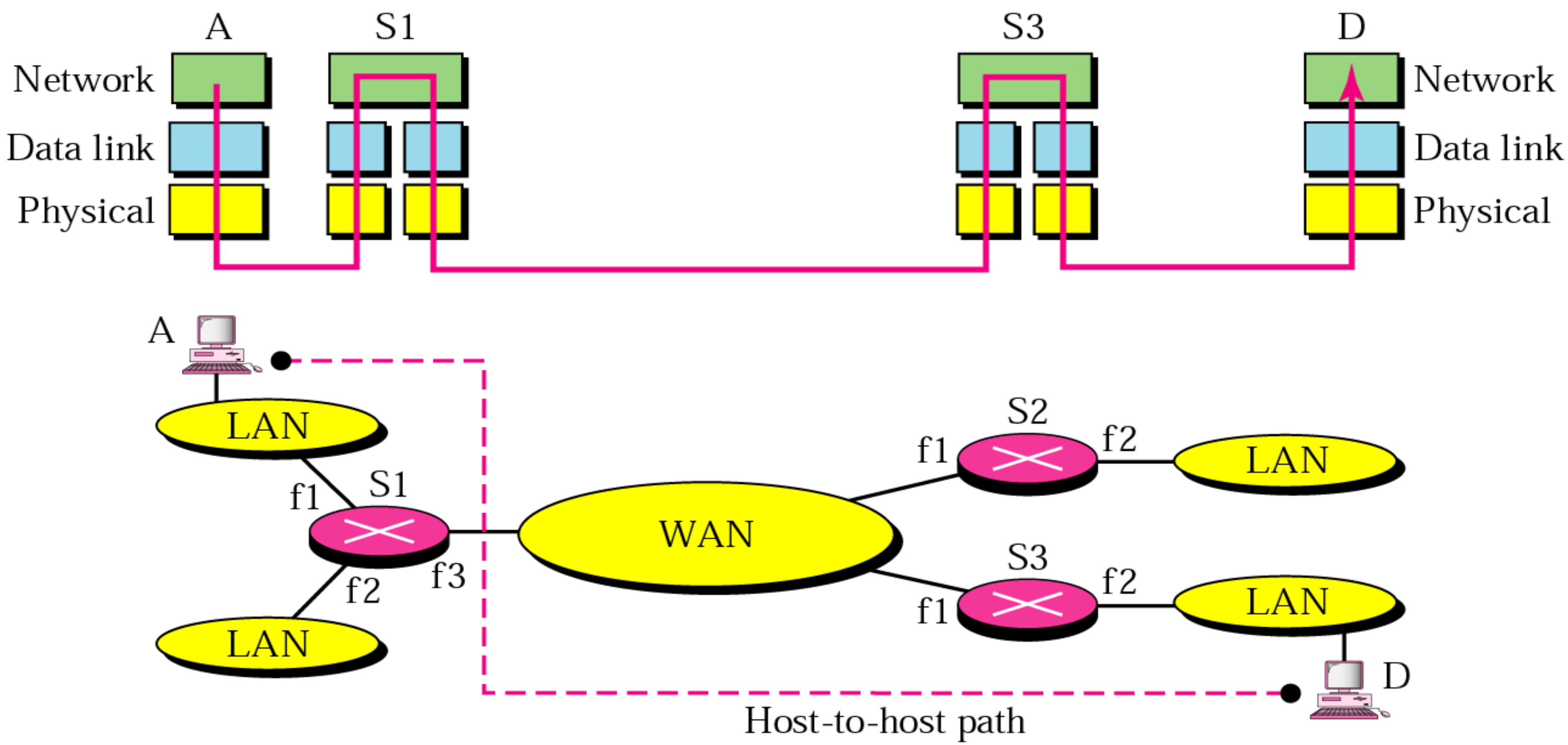
# Figure 19.1 Internetwork



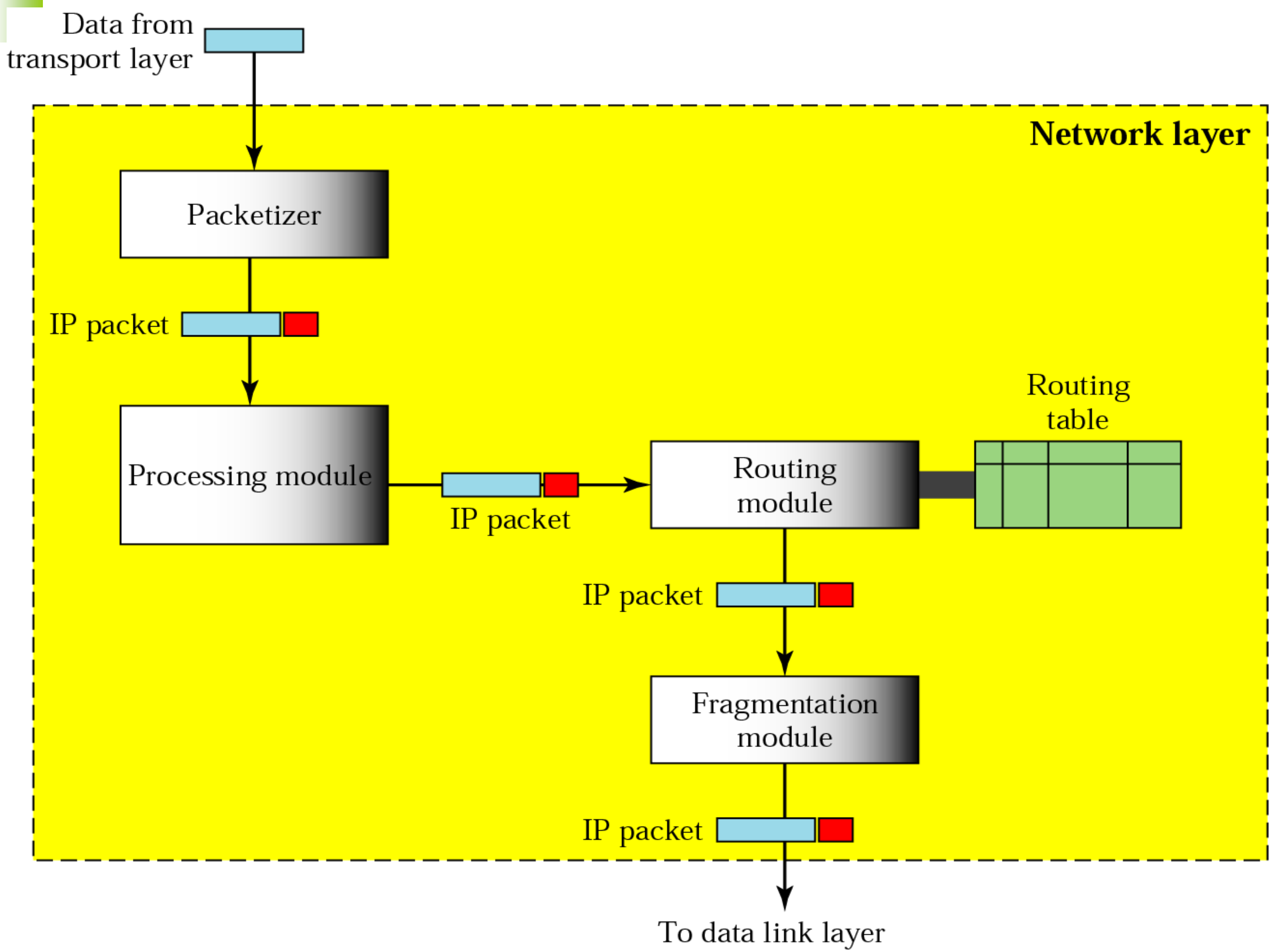
## Figure 19.2 Links in an internetwork



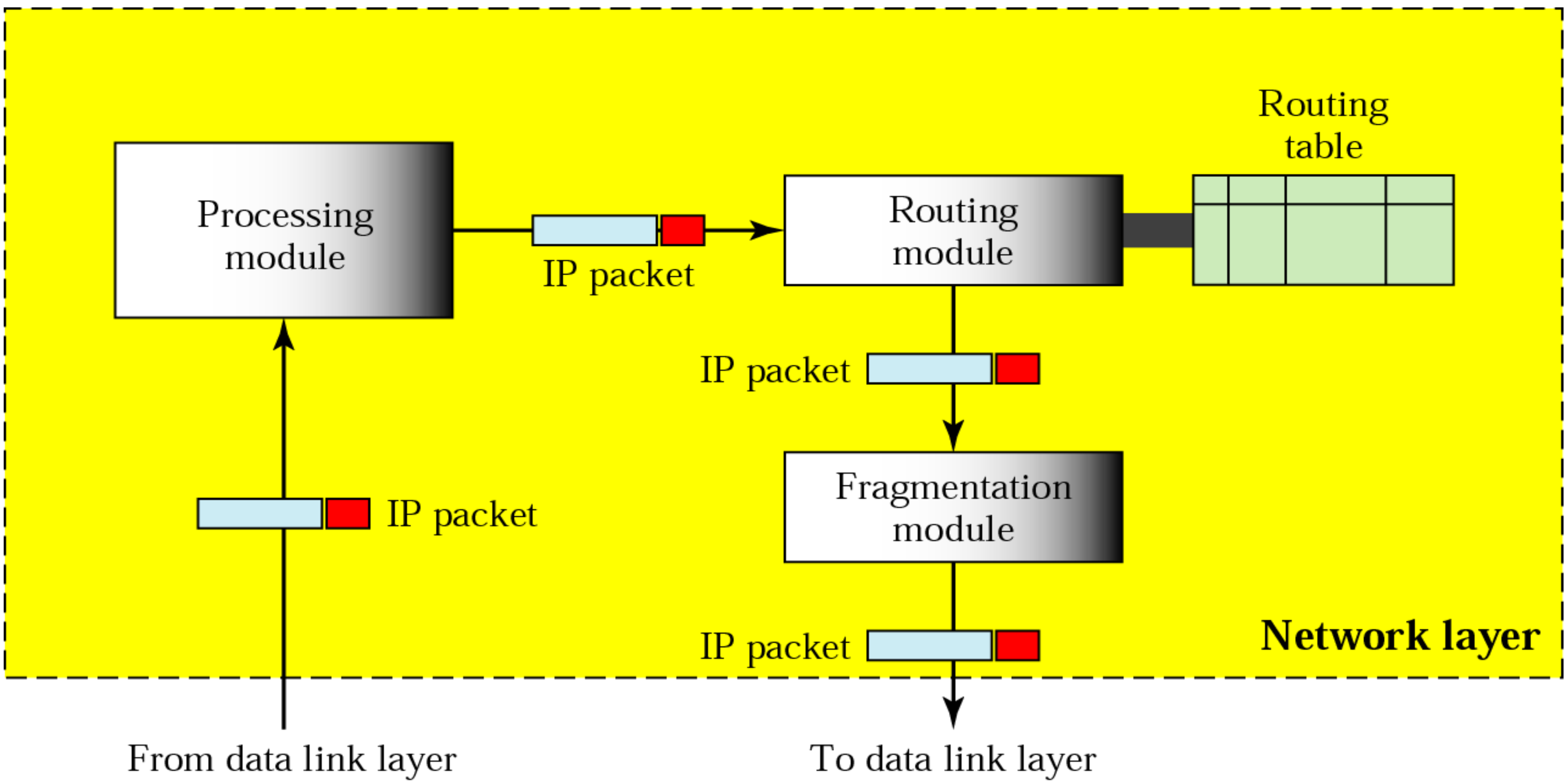
## Figure 19.3 Network layer in an internetwork



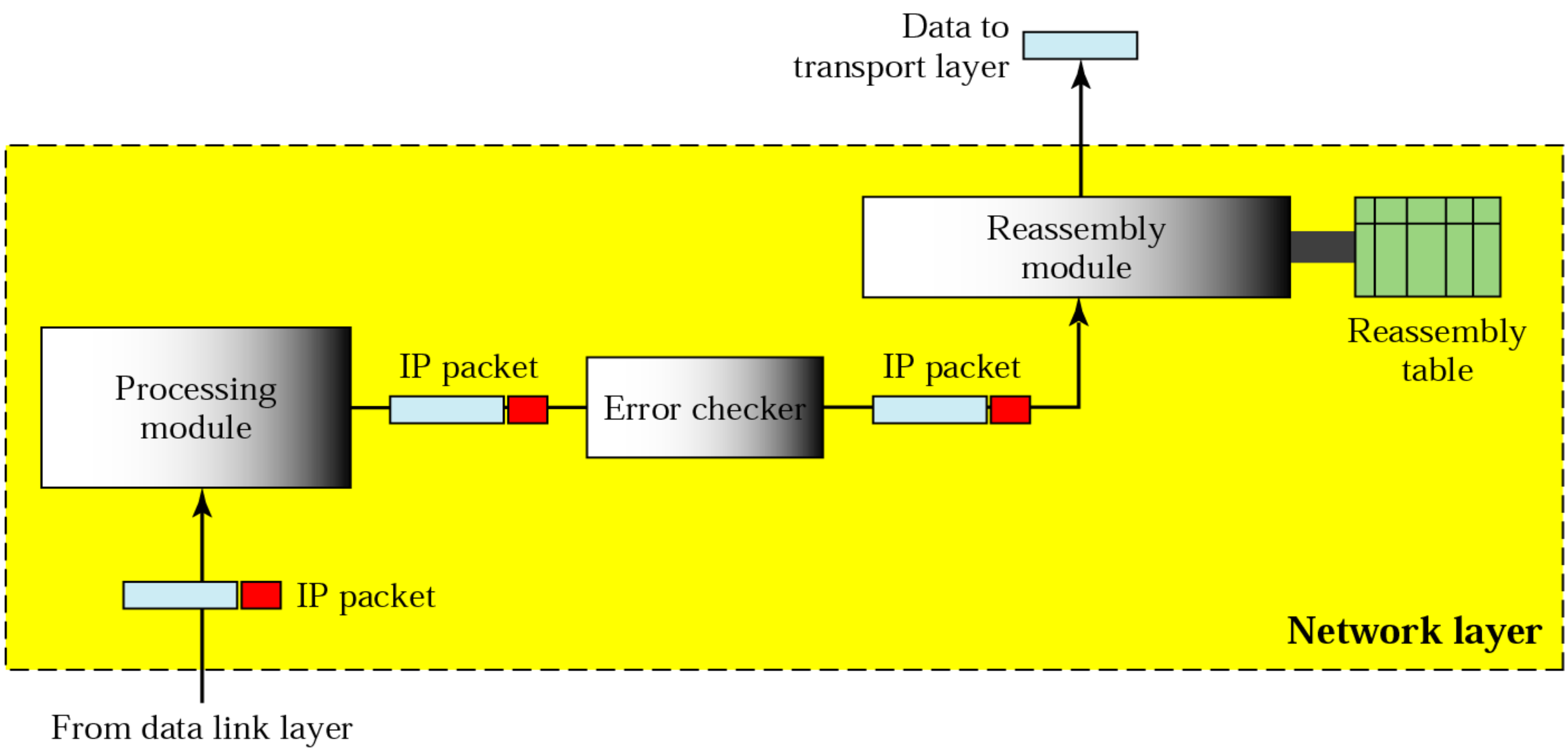
## Figure 19.4 Network layer at the source



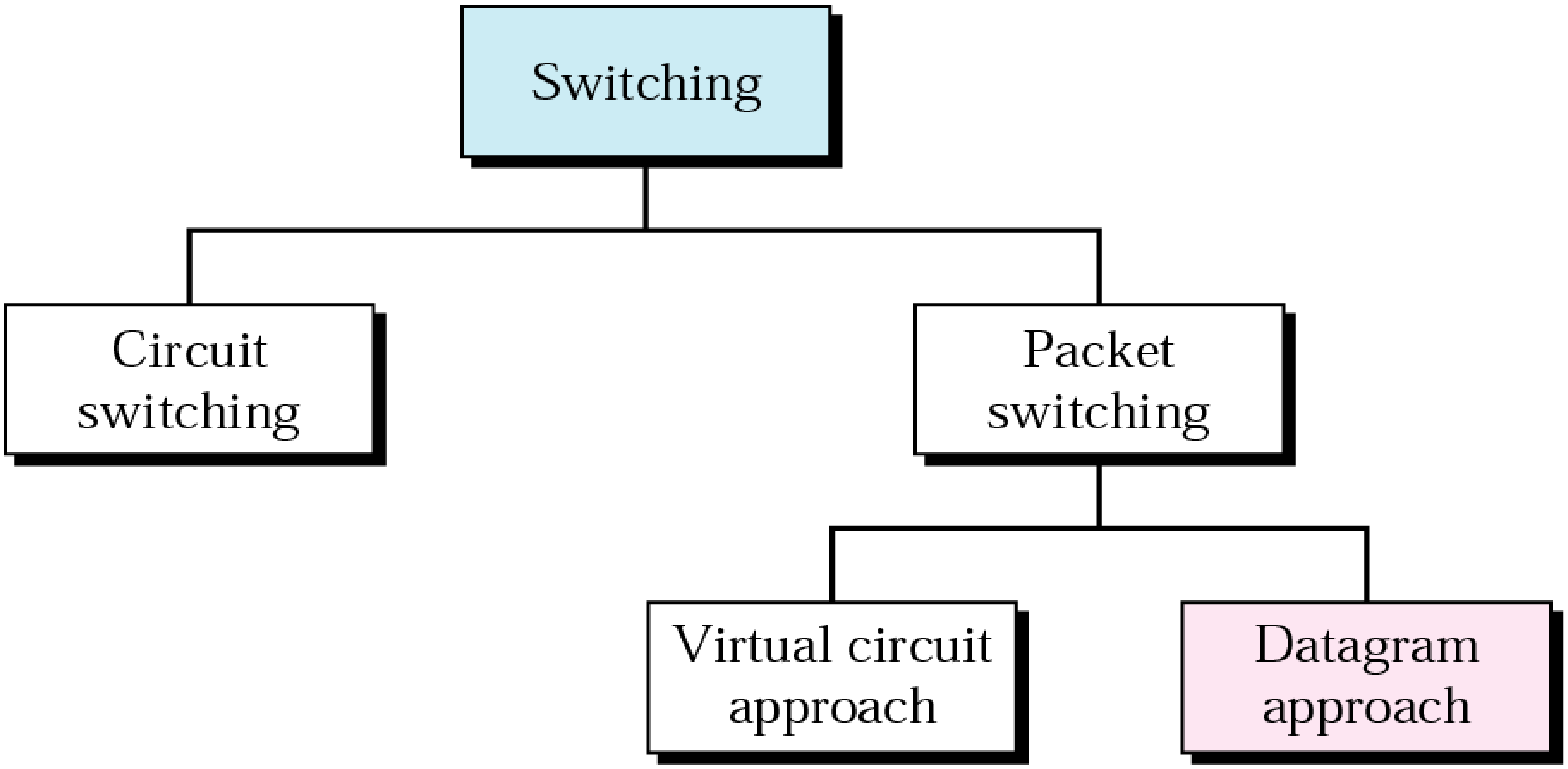
## Figure 19.5 Network layer at a router



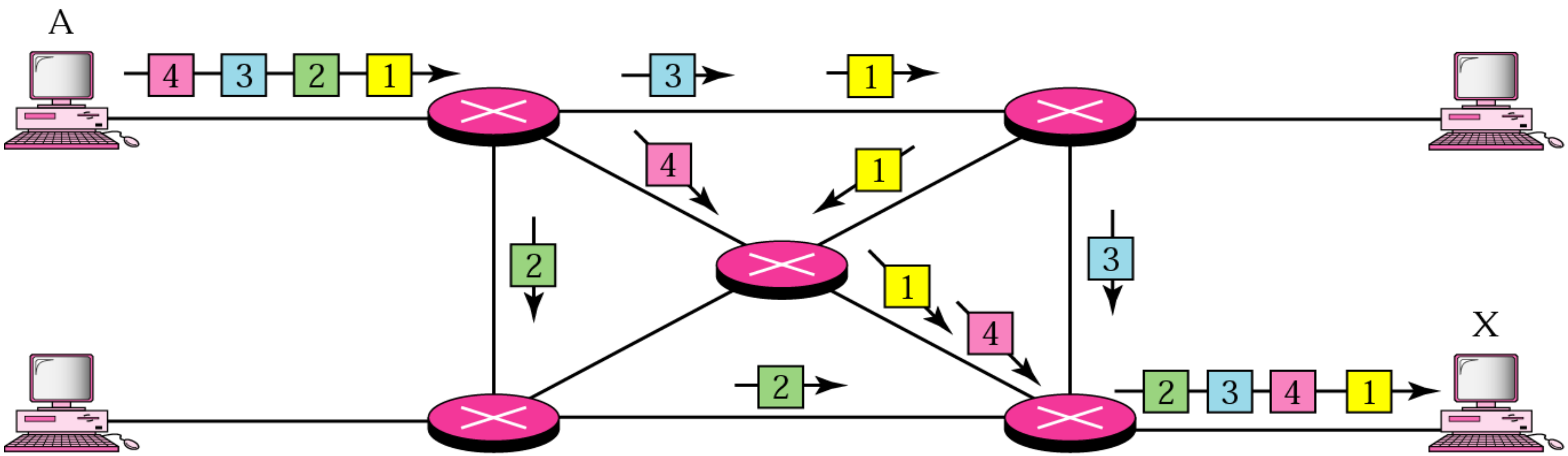
## Figure 19.6 Network layer at the destination



## Figure 19.7 Switching



# Figure 19.8 Datagram approach



**Note:**

***Switching at the network layer in the Internet is done using the datagram approach to packet switching.***

**Note:**

***Communication at the network layer in the Internet is connectionless.***

# 19.2 Addressing

***Internet Address***

***Classful Addressing***

***Subnetting***

***Supernetting***

***Classless Addressing***

***Dynamic Address Configuration***

***Network Address Translation***

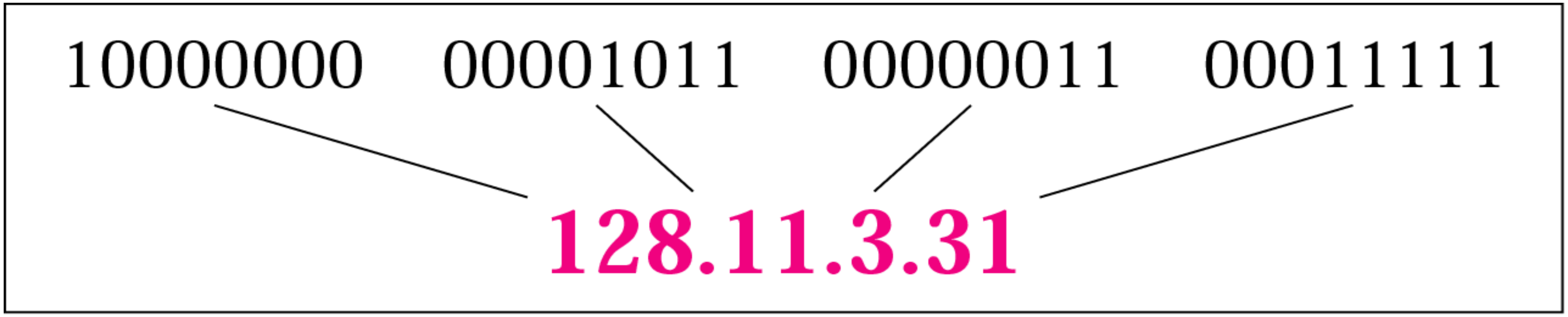
**Note:**

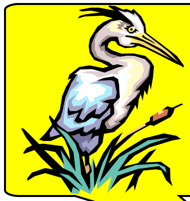
***An IP address is a 32-bit address.***

**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**

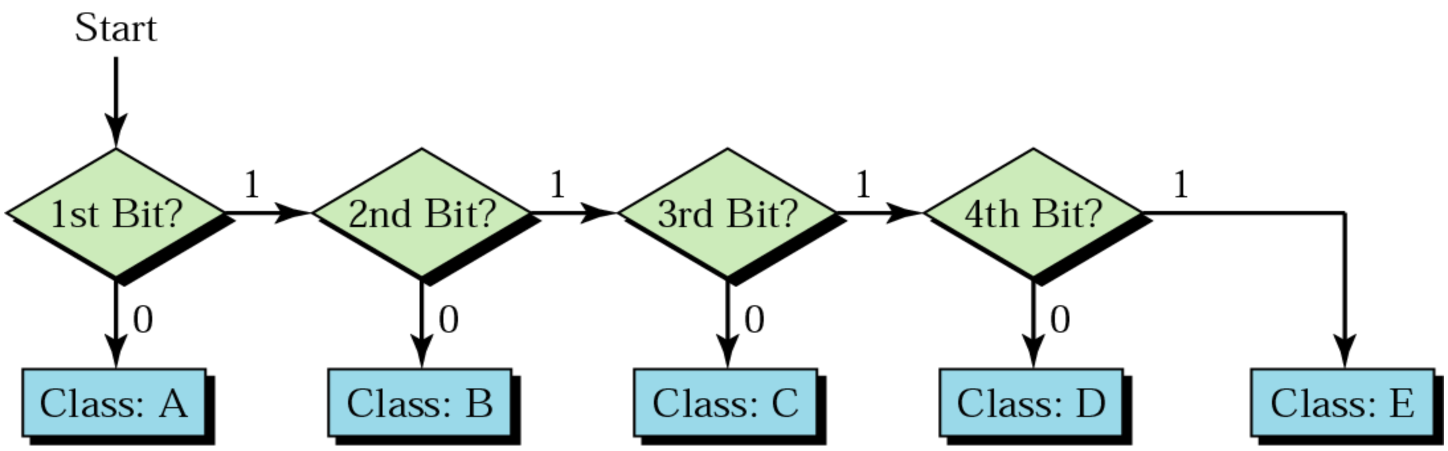
**Note:**

***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 notation

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

## 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.**

## Figure 19.12 Finding the class in decimal notation

| | 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** | | | |

## *Example 4*

Find the class of each address:

a. **227**.12.14.87

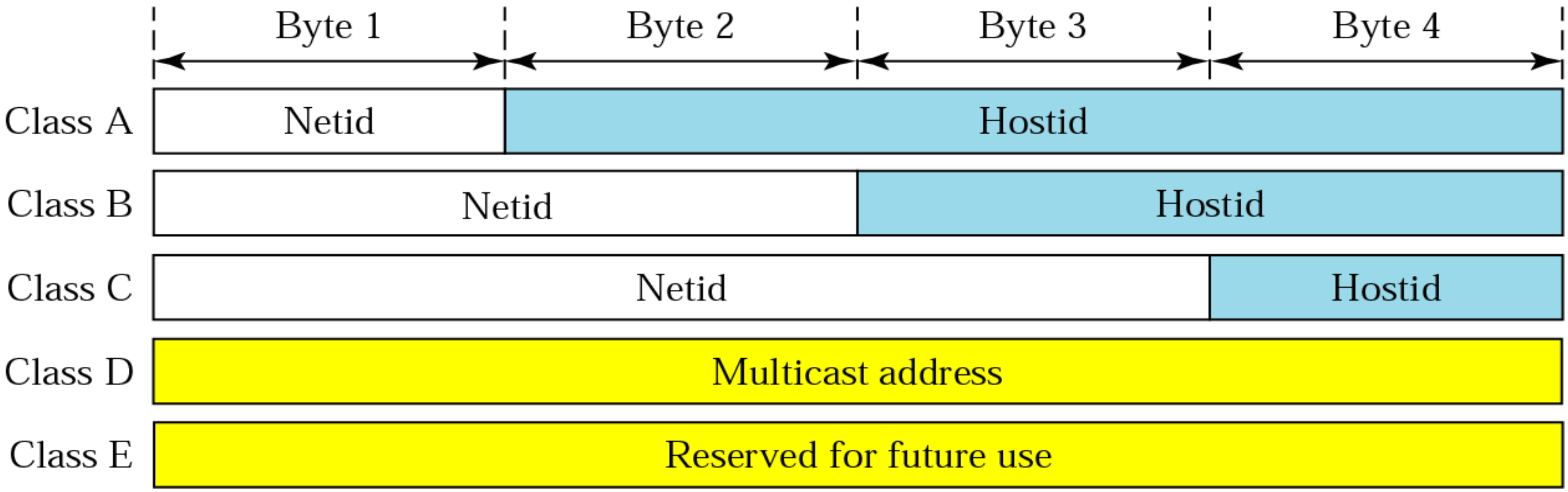
b. **252**.5.15.111

c. **134**.11.78.56

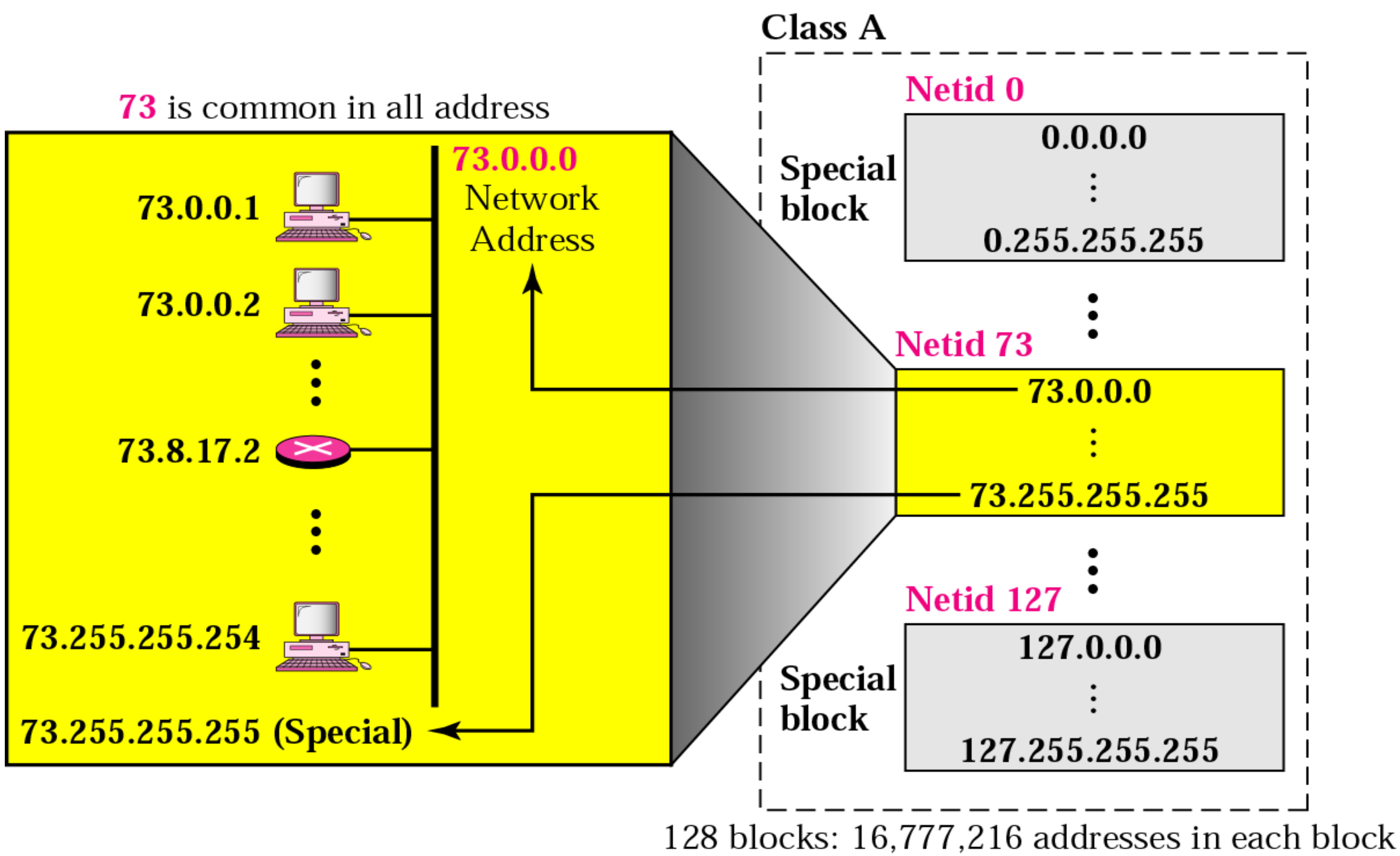
## *Solution*

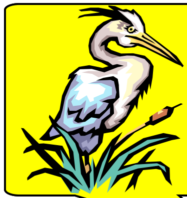
**a. The first byte is 227 (between 224 and 239); the class is D.**
**b. The first byte is 252 (between 240 and 255); the class is E.**
**c. The first byte is 134 (between 128 and 191); the class is B.**

# Figure 19.13 Netid and hostid



## Figure 19.14 Blocks in class A

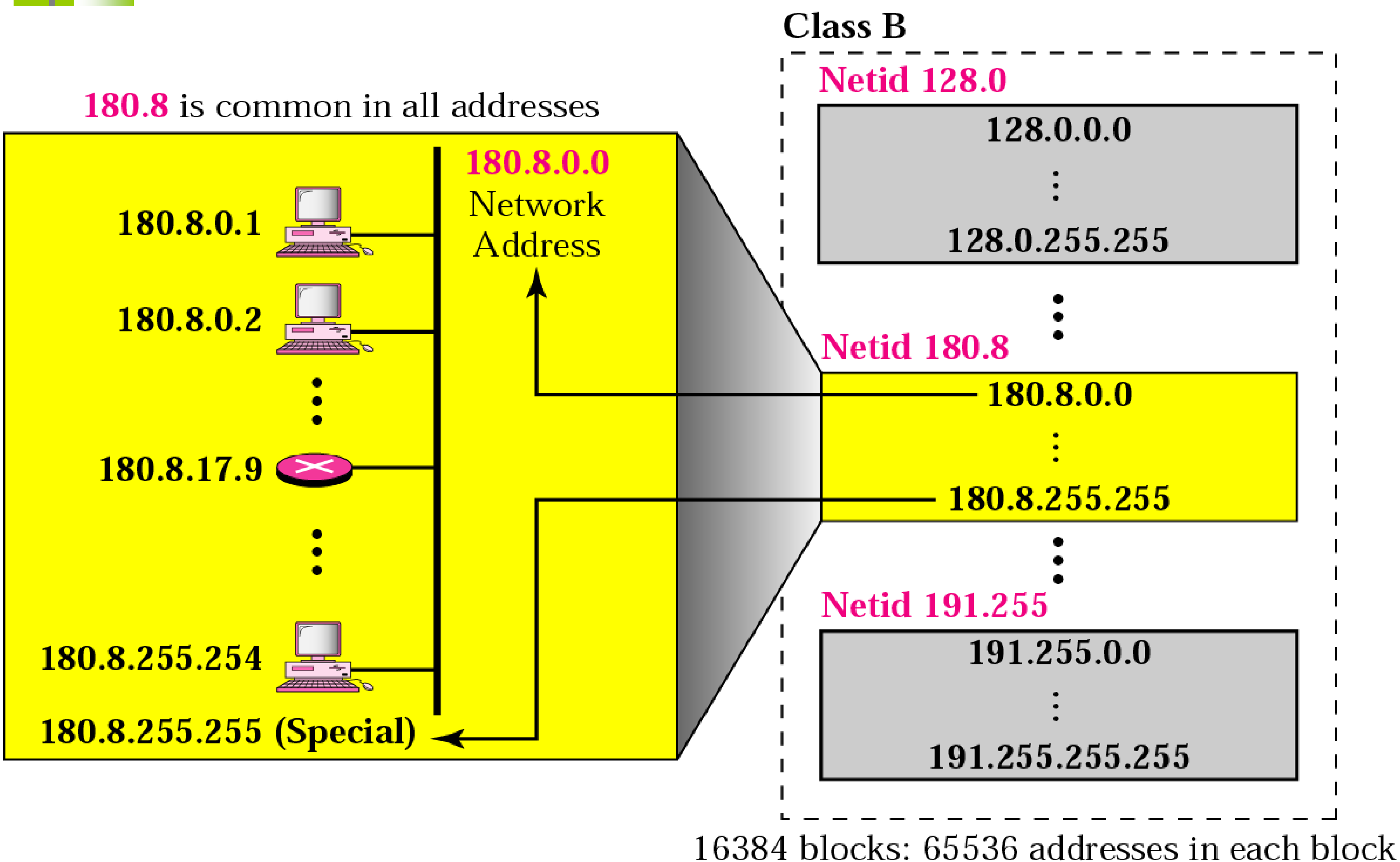


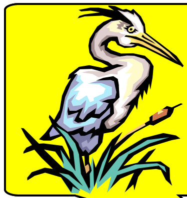


**Note:**

***Millions of class A addresses are wasted.***

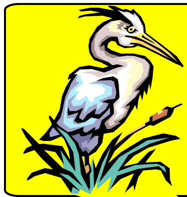
## Figure 19.15 Blocks in class B





**Note:**

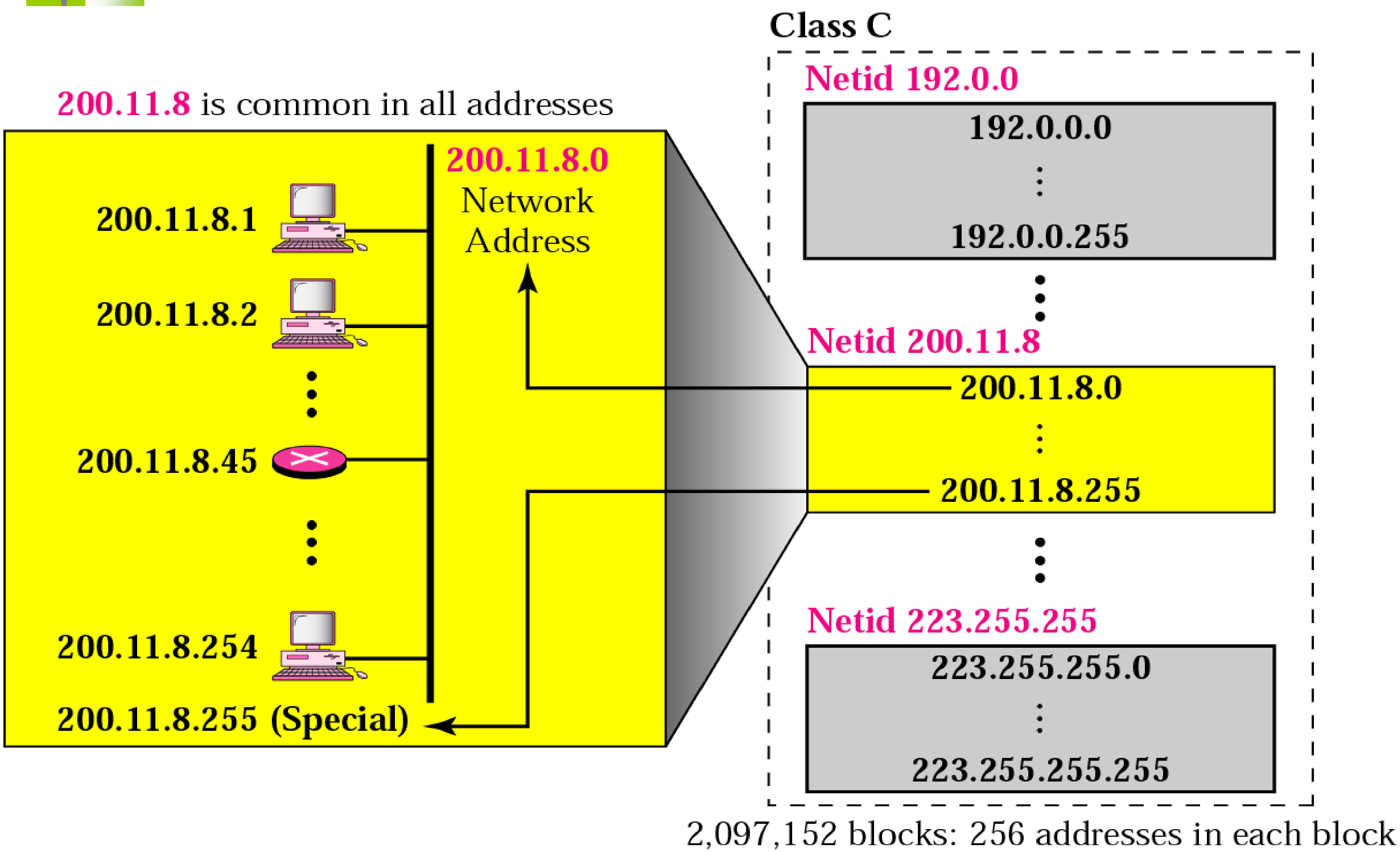
***Many class B addresses are wasted.***



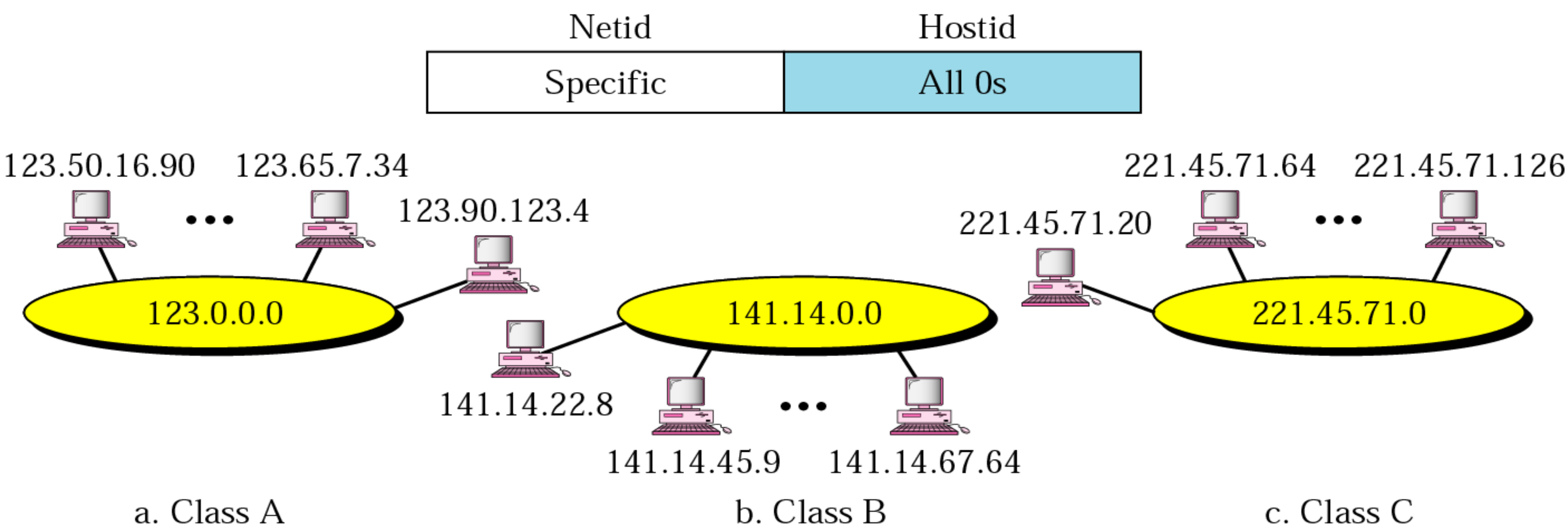
**Note:**

***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*

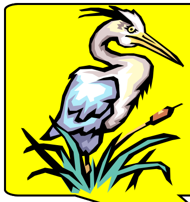
**The class is B. The first 2 bytes defines the netid. We can find the network address by replacing the hostid bytes (17.85) with 0s. Therefore, the network address is 132.6.0.0.**

## *Example 7*

Given the network address 17.0.0.0, find the class.

## *Solution*

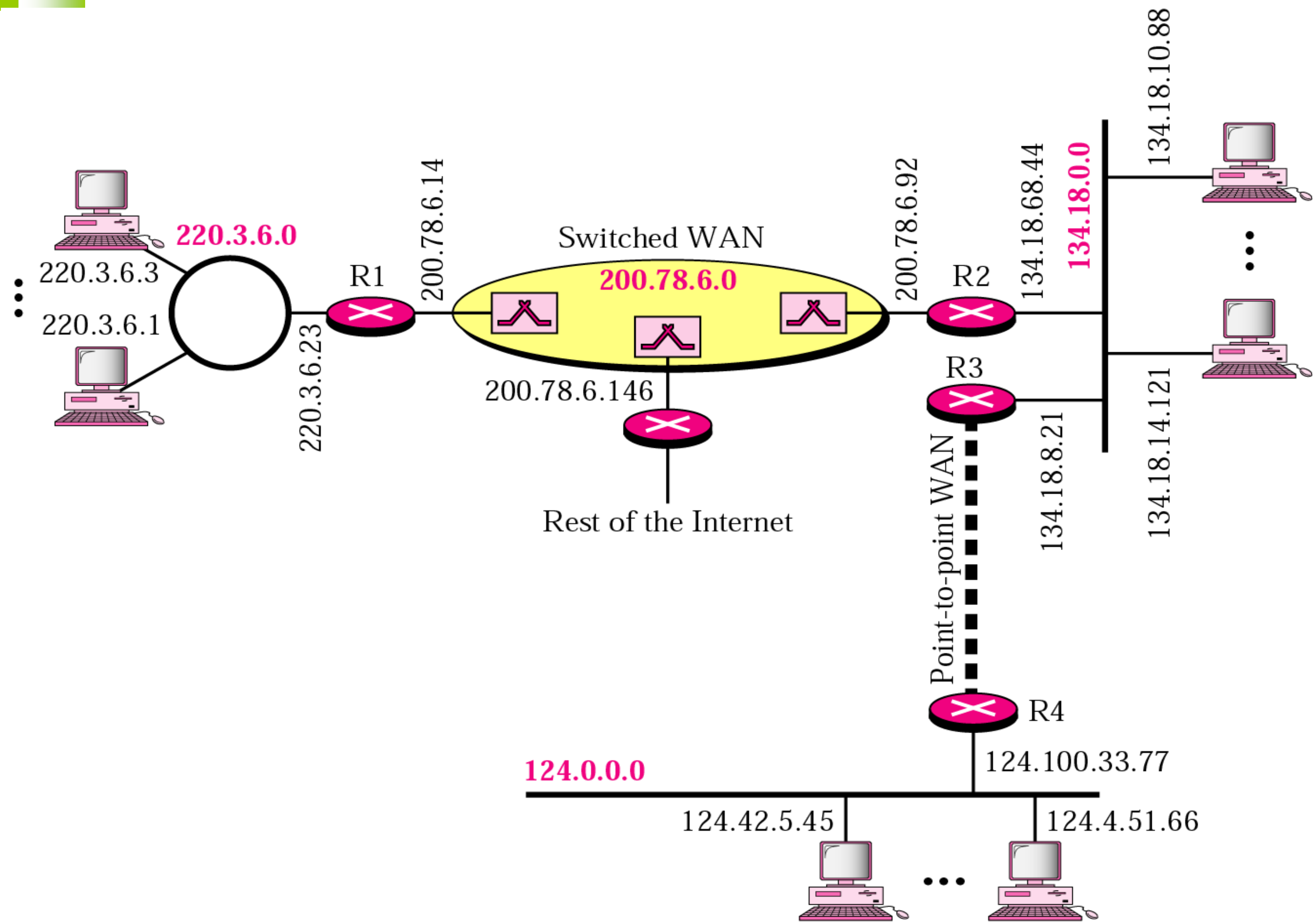
**The class is A because the netid is only 1 byte.**

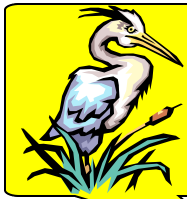


**Note:**

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

# Figure 19.18 Sample internet

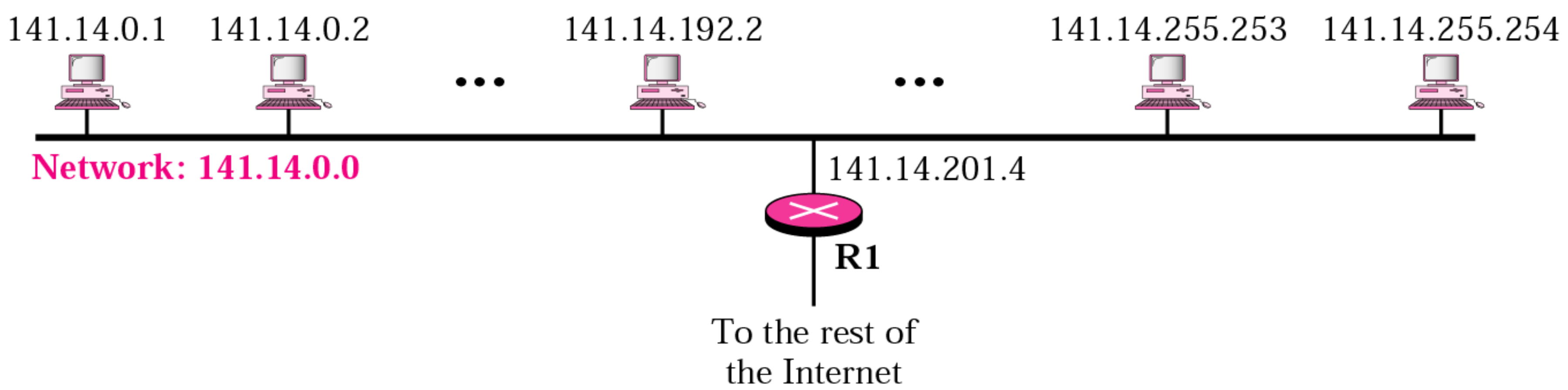




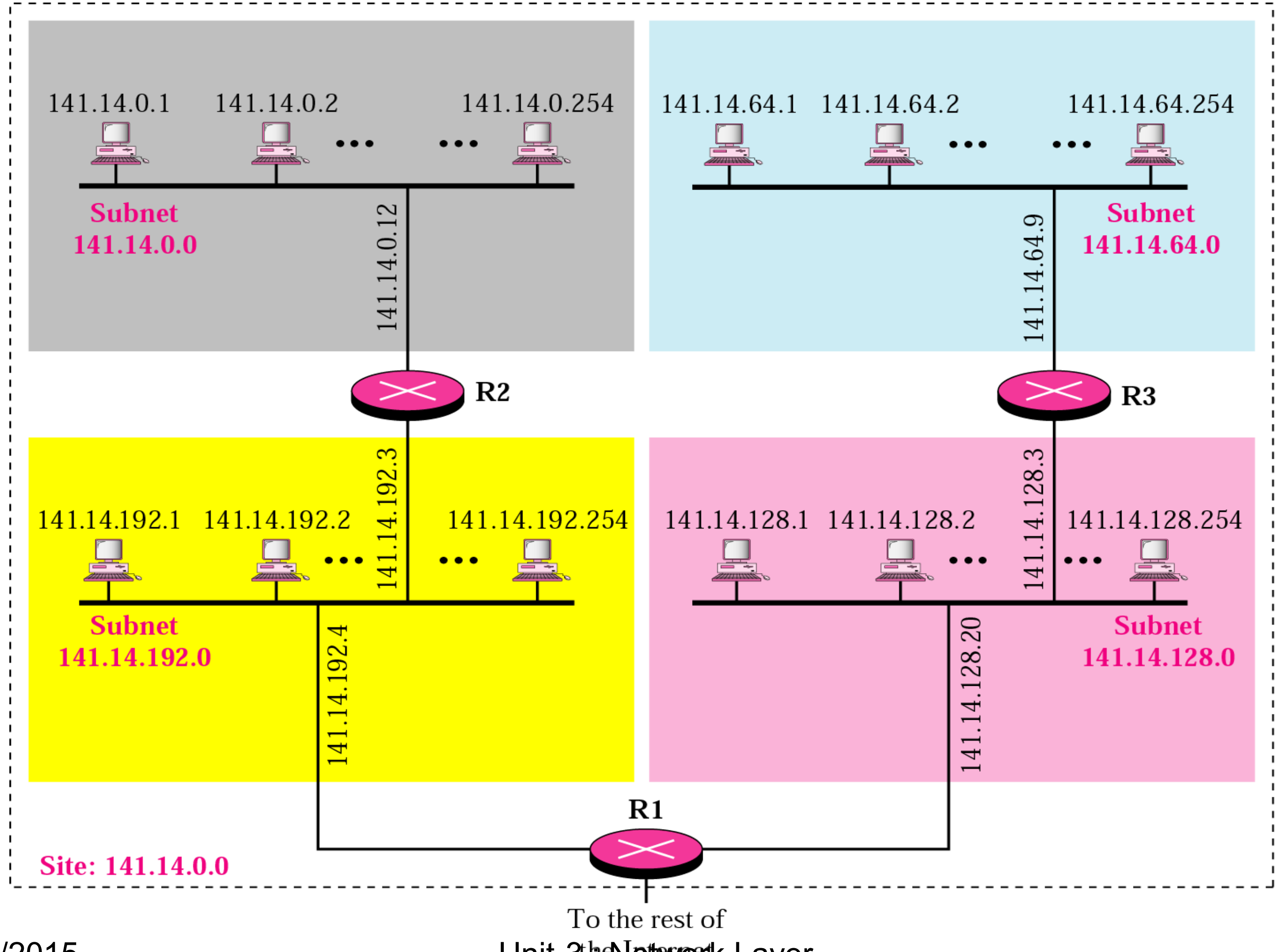
**Note:**

***IP addresses are designed with two levels of hierarchy.***

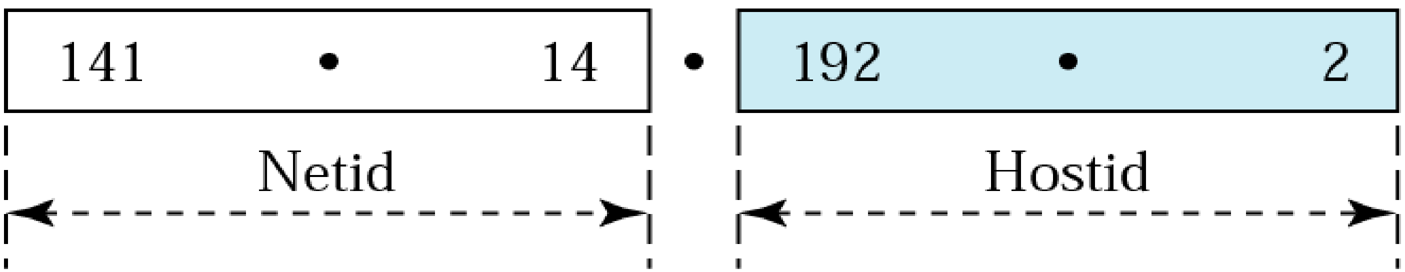
## Figure 19.19 A network with two levels of hierarchy



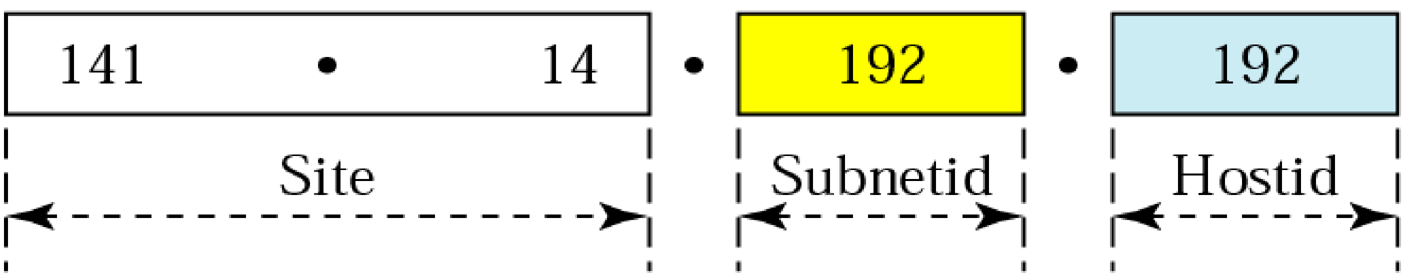
# Figure 19.20 A network with three levels of hierarchy (subnetted)



## Figure 19.21 Addresses in a network with and without subnetting




a. Without subnetting

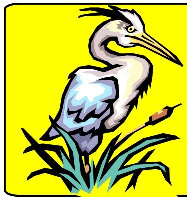



b. With subnetting

## Figure 19.22 Hierarchy concept in a telephone number

## *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 |



**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*

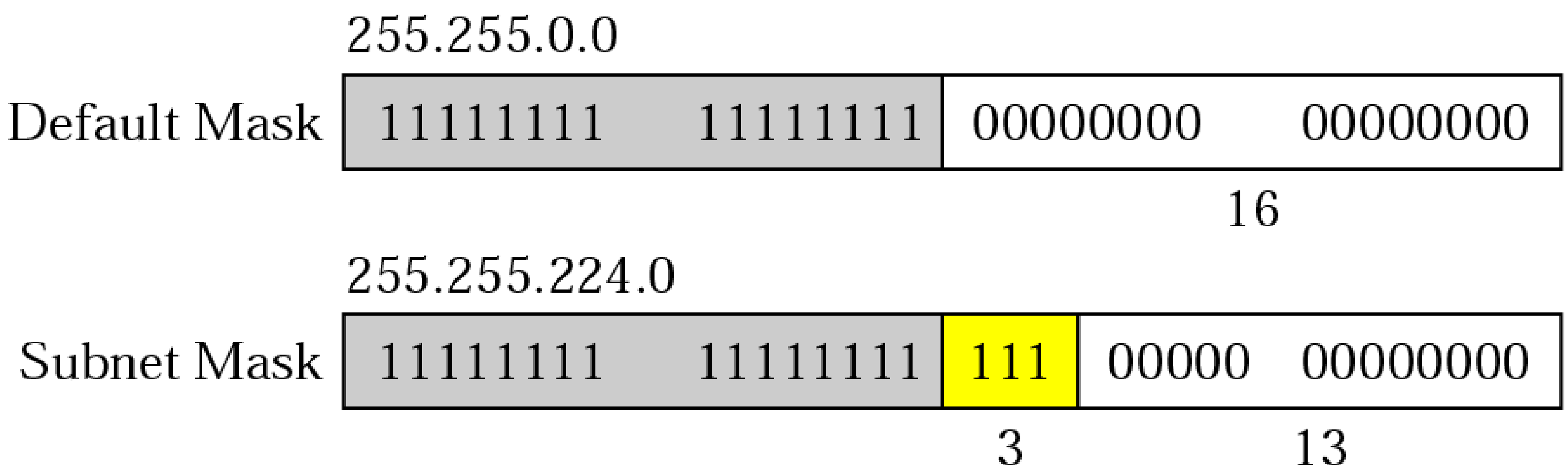
A router outside the organization receives a packet with destination address 190.240.7.91. Show how it finds the network address to route the packet.

## *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*

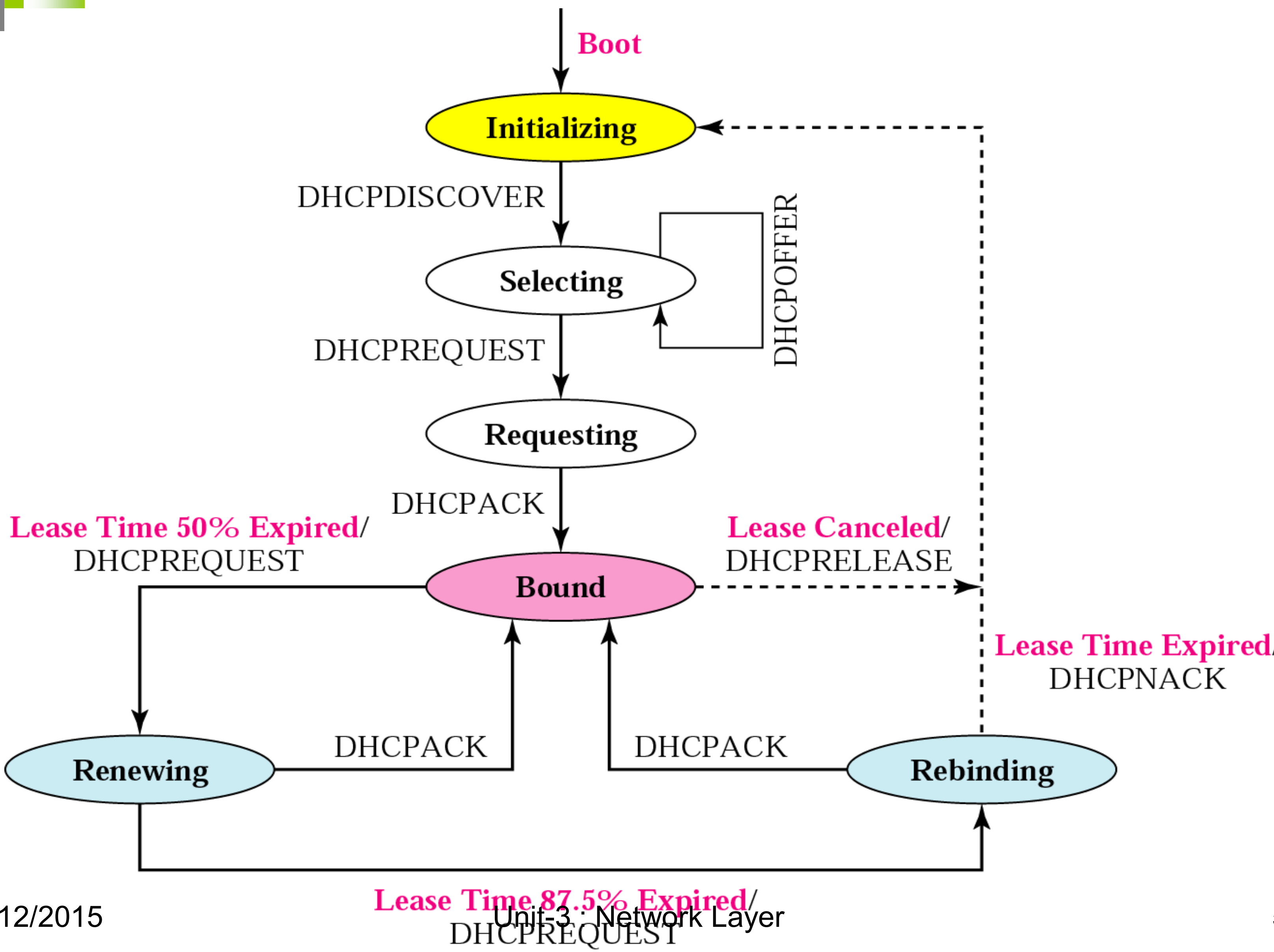
A router inside the organization receives the same packet with destination address 190.240.33.91. Show how it finds the subnetwork address to route the packet.

## *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.**

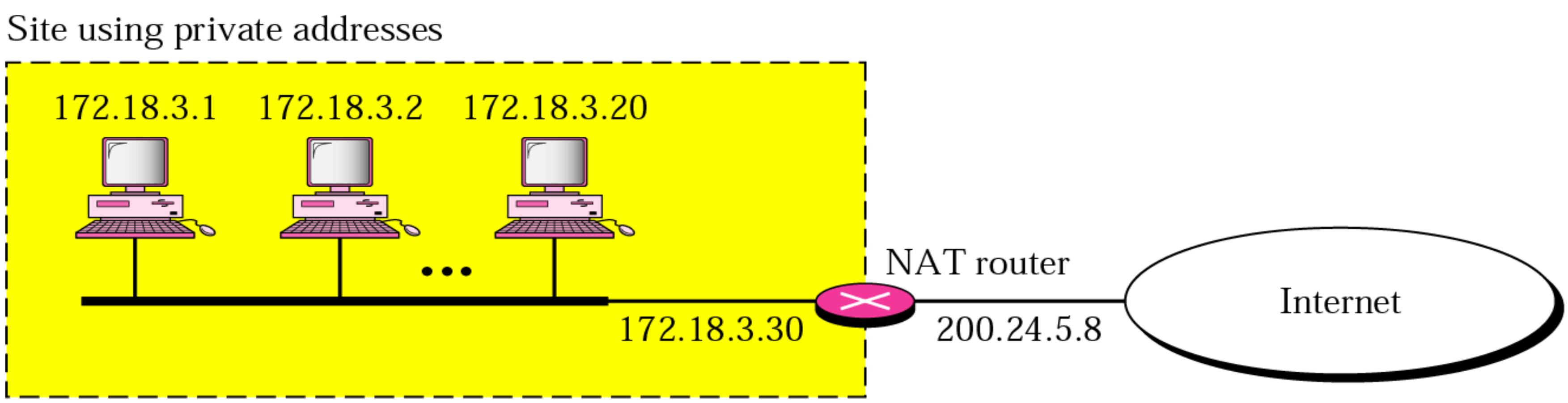
## Figure 19.24 DHCP transition diagram



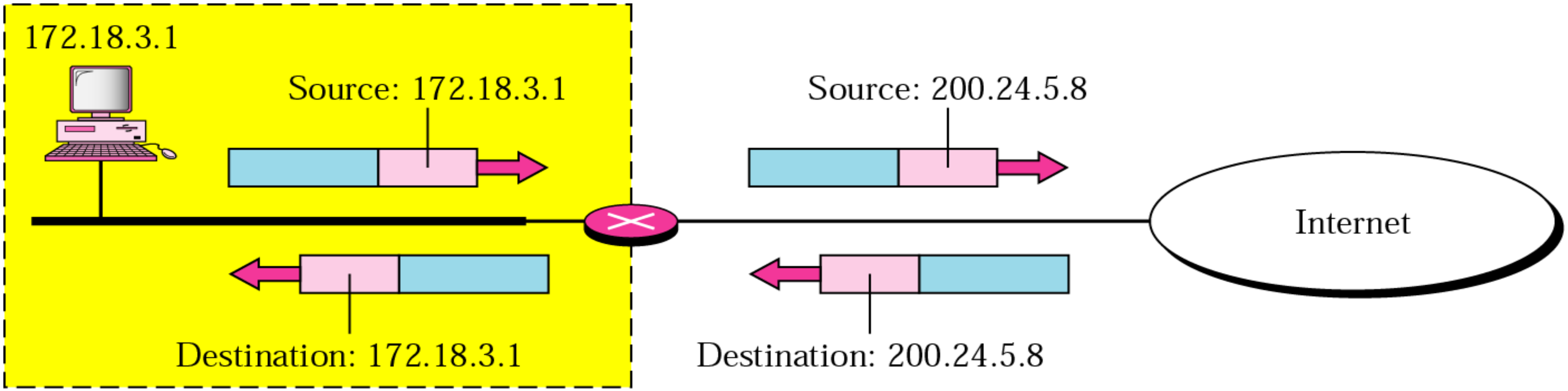
## *Table 19.2 Default masks*

| 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 | $2^{16}$ |

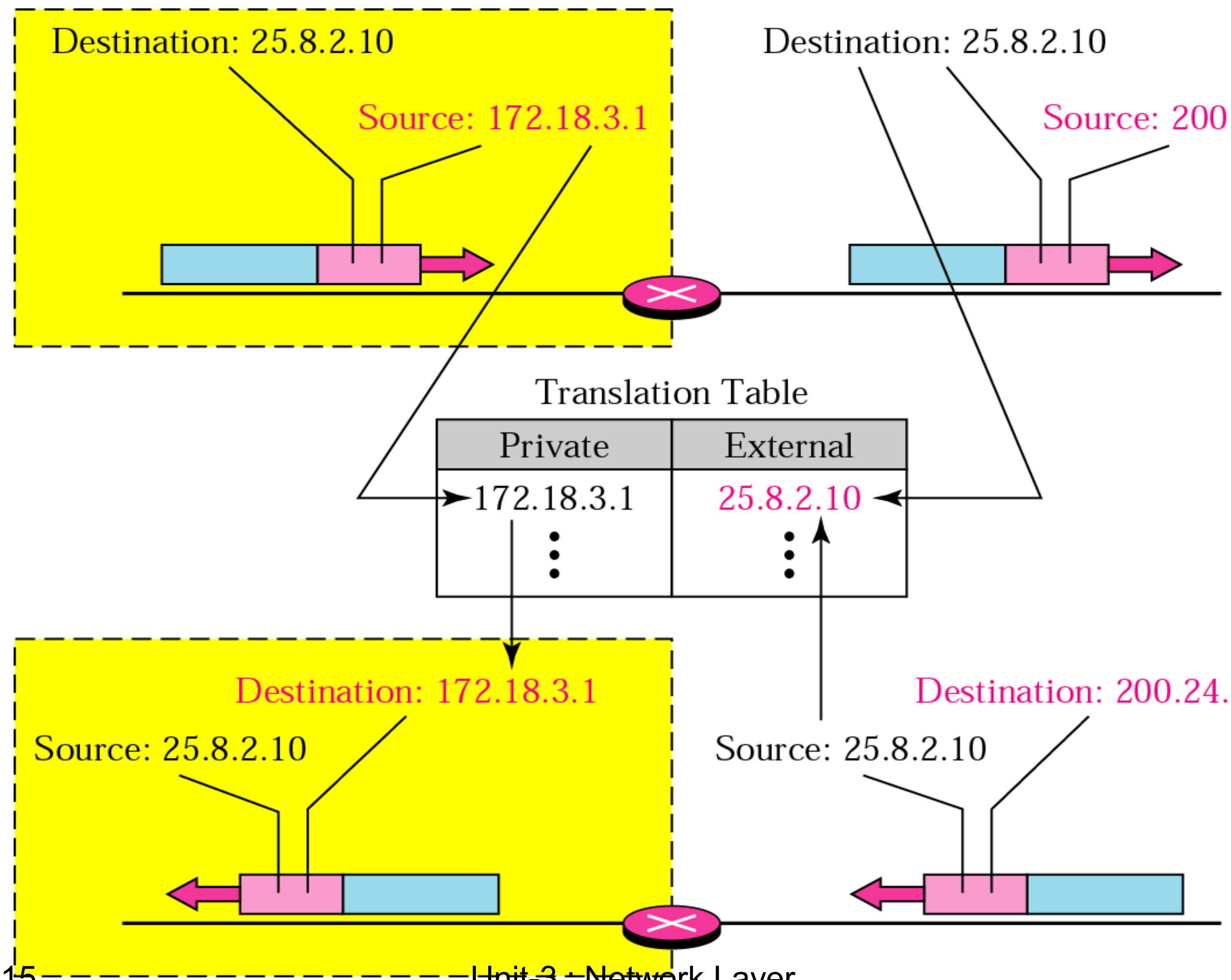
# Figure 19.25 NAT



## 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 |

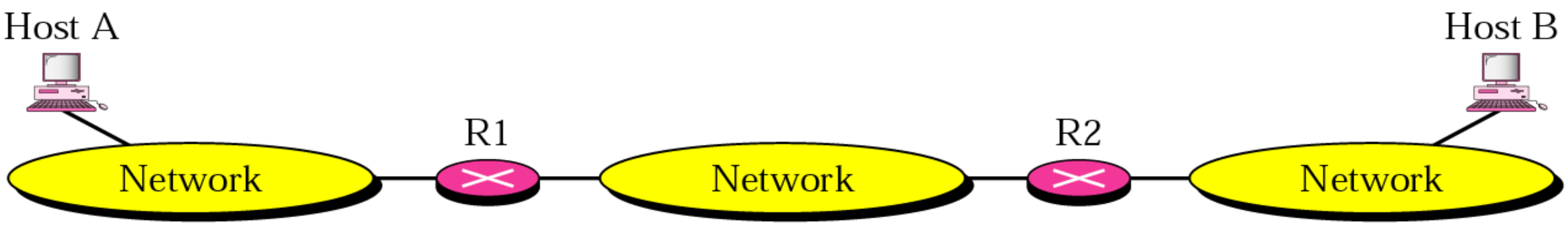
Routing table for R1

| 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

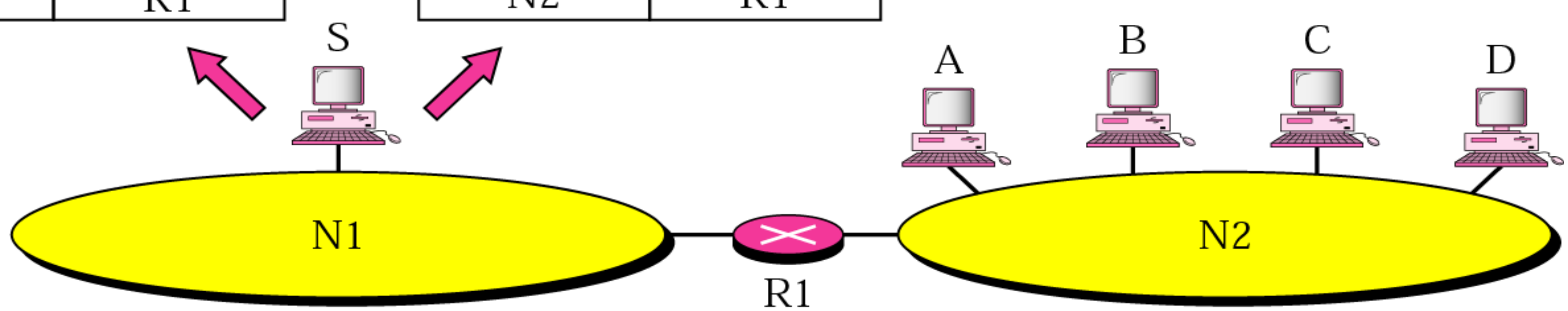
# Figure 19.29 Network-specific routing

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

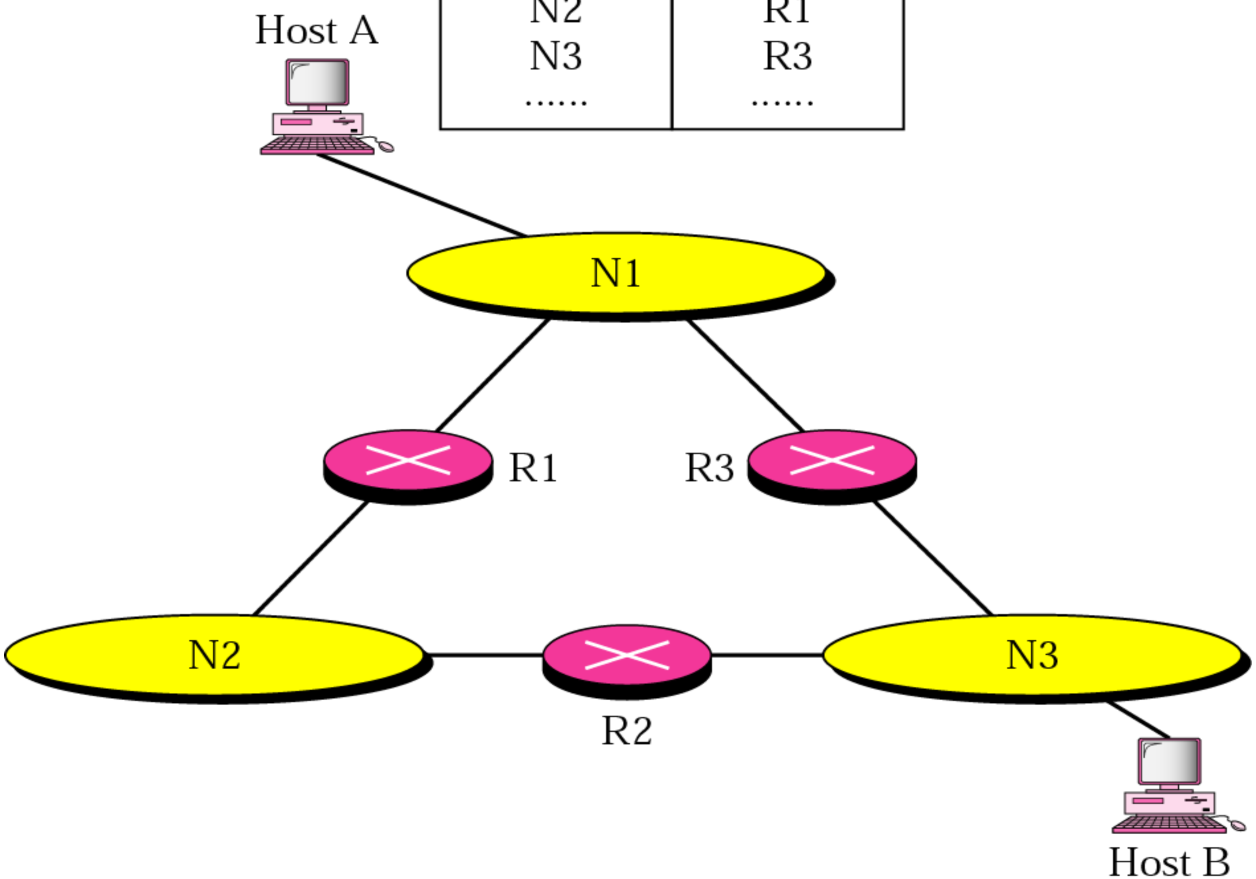
| Destination | Next Hop |
|---|---|
| N2 | R1 |



# Figure 19.30 Host-specific routing

Routing table for host A

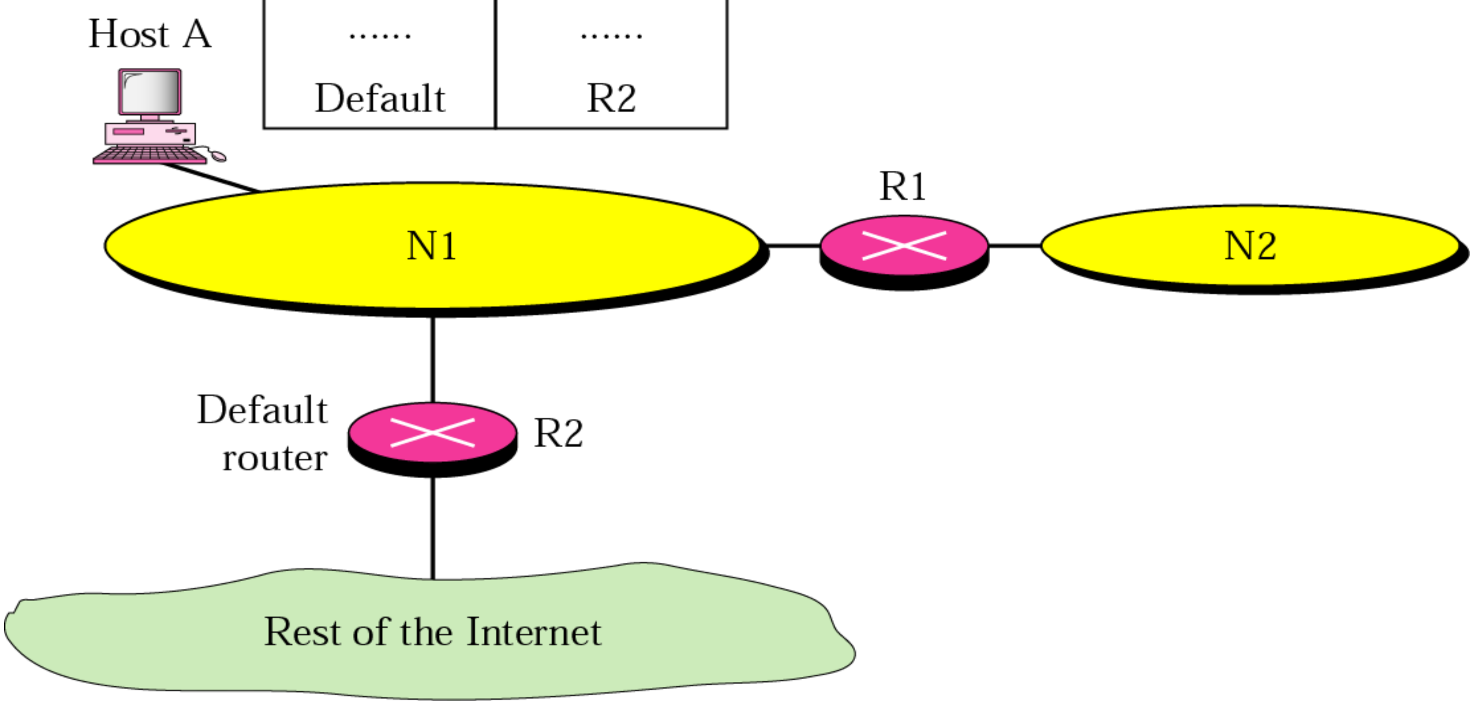
| Destination | Next Hop |
|---|---|
| Host B | R3 |
| N2 | R1 |
| N3 | R3 |
| …… | …… |



# 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 |

## *Example 10*

Using the table in Figure 19.32, the router receives a packet for destination 192.16.7.1. For each row, the mask is applied to the destination address until a match with the destination address is found. In this example, the router sends the packet through interface m0 (host specific).

# *Example 11*

Using the table in Figure 19.32, the router receives a packet for destination 193.14.5.22. For each row, the mask is applied to the destination address until a match with the next-hop address is found. In this example, the router sends the packet through interface m2 (network specific).

# *Example 12*

Using the table in Figure 19.32, the router receives a packet for destination 200.34.12.34. For each row, the mask is applied to the destination address, but no match is found. In this example, the router sends the packet through the default interface m0.

# Routing Algorithms

1. Distance Vector Routing
2. Link State Routing

Figure 21-18

# The Concept of Distance Vector Routing

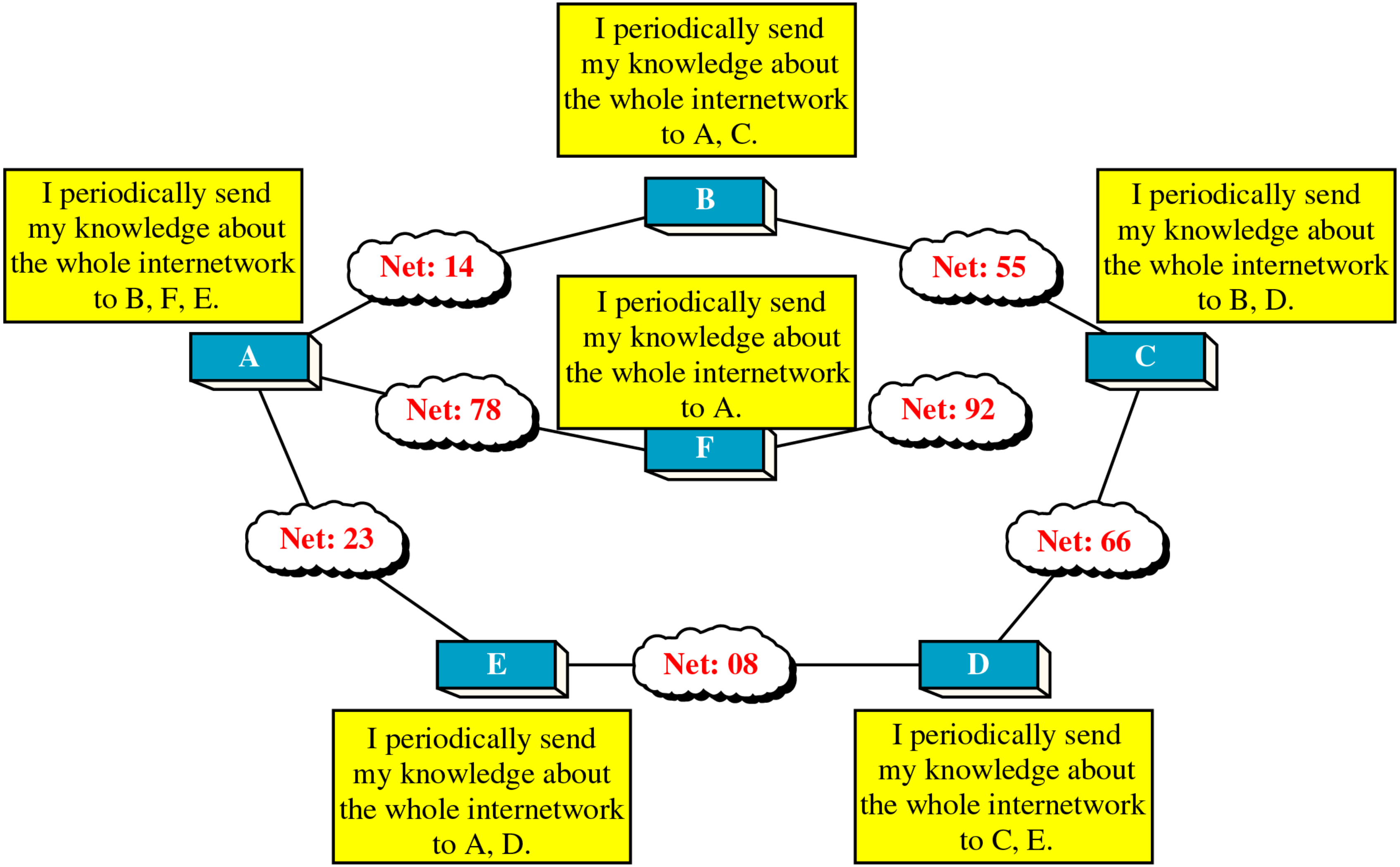


**Figure 21-19**

# Distance Vector Routing Table

| Network ID | Cost | Next Hop |
| --- | --- | --- |
| . . . . . . . . . . | . . . . . . . | . . . . . . . . . . . |
| . . . . . . . . . . | . . . . . . . | . . . . . . . . . . . |
| . . . . . . . . . . | . . . . . . . | . . . . . . . . . . . |
| . . . . . . . . . . | . . . . . . . | . . . . . . . . . . . |
| . . . . . . . . . . | . . . . . . . | . . . . . . . . . . . |

Figure 21-20

# Routing Table Distribution

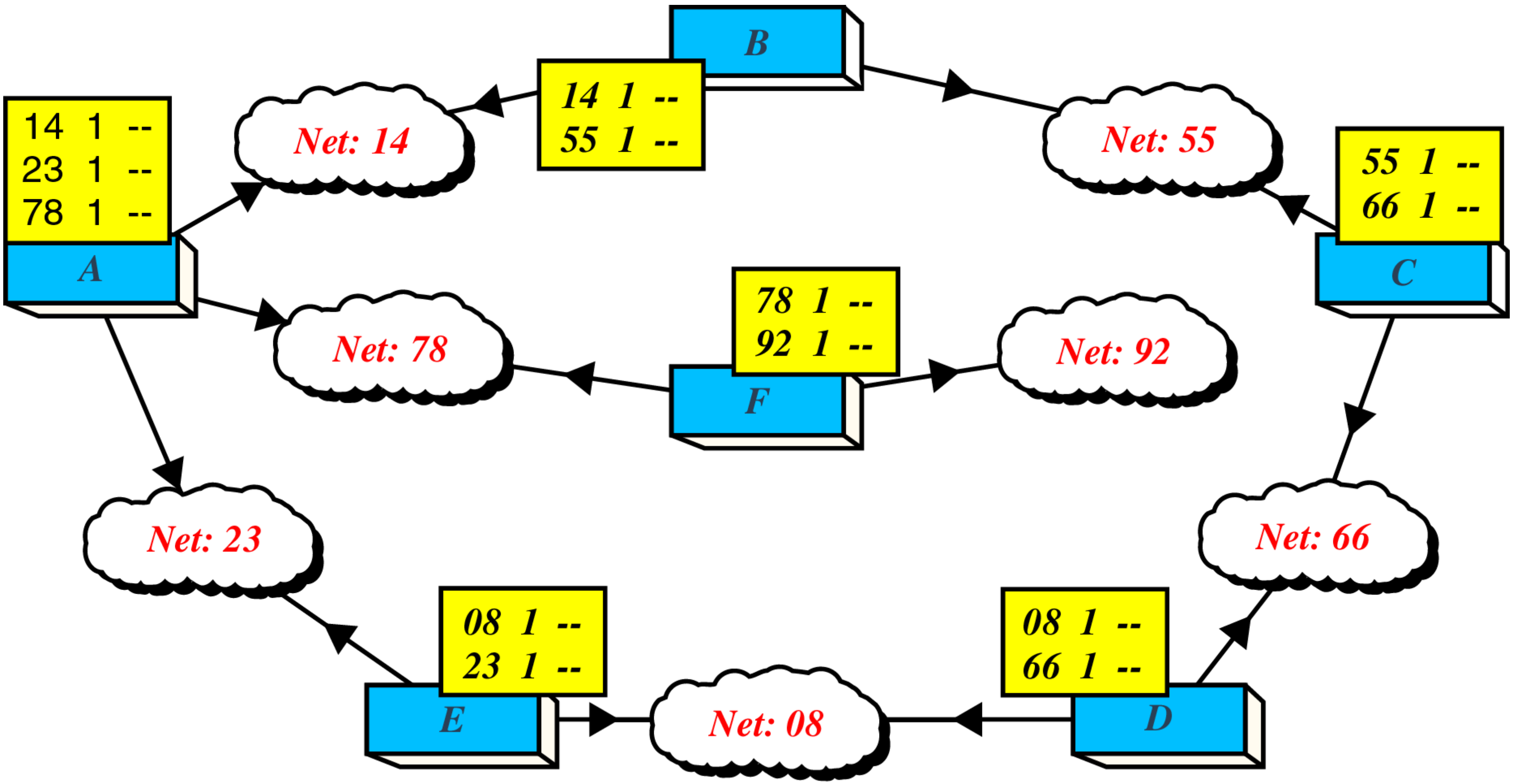


Figure 21-21

# Updating Routing Table for Router A

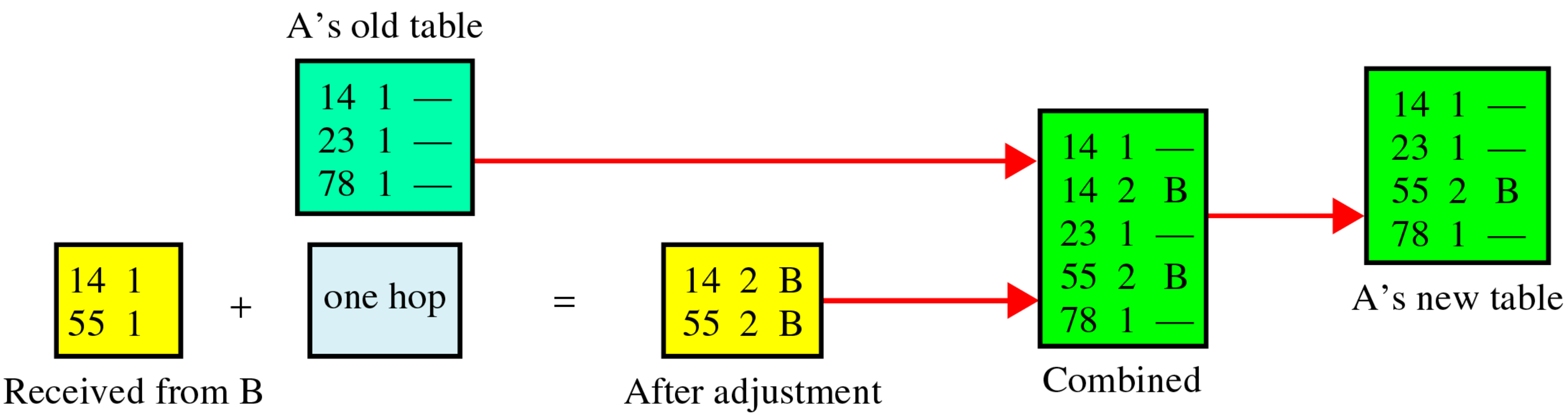


Figure 21-22

# Final Routing Tables

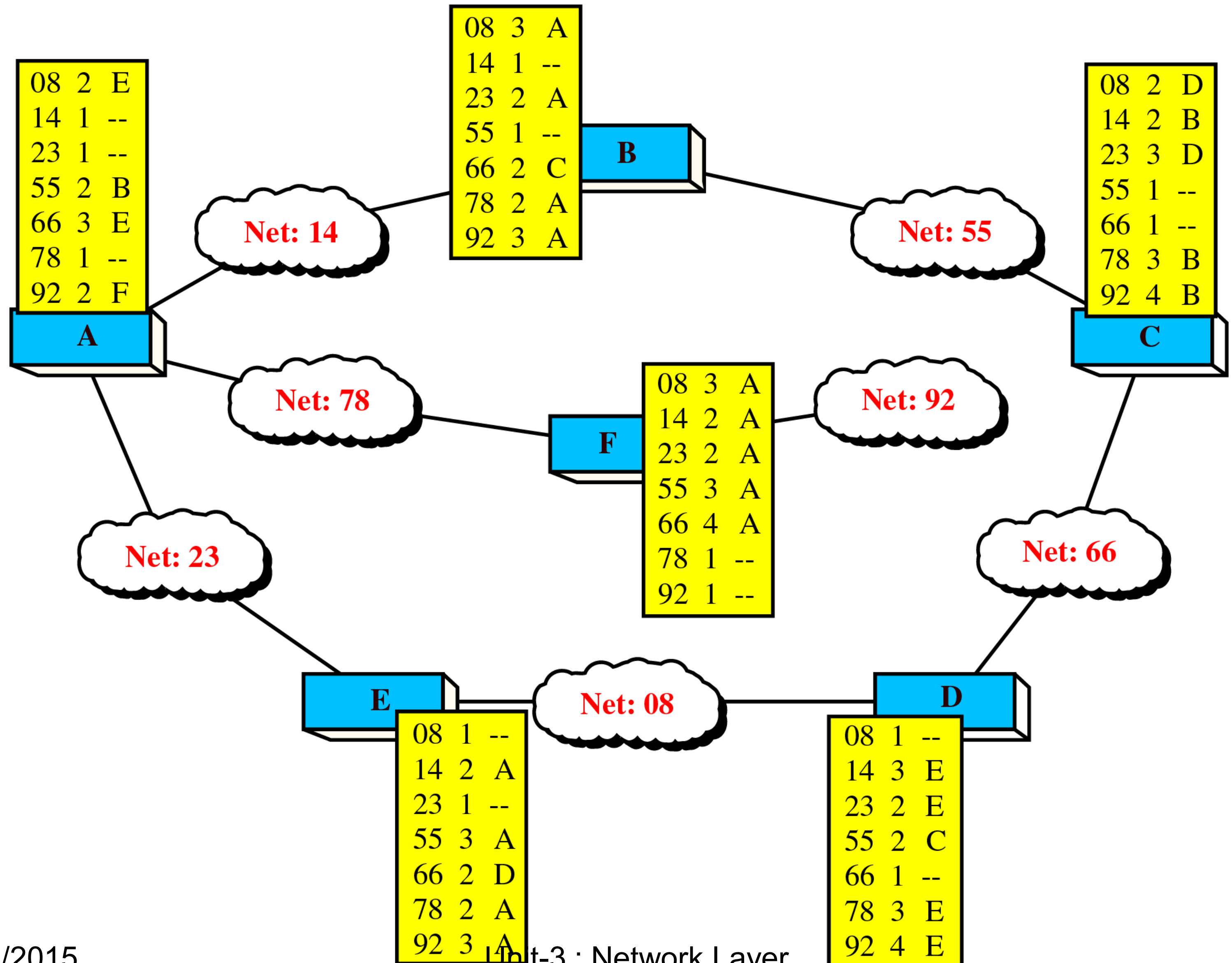
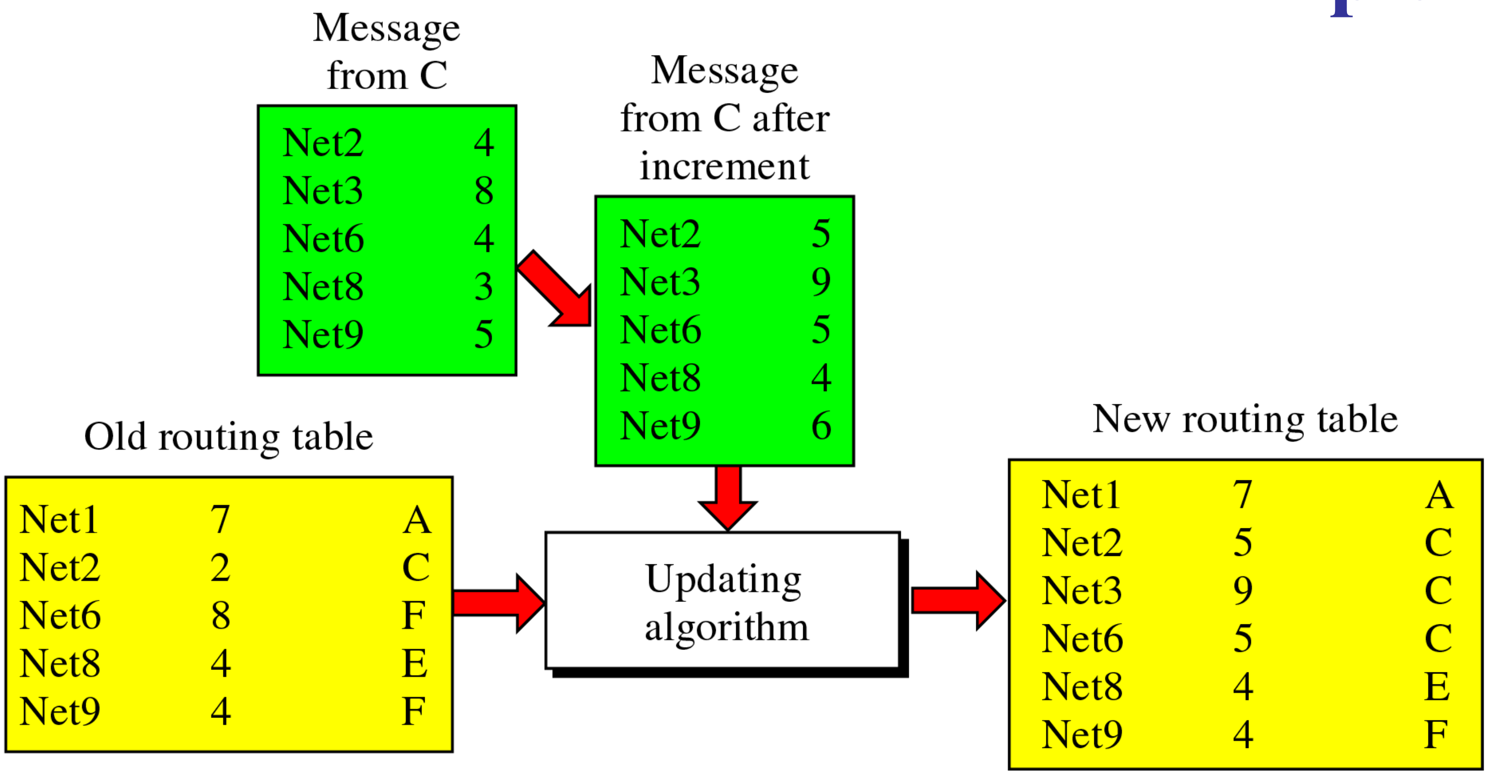


**Figure 21-23**

# Example 21.1




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

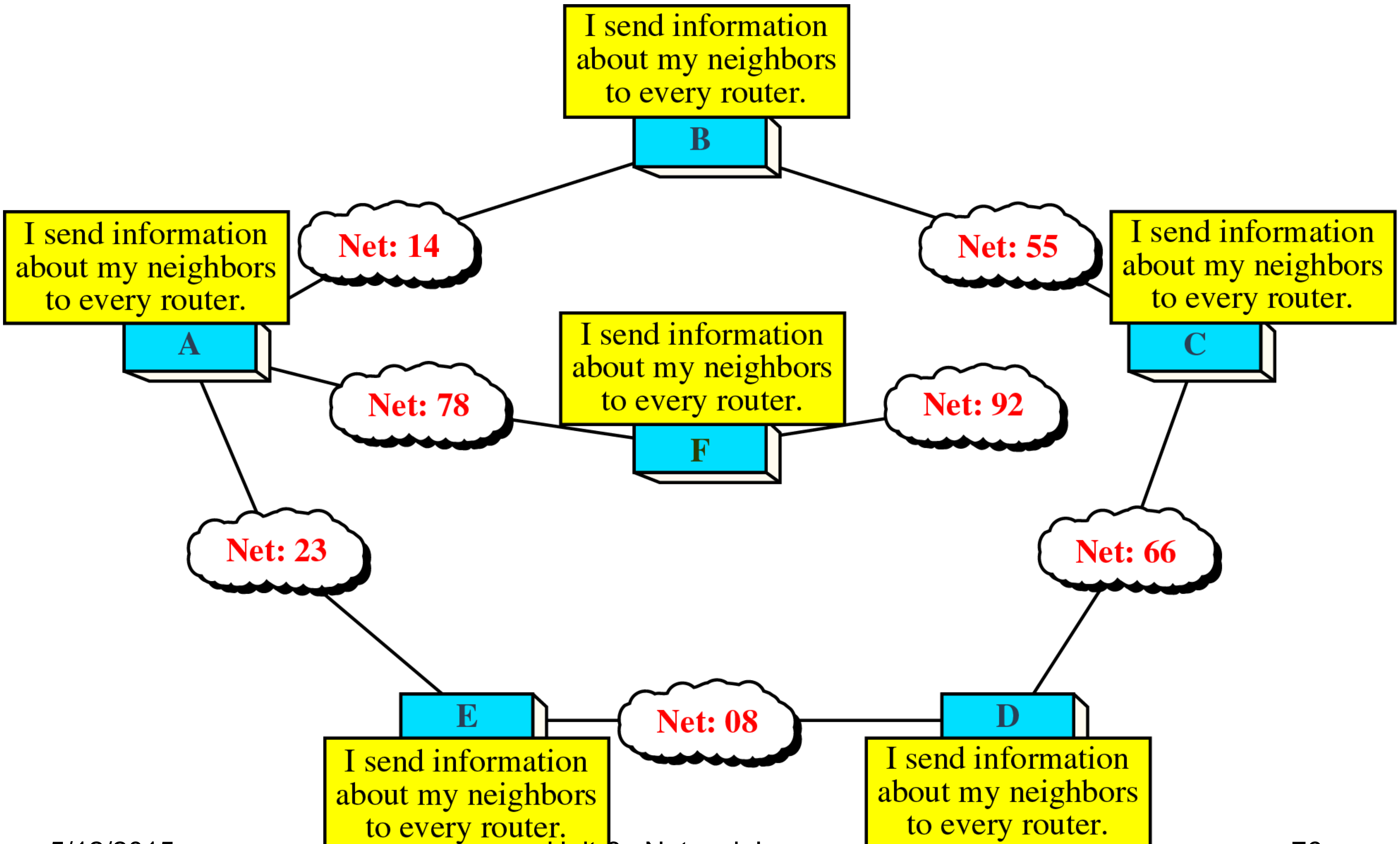


Figure 21-25

# Cost in Link State Routing

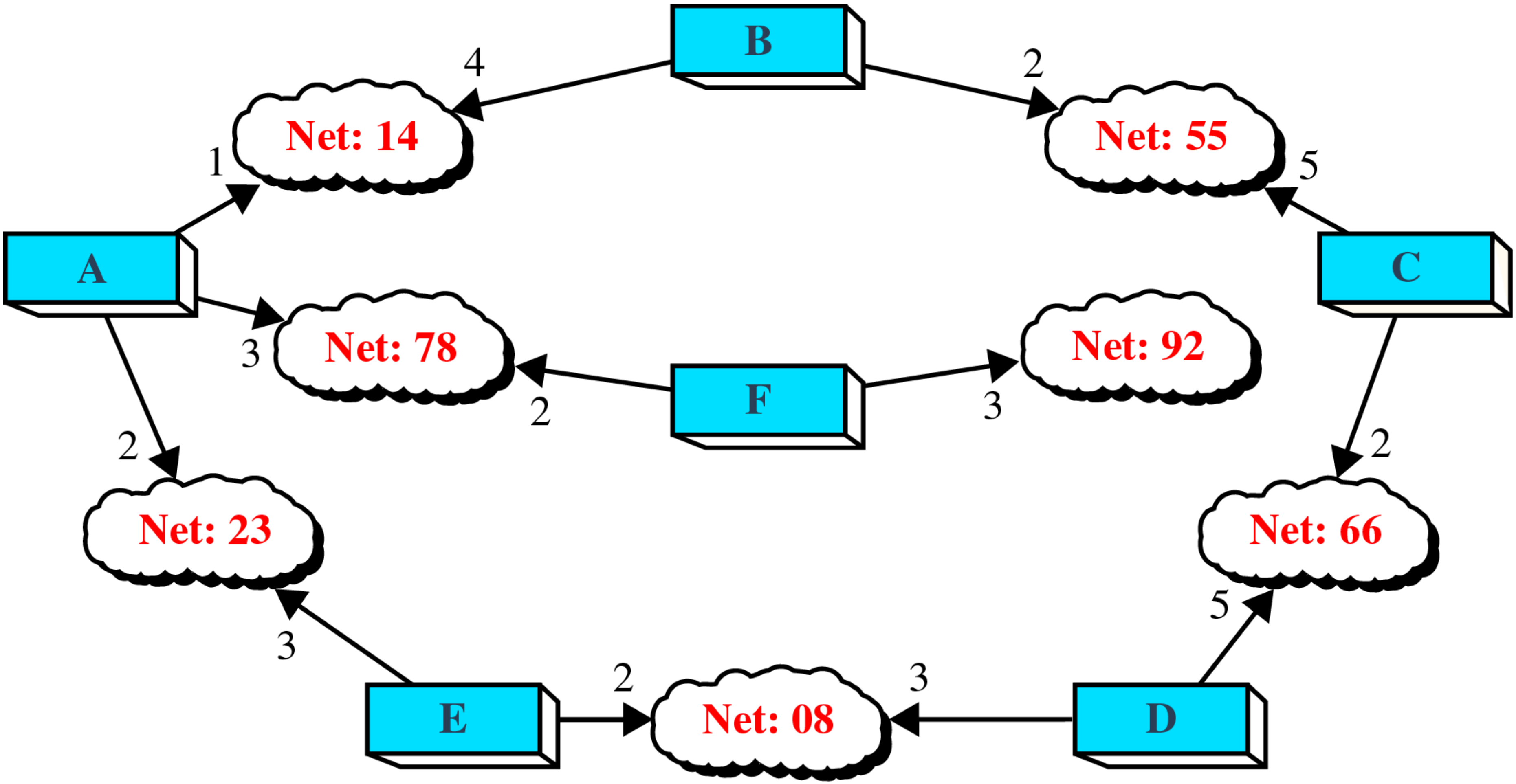


Figure 21-26

# Link State Packet

| Advertiser | Network | Cost | Neighbor |
| --- | --- | --- | --- |
| . . . . . . . | . . . . . . | . . . . . . . . . . . | . . . . . . . . . . . |
| . . . . . . . | . . . . . . | . . . . . . . . . . . | . . . . . . . . . . . |
| . . . . . . . | . . . . . . | . . . . . . . . . . . | . . . . . . . . . . . |

Figure 21-27

# Flooding of A's LSP

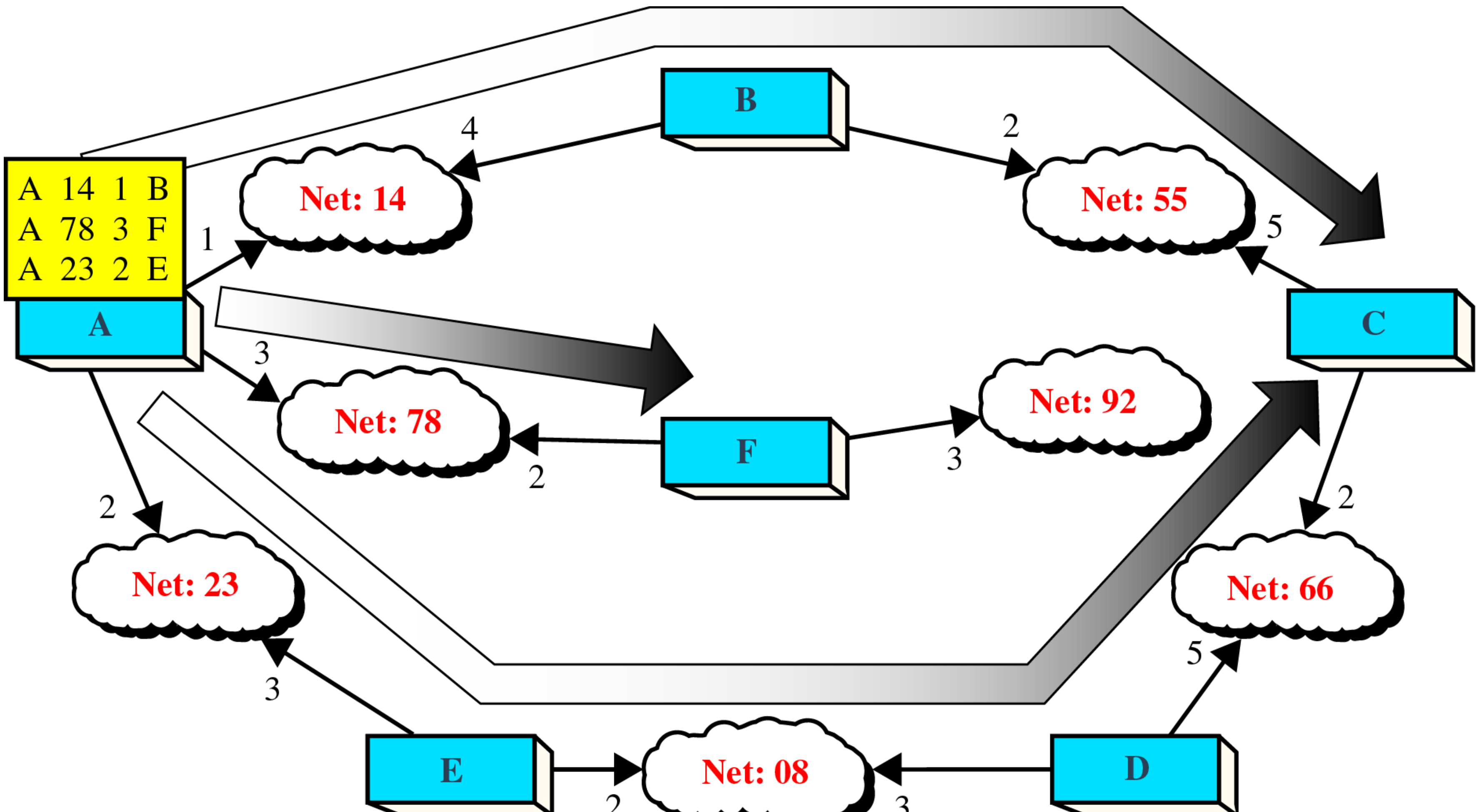


Figure 21-28

# 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 | — |

Figure 21-29

# Costs in the Dijkstra Algorithm

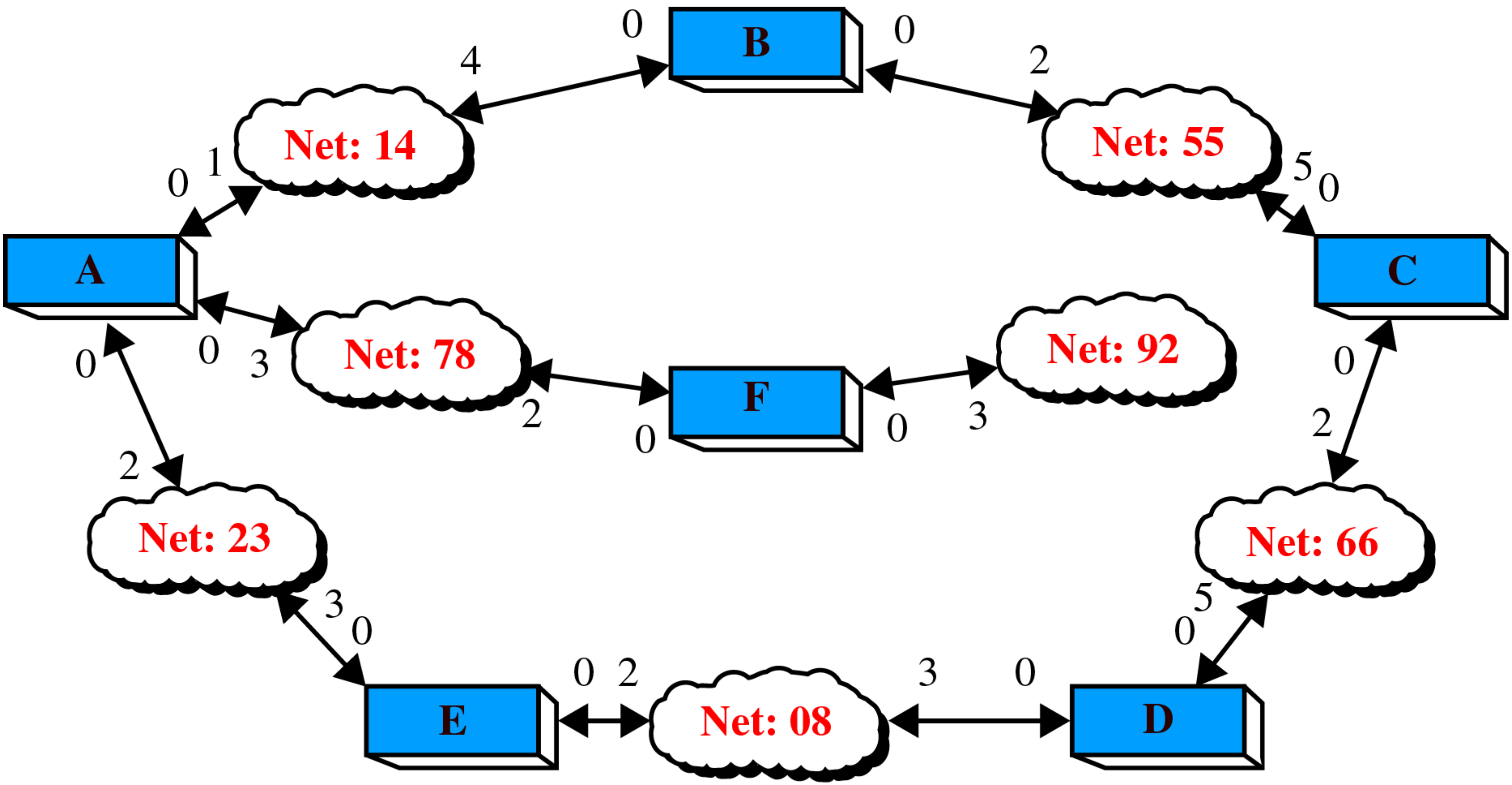
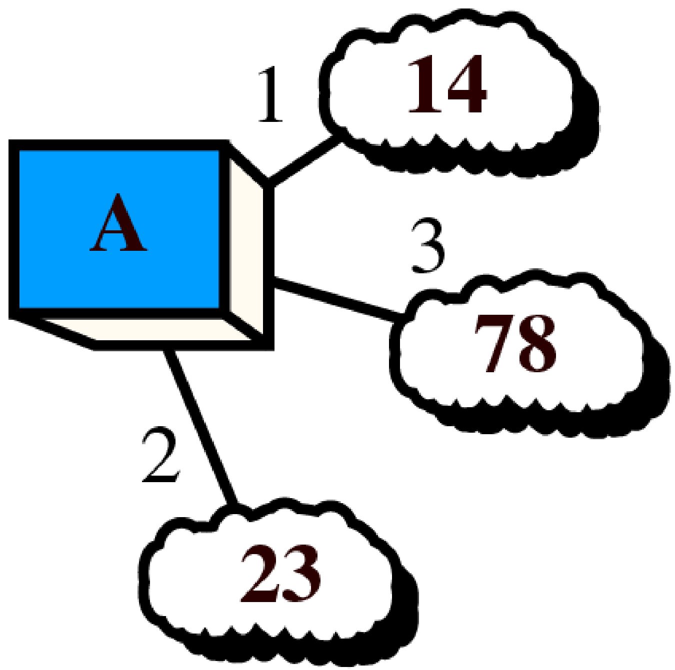


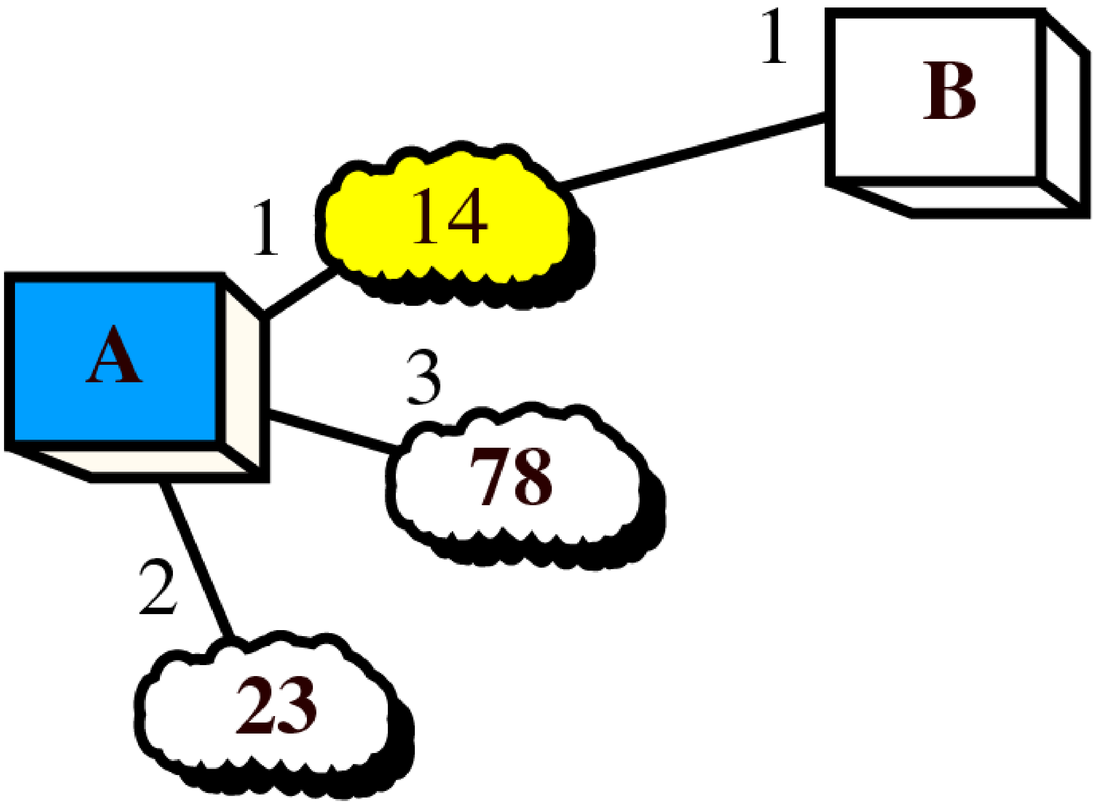
Figure 21-30, Part I

# Shortest Path Calculation, Part I



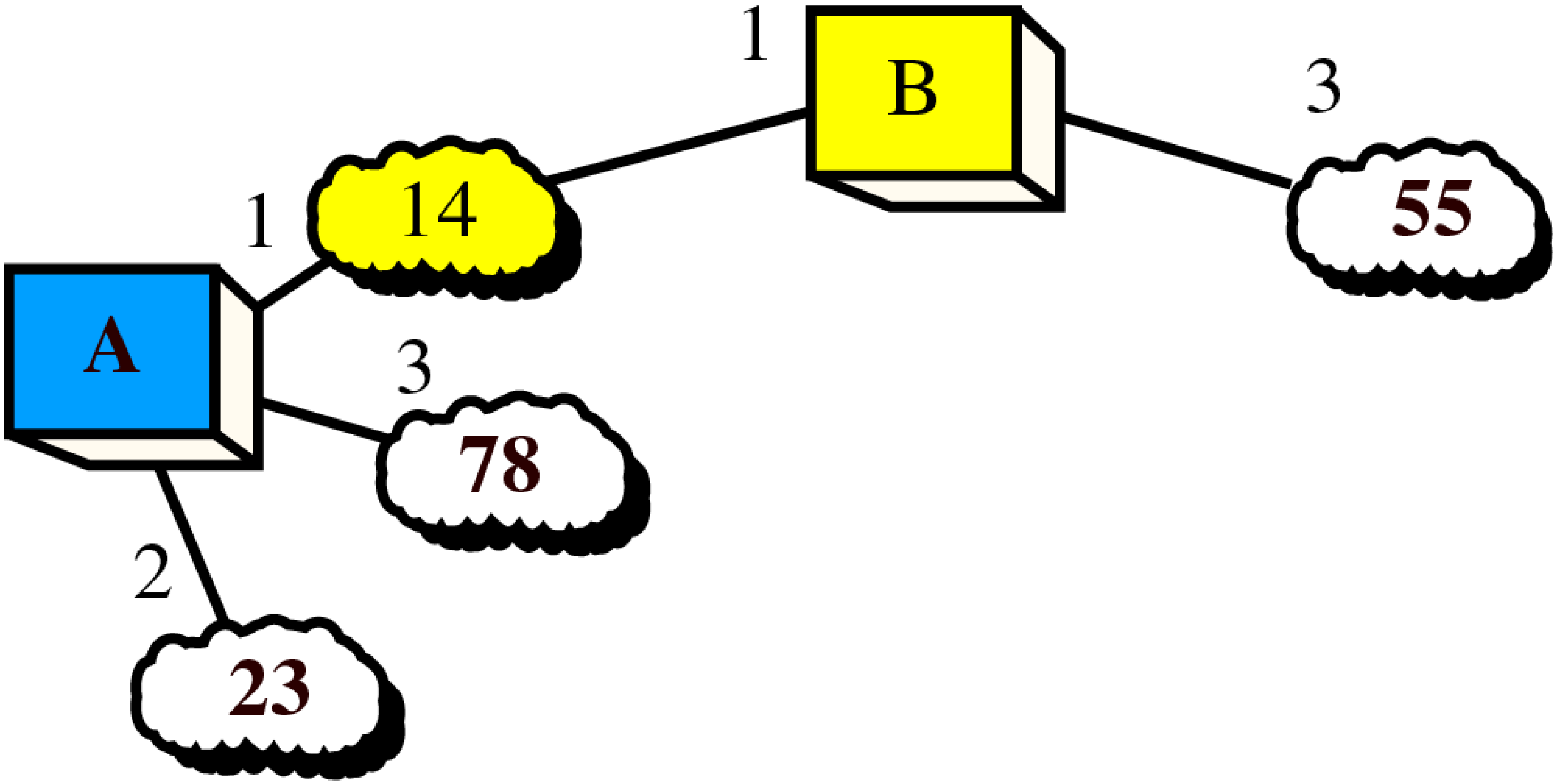

Root is A, networks
14, 78, 23 added

# Shortest Path Calculation, Part II




14 permanent, B added

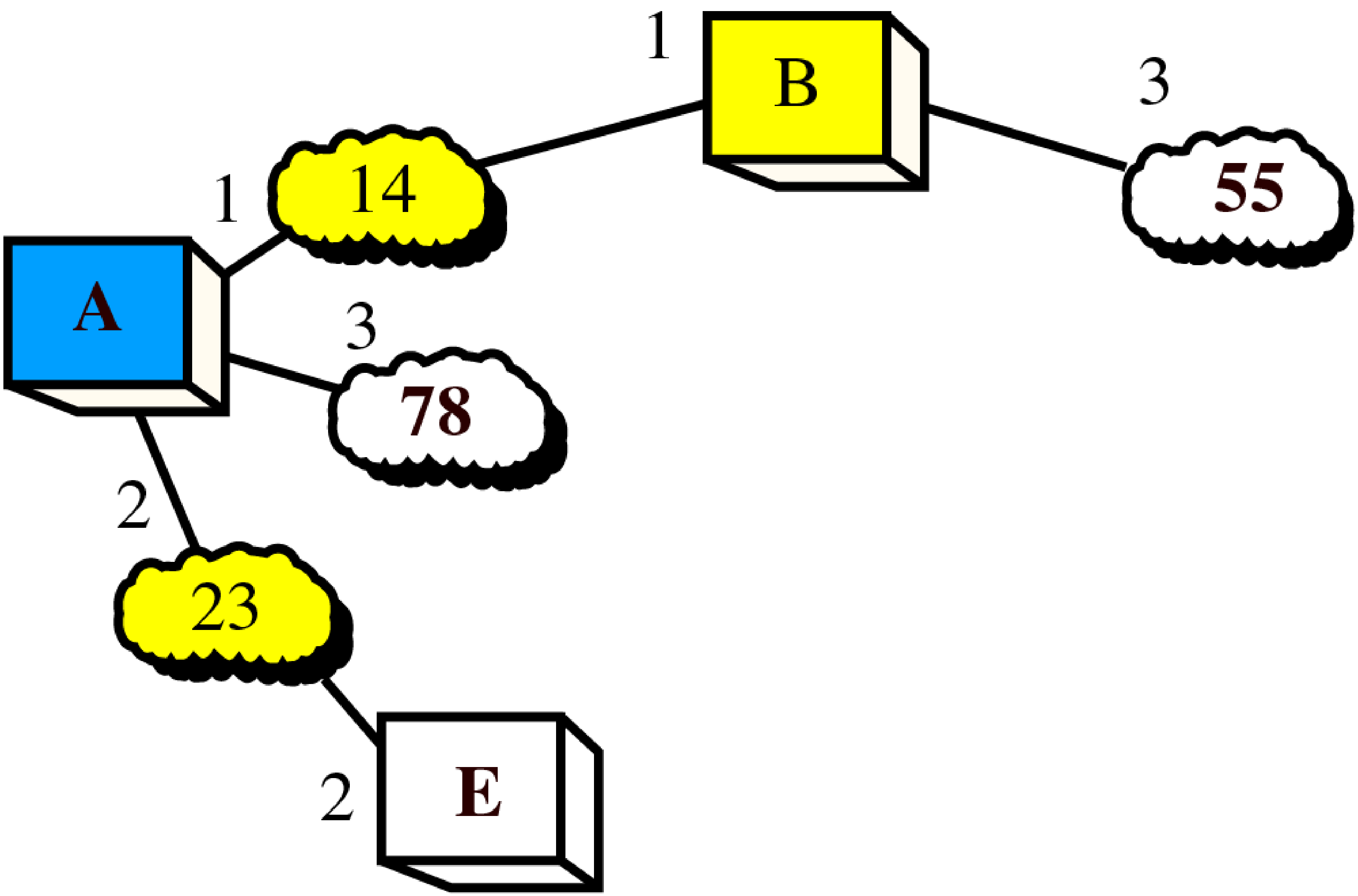
# Shortest Path Calculation, Part III




B Permanent, 55 added

Figure 21-30, Part IV

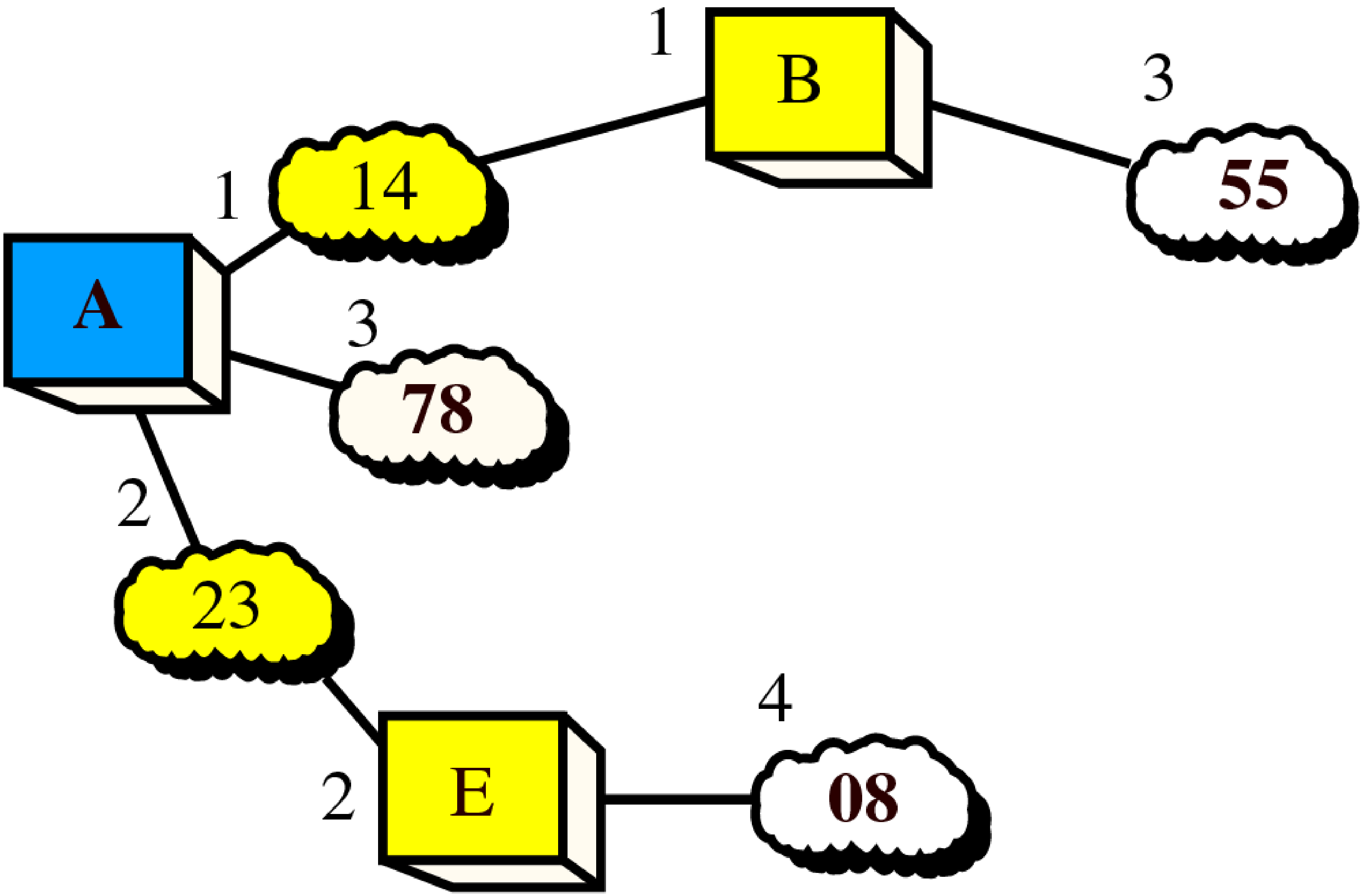
# Shortest Path Calculation, Part IV




23 permanent, E added

Figure 21-30, Part V

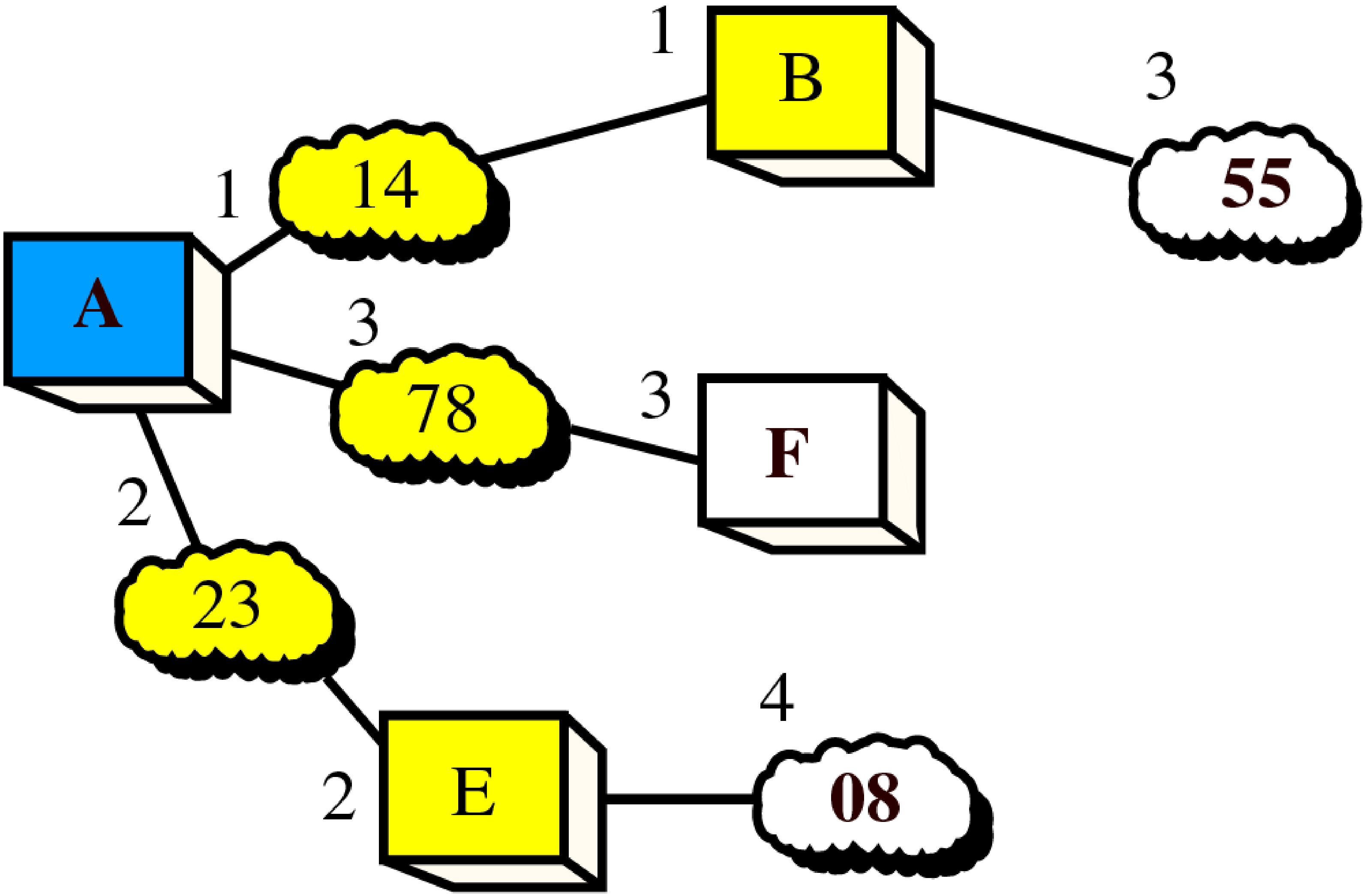
# Shortest Path Calculation, Part V




E permanent, 08 added

Figure 21-30, Part VI

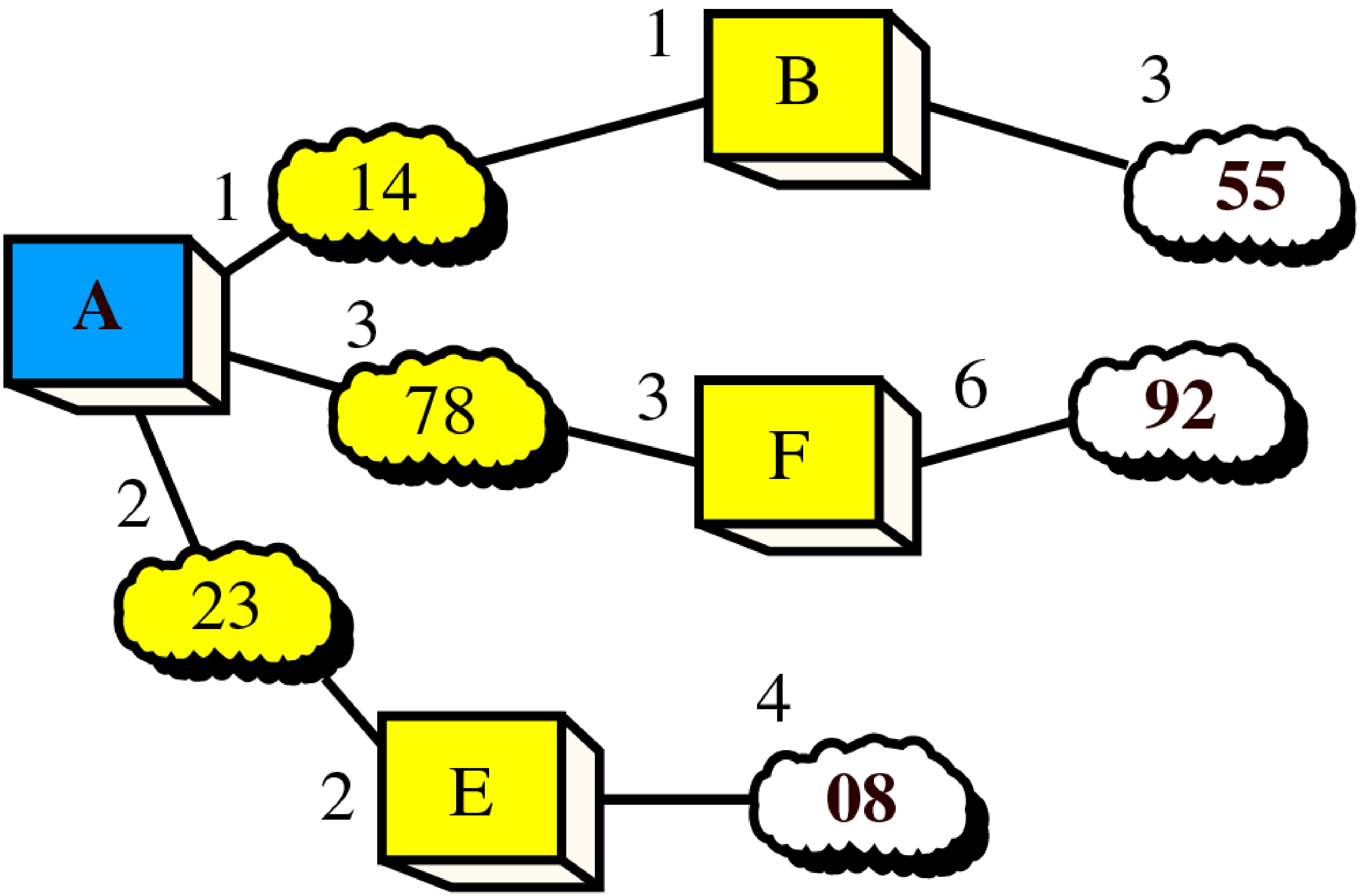
# Shortest Path Calculation, Part VI




78 permanent, F added

Figure 21-31, Part VII

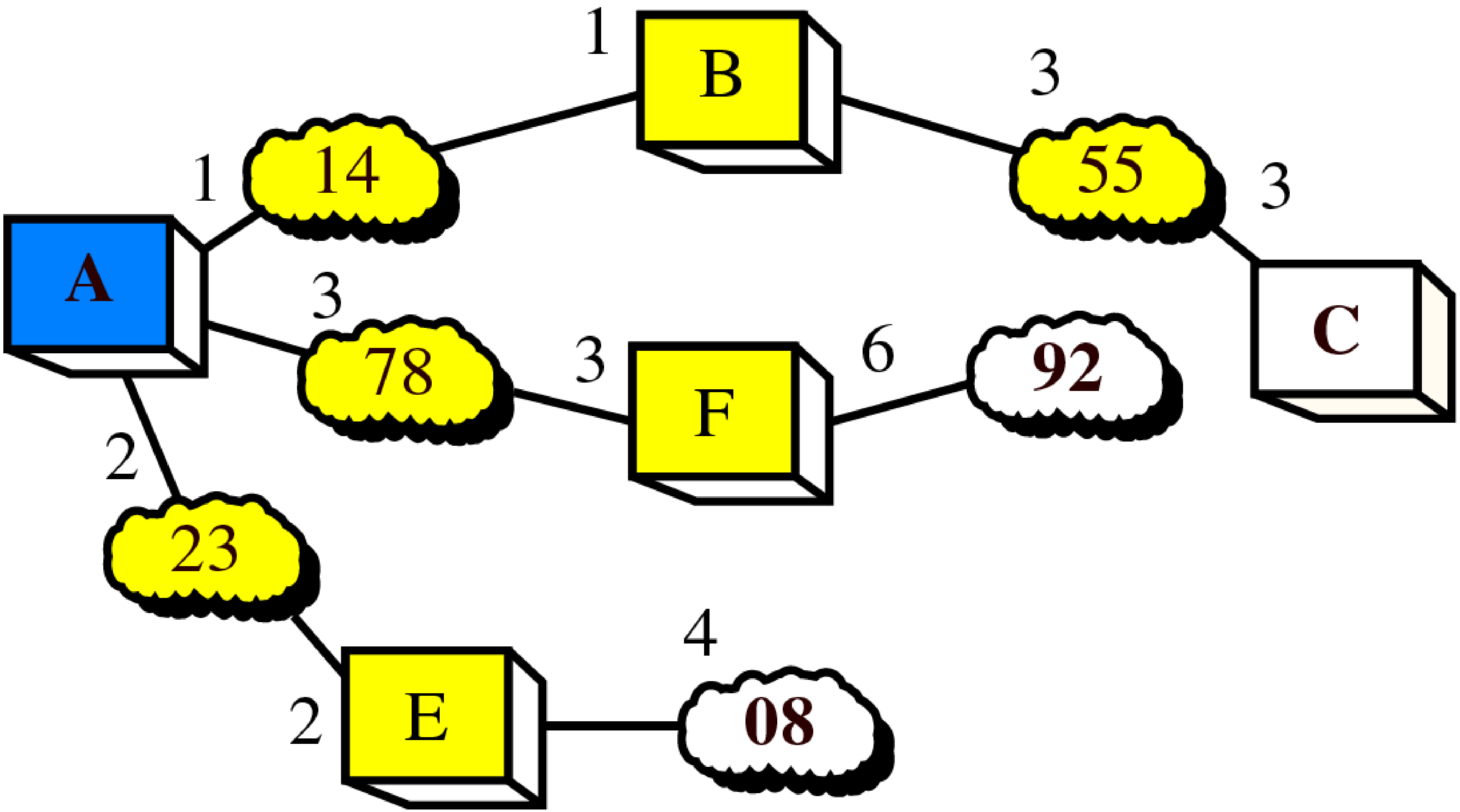
# Shortest Path Calculation, Part VII




F permanent, 92 added

Figure 21-31, Part I

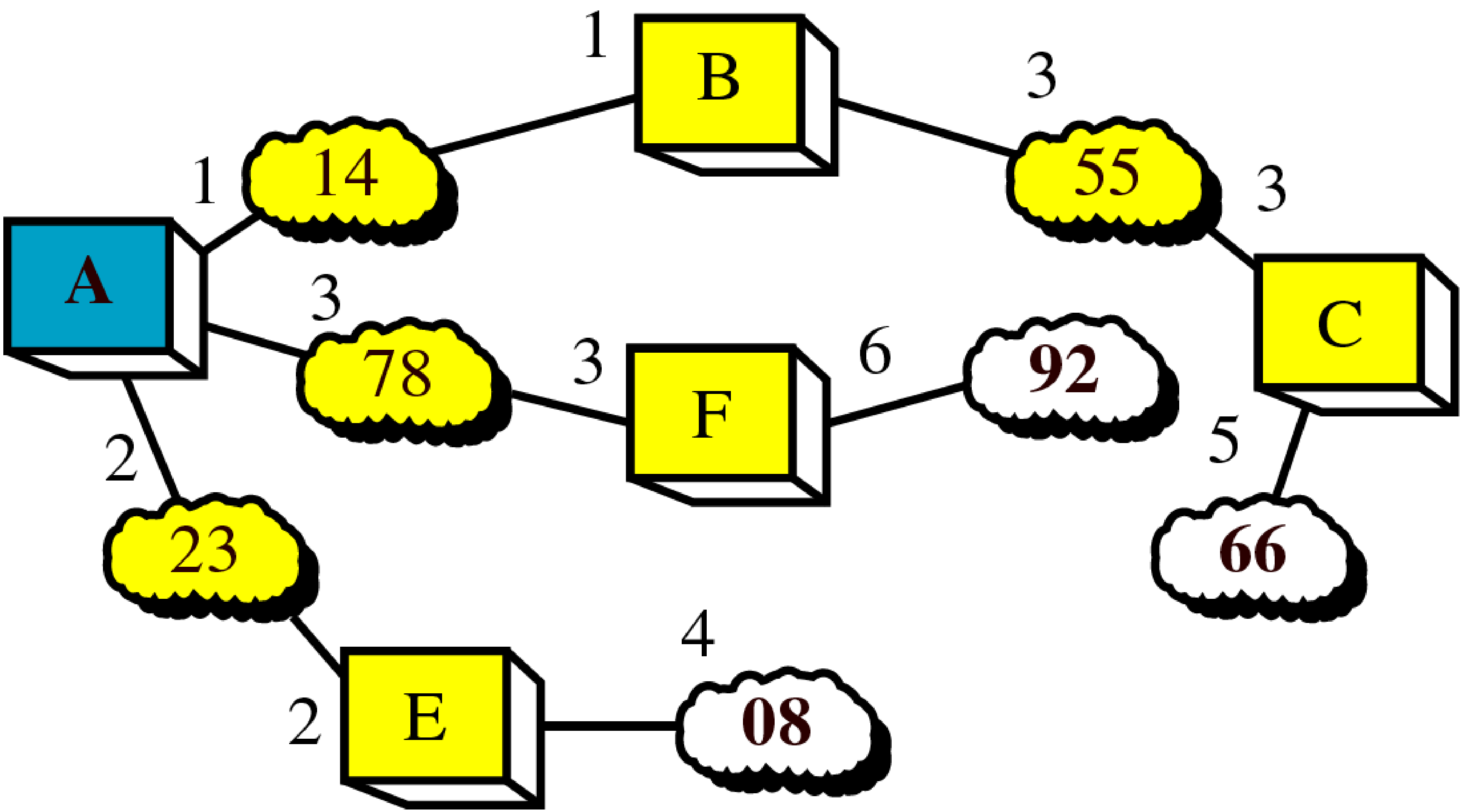
# Shortest Path Calculation, Part VIII




55 permanent, C added

Figure 21-31, Part II

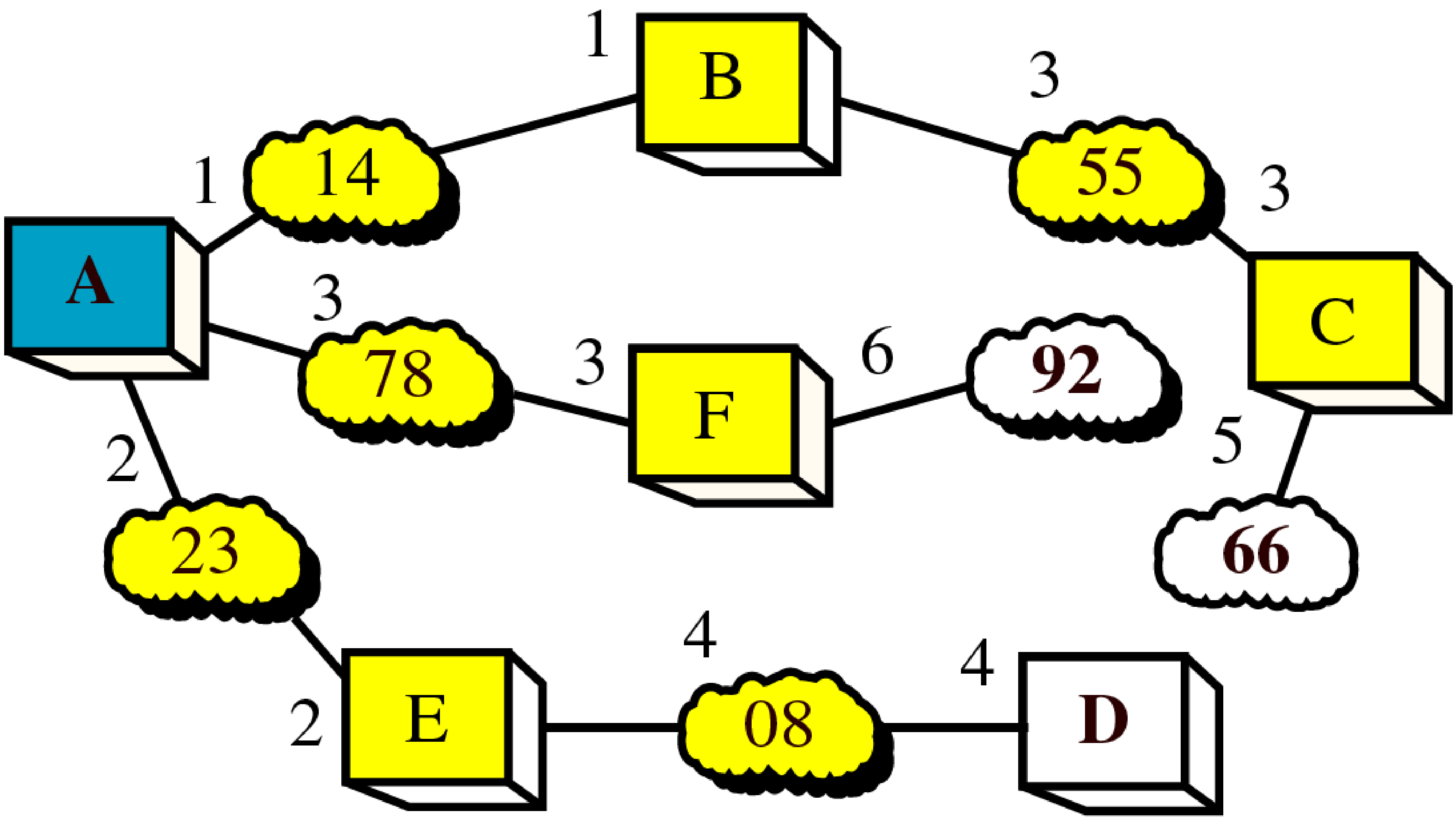
# Shortest Path Calculation, Part IX




C permanent, 66 added

Figure 21-31, Part III

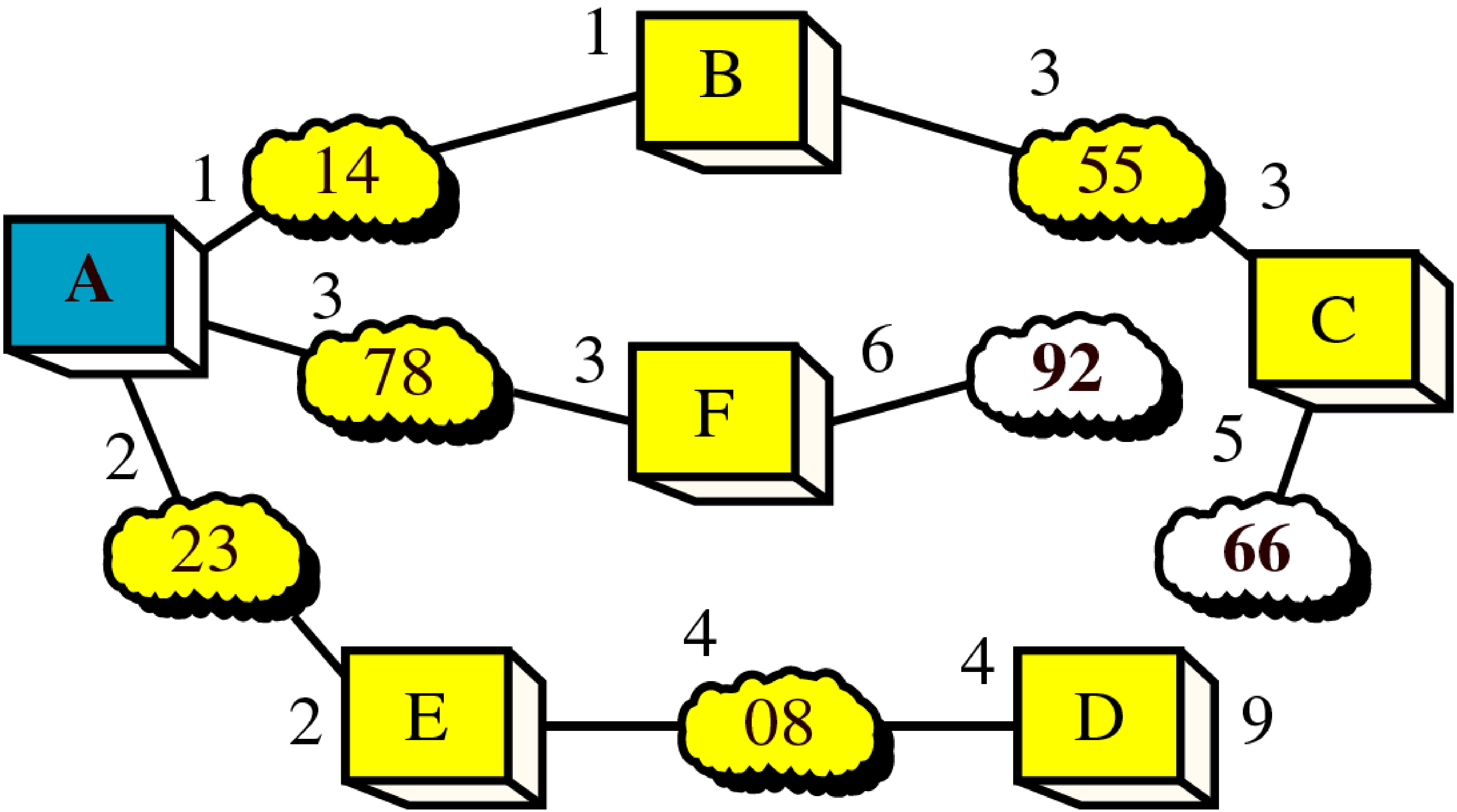
# Shortest Path Calculation, Part X




08 permanent, D added

Figure 21-31, Part IV

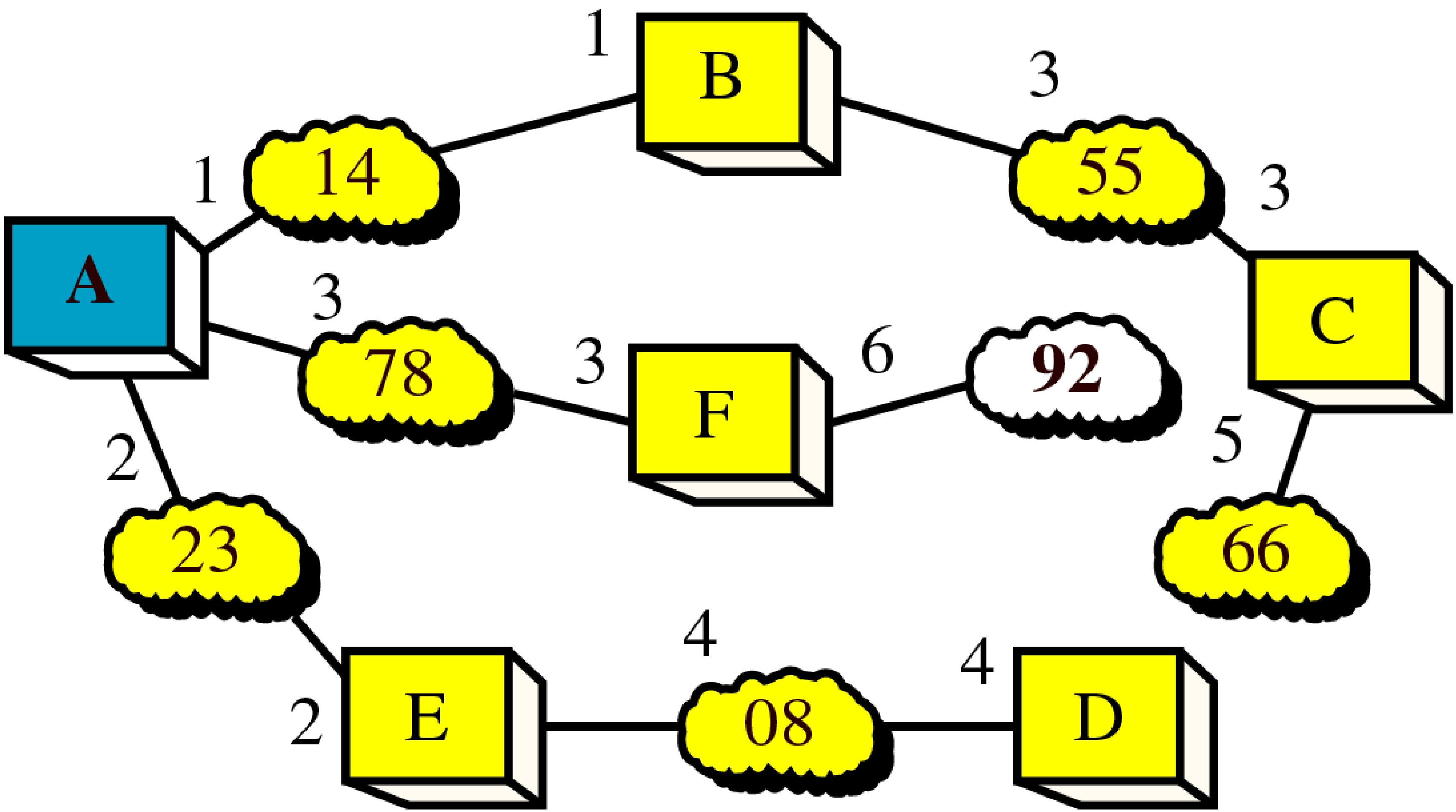
# Shortest Path Calculation, Part XI




D permanent, 66 added.

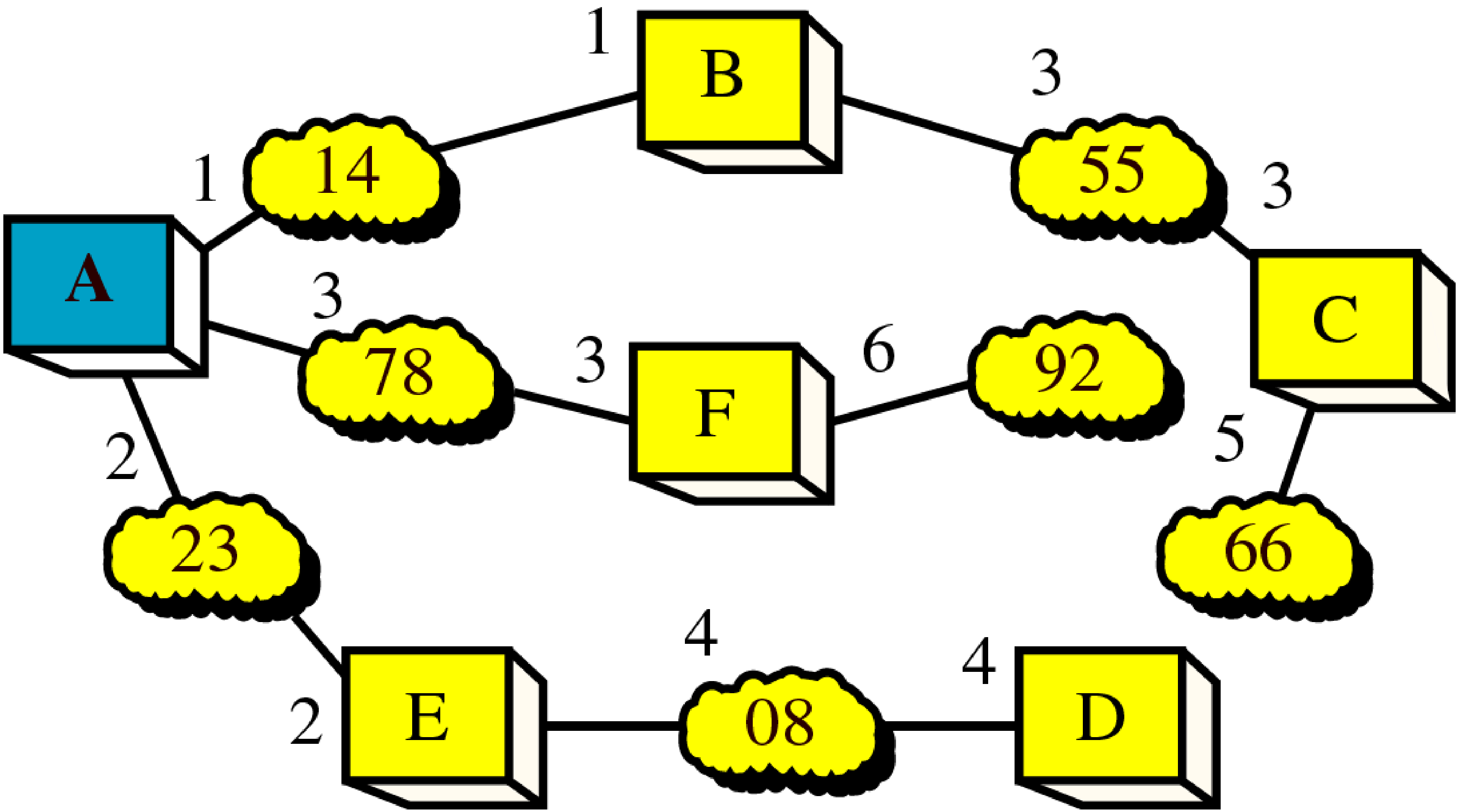
But 9 > 5, so that link deleted

# Shortest Path Calculation, Part XII




66 permanent

# Shortest Path Calculation, Part XIII




92 permanent

Figure 21-32

# Routing Table for Router A

| Net | Cost | Next router |
|---|---|---|
| 08 | 4 | E |
| 14 | 1 | -- |
| 23 | 2 | -- |
| 55 | 3 | B |
| 66 | 5 | B |
| 78 | 3 | -- |
| 92 | 6 | F |