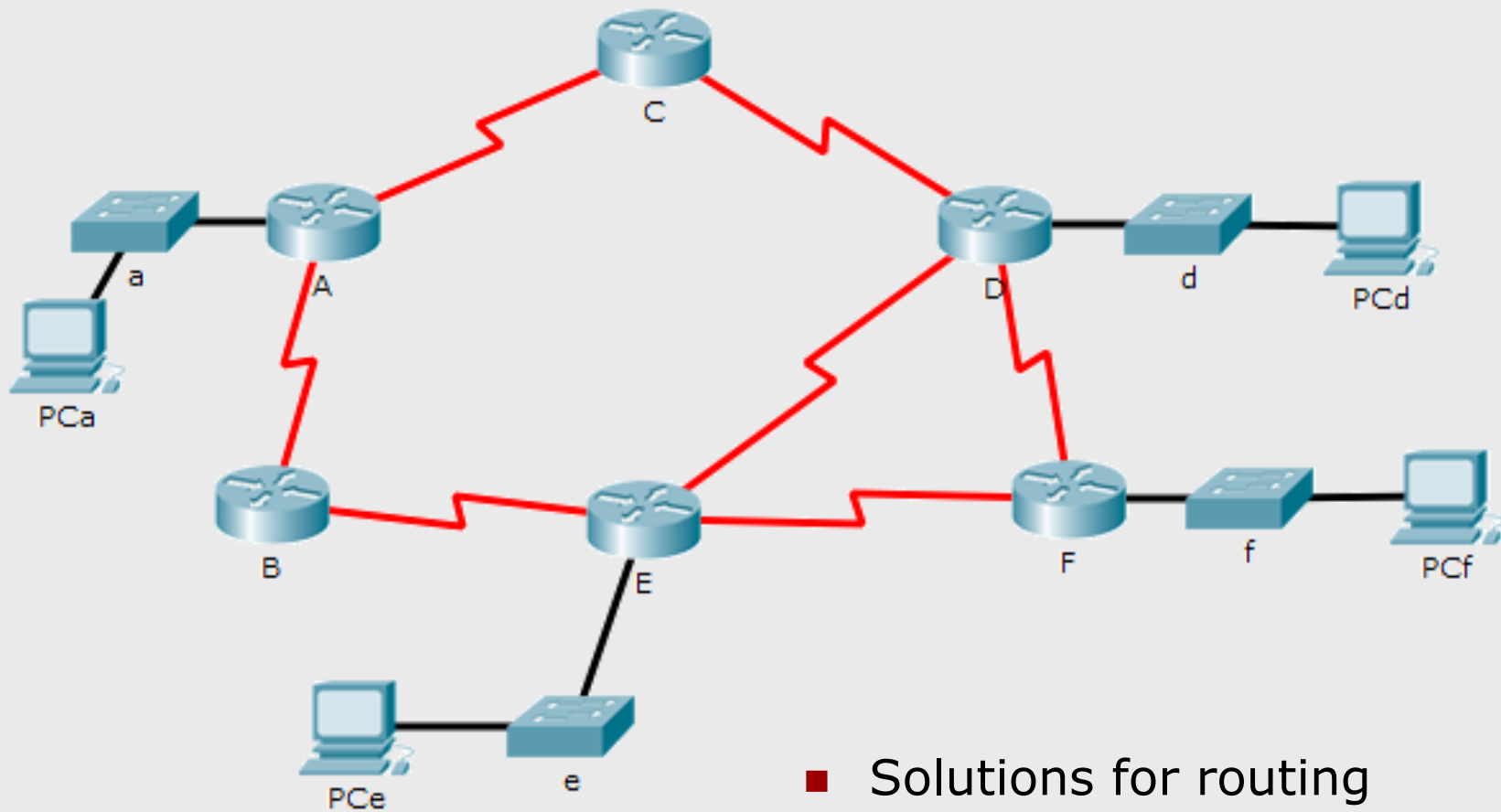


# Lab 3

---

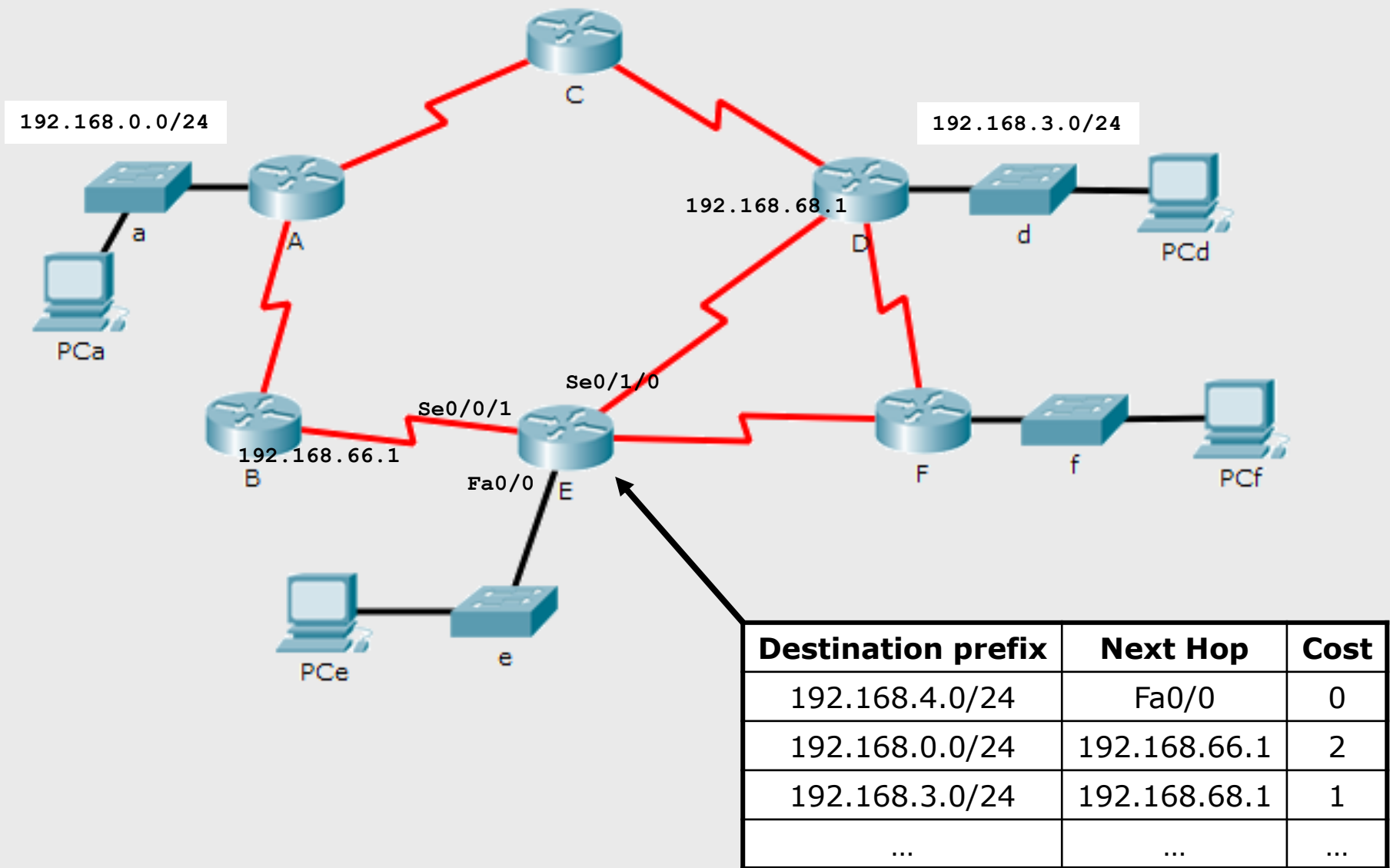
1. IP routing table
2. Static route configuration

# Routing of packets



- Solutions for routing
  - *Routing by destination address*
  - *Label swapping*
  - *Source routing*

# Routing of packets – IP protocol



# Routing table in Cisco IOS

- Stored in RAM, displayed with the **show ip route** command
- Contains information about
  - Directly Connected Routes
  - Static Routes
  - Dynamic Routes

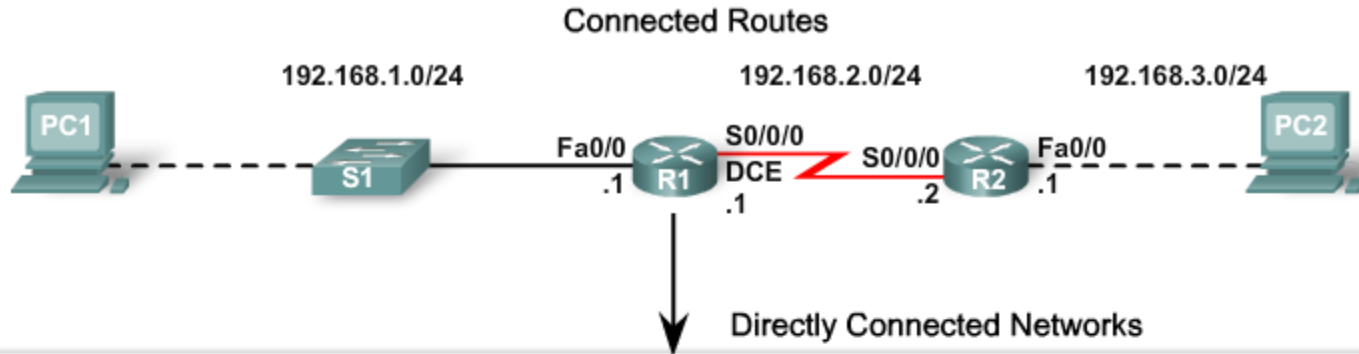
```
RE#show ip route
```

```
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP  
D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area  
N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2  
E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP  
i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area  
* - candidate default, U - per-user static route, o - ODR  
P - periodic downloaded static route
```

```
Gateway of last resort is not set
```

```
R 192.168.0.0/24 [120/2] via 192.168.66.1, 00:00:03, Serial0/0/1  
R 192.168.3.0/24 [120/1] via 192.168.68.1, 00:00:02, Serial0/1/0  
C 192.168.4.0/24 is directly connected, FastEthernet0/0  
R 192.168.5.0/24 [120/1] via 192.168.70.2, 00:00:03, Serial0/0/0  
R 192.168.64.0/24 [120/1] via 192.168.66.1, 00:00:03, Serial0/0/1  
R 192.168.65.0/24 [120/2] via 192.168.68.1, 00:00:02, Serial0/1/0  
[120/2] via 192.168.66.1, 00:00:03, Serial0/0/1  
C 192.168.66.0/24 is directly connected, Serial0/0/1  
R 192.168.67.0/24 [120/1] via 192.168.68.1, 00:00:02, Serial0/1/0  
C 192.168.68.0/24 is directly connected, Serial0/1/0  
R 192.168.69.0/24 [120/1] via 192.168.70.2, 00:00:03, Serial0/0/0  
[120/1] via 192.168.68.1, 00:00:02, Serial0/1/0  
C 192.168.70.0/24 is directly connected, Serial0/0/0
```

# Directly-connected networks



```
R1#show ip route
```

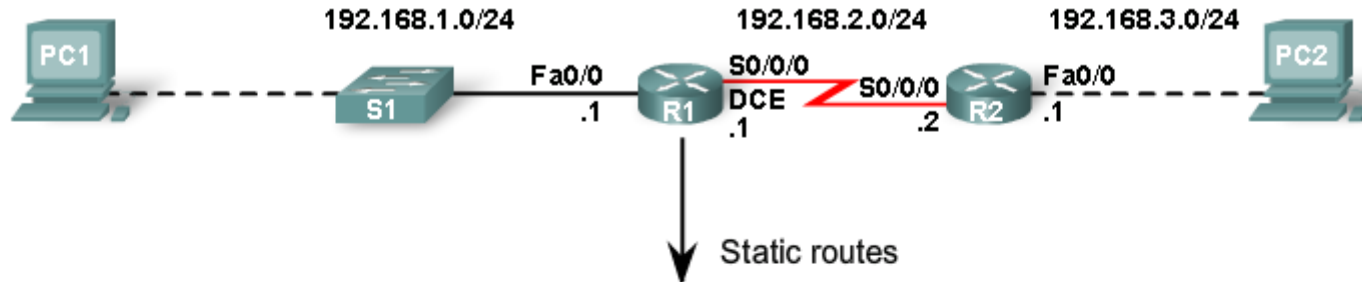
```
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP  
D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area  
N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2  
E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP  
i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area  
* - candidate default, U - per-user static route, o - ODR  
P - periodic downloaded static route
```

```
Gateway of last resort is not set
```

```
C    192.168.1.0/24 is directly connected, FastEthernet0/0  
C    192.168.2.0/24 is directly connected, Serial0/0/0
```

# Static routes

Connected and Static Routes



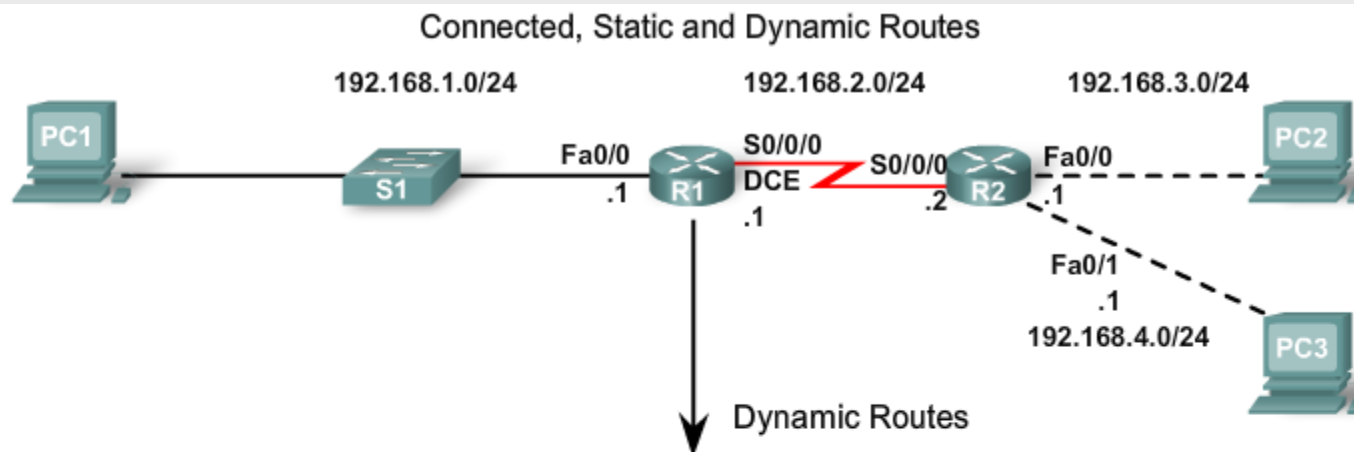
```
R1#show ip route
```

```
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area
       * - candidate default, U - per-user static route, o - ODR
       P - periodic downloaded static route
```

```
Gateway of last resort is not set
```

```
C    192.168.1.0/24 is directly connected, FastEthernet0/0
C    192.168.2.0/24 is directly connected, Serial0/0/0
S    192.168.3.0/24 [1/0] via 192.168.2.2
```

# Dynamic routes



```
R1#show ip route
```

```
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
        D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
        N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
        E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
        i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter
        area
        * - candidate default, U - per-user static route, o - ODR
        P - periodic downloaded static route
```

```
Gateway of last resort is not set
```

```
C    192.168.1.0/24 is directly connected, FastEthernet0/0
```

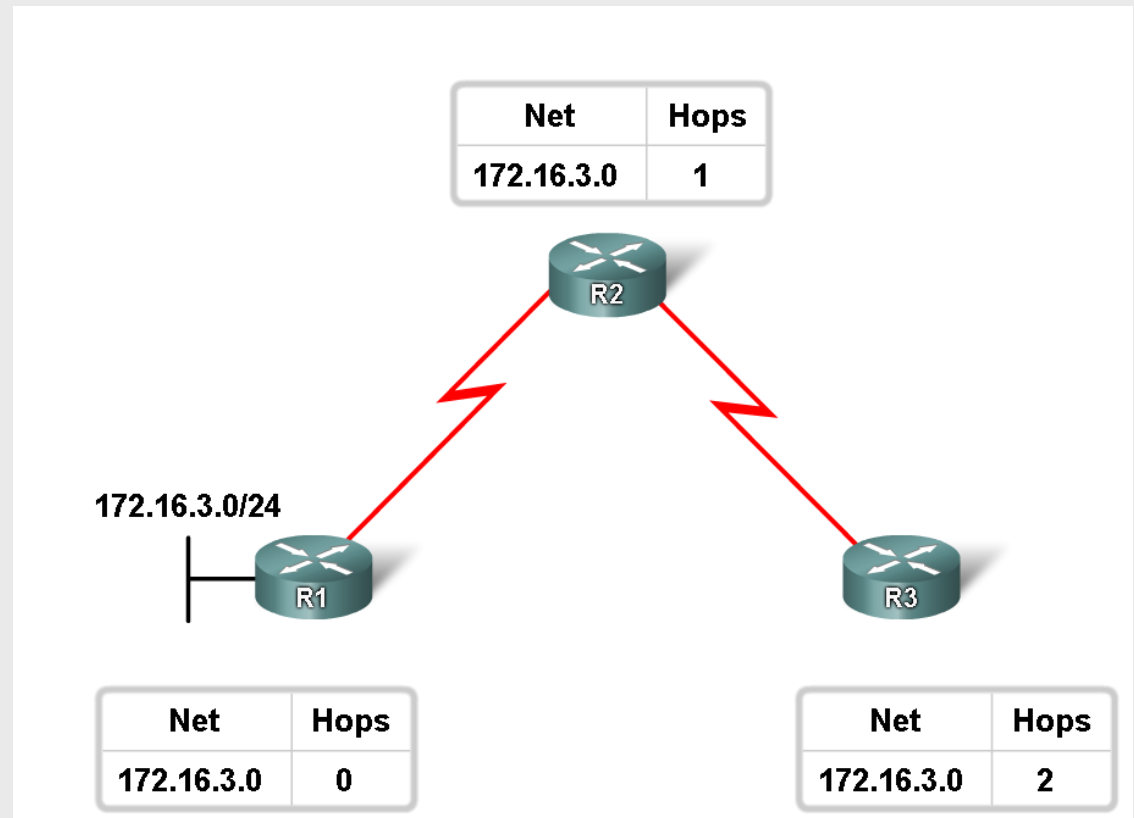
```
C    192.168.2.0/24 is directly connected, Serial0/0/0
```

```
S    192.168.3.0/24 [1/0] via 192.168.2.2
```

```
R    192.168.4.0/24 [120/1] via 192.168.2.2, 00:00:20, Serial0/0/0
```

# Routing metrics

- A quantitative cost of a path to a given destination, needed to compare paths for determining the best one
  - Hop count
  - Bandwidth
  - Cost
  - Delay
  - Load
  - Reliability

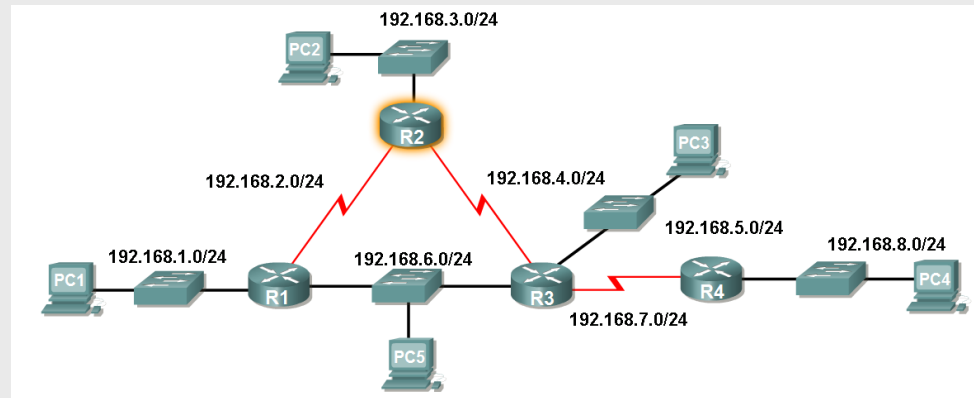




# Metric field in the routing table

- **Metric** used for each routing protocol

- RIP - hop count
- IGRP & EIGRP - Bandwidth (used by default), Delay (used by default), Load, Reliability
- IS-IS & OSPF – Cost, Bandwidth (Cisco's implementation)



```
R2#show ip route
<output omitted>

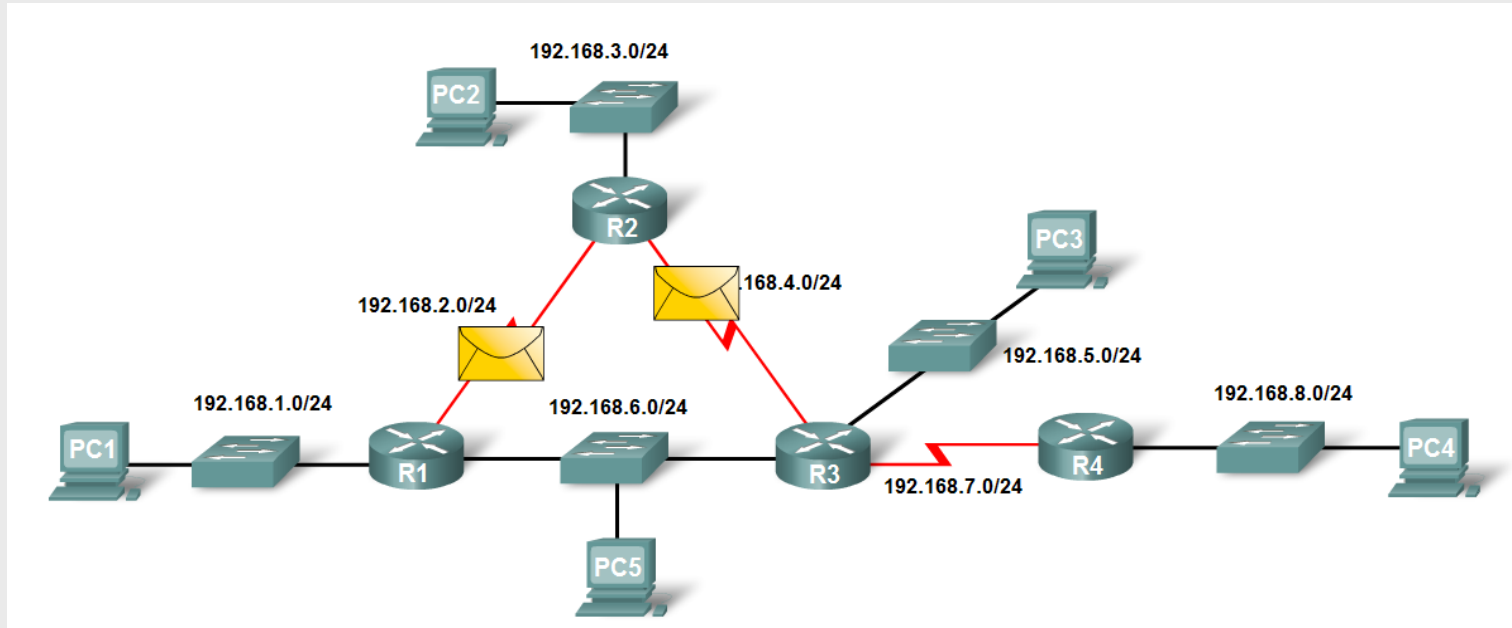
Gateway of last resort is not set

R   192.168.1.0/24 [120/1] via 192.168.2.1, 00:00:24, Serial0/0
C   192.168.2.0/24 is directly connected, Serial0/0
C   192.168.3.0/24 is directly connected, FastEthernet0/0
C   192.168.4.0/24 is directly connected, Serial0/1
R   192.168.5.0/24 [120/1] via 192.168.4.1, 00:00:26, Serial0/1
R   192.168.6.0/24 [120/1] via 192.168.2.1, 00:00:24, Serial0/0
                                   [120/1] via 192.168.4.1, 00:00:26, Serial0/1
R   192.168.7.0/24 [120/1] via 192.168.4.1, 00:00:26, Serial0/1
R   192.168.8.0/24 [120/2] via 192.168.4.1, 00:00:26, Serial0/1
```

It is 2 hops from R2 to 192.168.8.0/24

# Load balancing

- Packets are forwarded using all equal-cost paths

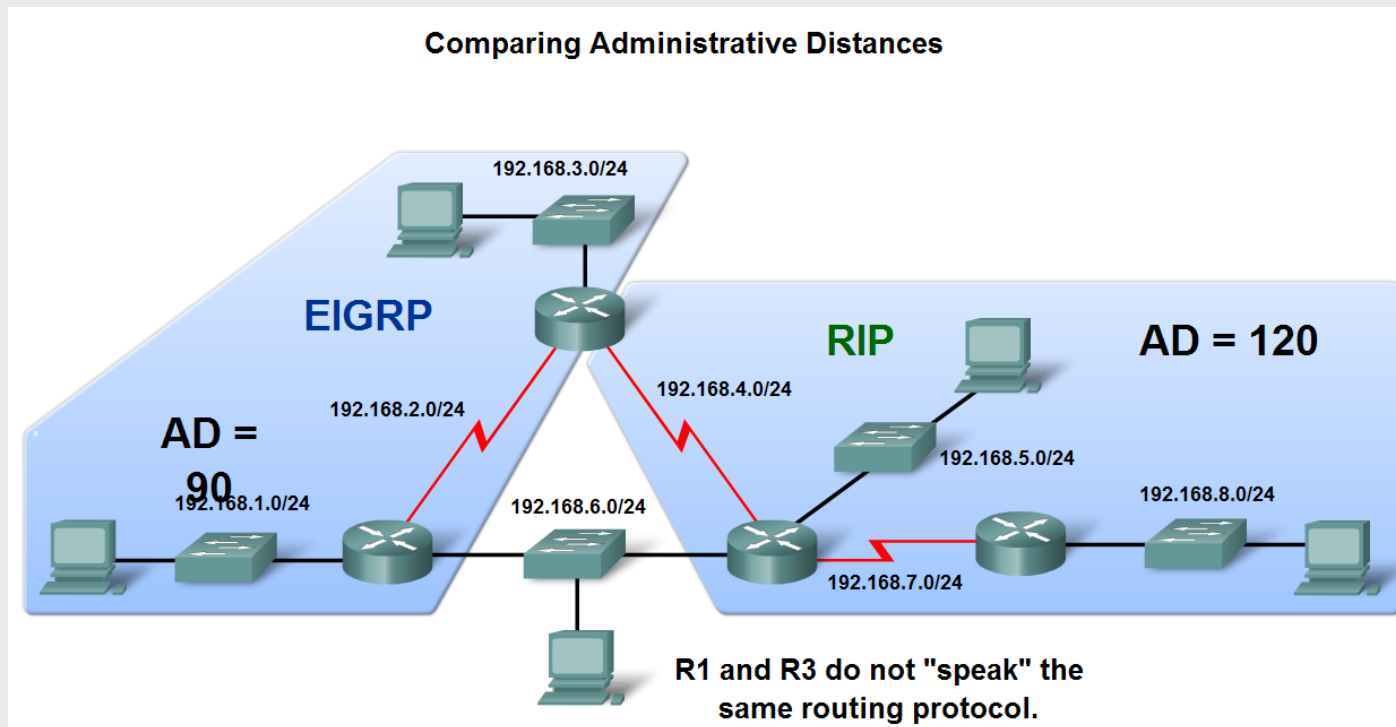


```
R2#show ip route
<output omitted>

R    192.168.6.0/24 [120/1] via 192.168.2.1, 00:00:24, Serial0/0/0
                        [120/1] via 192.168.4.1, 00:00:26, Serial0/0/1
```

# Administrative distance

- Administrative Distance (AD) defines the preference of a routing source
  - Integer value from 0 to 255
  - The lower the value the more preferred the route source (the more trustworthy the route)



# AD in the routing table

- First number in the brackets in the routing table

```
R2#show ip route
```

```
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP  
D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area  
N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2  
E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP  
i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area  
* - candidate default, U - per-user static route, o - ODR  
P - periodic downloaded static route
```

```
Gateway of last resort is not set
```

```
D    192.168.1.0/24 [90/2172416] via 192.168.2.1, 00:00:24, Serial0/0/0  
C    192.168.2.0/24 is directly connected, Serial0/0/0  
C    192.168.3.0/24 is directly connected, FastEthernet0/0  
C    192.168.4.0/24 is directly connected, Serial0/0/1  
R    192.168.5.0/24 [120/1] via 192.168.4.1, 00:00:08, Serial0/0/1  
D    192.168.6.0/24 [90/2172416] via 192.168.2.1, 00:00:24, Serial0/0/0  
R    192.168.7.0/24 [120/1] via 192.168.4.1, 00:00:08, Serial0/0/1  
R    192.168.8.0/24 [120/2] via 192.168.4.1, 00:00:08, Serial0/0/1
```

# Default AD

Route Source	Administrative Distance
Connected	0
Static	1
EIGRP summary route	5
External BGP	20
Internal EIGRP	90
IGRP	100
OSPF	110
IS-IS	115
RIP	120
External EIGRP	170
Internal BGP	200

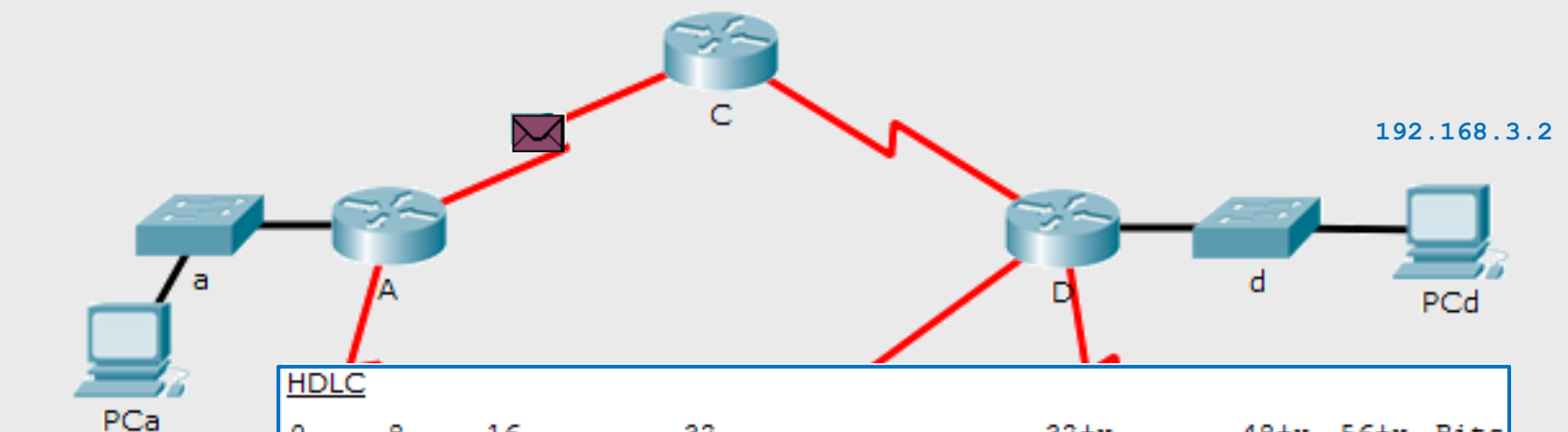


# Path determination and switching

---

- **Path determination** – pick the best path to a destination
  - Directly connected network
  - Remote network
  - No route determined
    - Destination unreachable
  
- **Switching** – switch a packet from an incoming interface to an outgoing interface
  - The Source and Destination IP addresses **never** change
  - The Source & Destination MAC addresses **change** as packet is forwarded from one router to the next.
  - TTL field decrements by one until a value of zero is reached, at which point the router discards the packet
    - this prevents packets from endlessly traversing the network

# Switching



## HDLC

0	8	16	32	32+x	48+x	56+x	Bits
FLG: 0111 1110	ADR: 0x8f	CONTROL: 0x0	DATA: (VARIABLE LENGTH)	FCS: 0x0	FLG: 0111 1110		

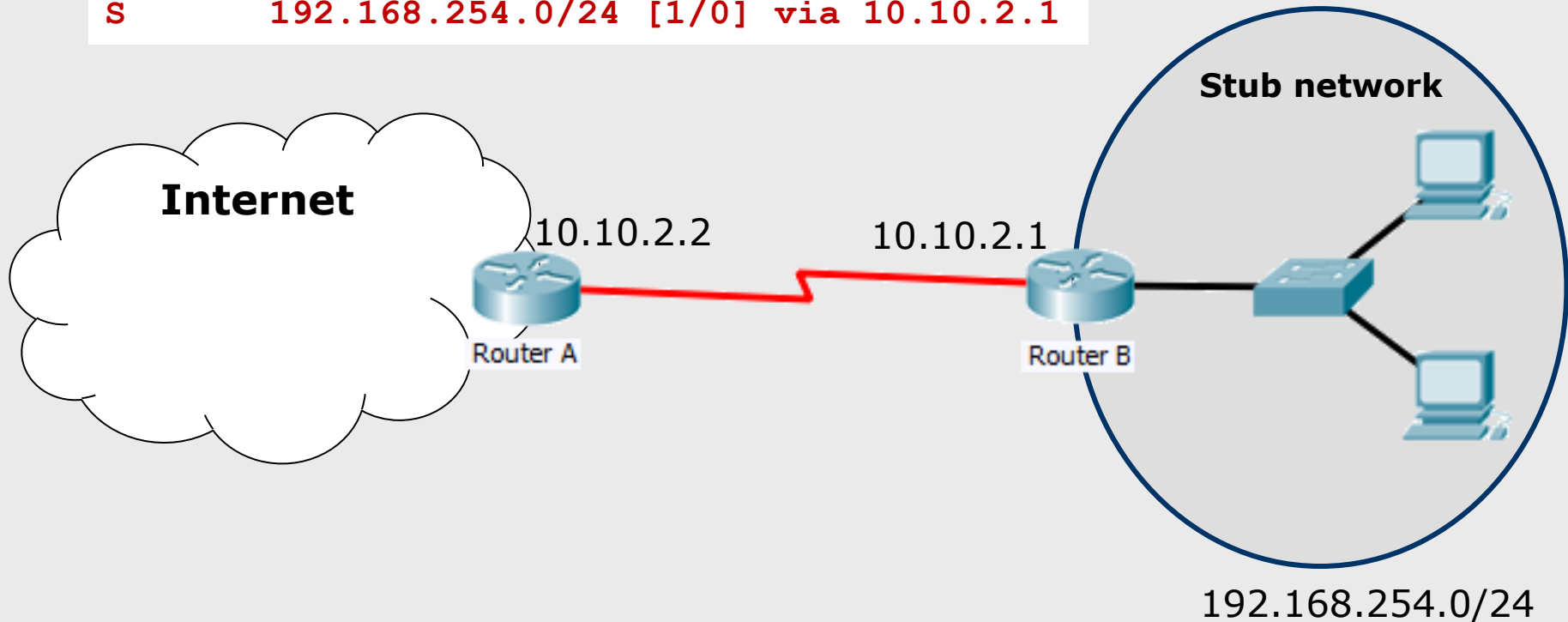
## IP

0	4	8	16	19	31	Bits
4	IHL	DSCP: 0x0	TL: 128			
ID: 0x5			0x0	0x0		
TTL: 127		PRO: 0x1	CHKSUM			
SRC IP: 192.168.0.2						
DST IP: 192.168.3.2						
OPT: 0x0				0x0		
DATA (VARIABLE LENGTH)						

# Static routing – example of use

## Static route in Router A

**S**      **192.168.254.0/24 [1/0] via 10.10.2.1**





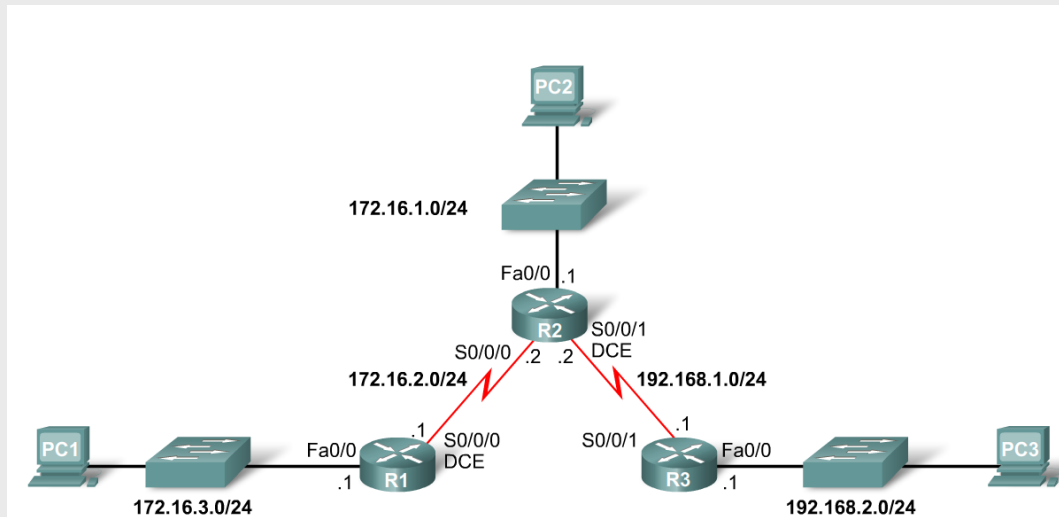
# Static route configuration

## ■ Command **ip route**

```
Router(config)# ip route network-address subnet-mask  
{ip-address | exit-interface } [Distance]
```

Parameter	Description
<b>network-address</b>	Destination network address of the remote network to be added to the routing table.
<b>subnet-mask</b>	Subnet mask of the remote network to be added to the routing table. The subnet mask can be modified to summarize a group of networks.
<b>ip-address</b>	Commonly referred to as the next-hop router's IP address.
<b>exit-interface</b>	Outgoing interface that is used to forward packets to the destination network.

# Static route configuration



```
R1#debug ip routing
(**output omitted**)

R1#conf t
R1(config)#ip route 172.16.1.0 255.255.255.0 172.16.2.2

00:20:15: RT: add 172.16.1.0/24 via 172.16.2.2, static metric [1/0]

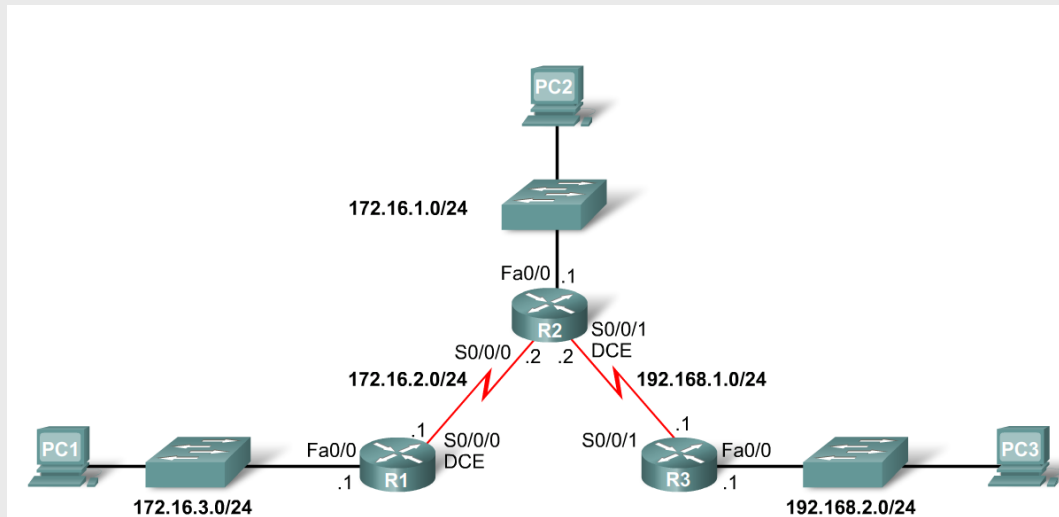
R1#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area
       * - candidate default, U - per-user static route, o - ODR
       P - periodic downloaded static route

Gateway of last resort is not set

      172.16.0.0/24 is subnetted, 3 subnets
S       172.16.1.0 [1/0] via 172.16.2.2
C       172.16.2.0 is directly connected, Serial0/0/0
C       172.16.3.0 is directly connected, FastEthernet0/0
R1#
```

# Static route configuration

- Configuring routes to two or more remote networks



```
R1(config)#ip route 192.168.1.0 255.255.255.0 172.16.2.2
R1(config)#ip route 192.168.2.0 255.255.255.0 172.16.2.2
R1(config)#end
R1#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area
       * - candidate default, U - per-user static route, o - ODR
       P - periodic downloaded static route

Gateway of last resort is not set

    172.16.0.0/24 is subnetted, 3 subnets
S       172.16.1.0 [1/0] via 172.16.2.2
C       172.16.2.0 is directly connected, Serial0/0/0
C       172.16.3.0 is directly connected, FastEthernet0/0
S       192.168.1.0/24 [1/0] via 172.16.2.2
S       192.168.2.0/24 [1/0] via 172.16.2.2
```

# Static route configuration

- Configure a static route with an exit interface
  - Lookup is more efficient

```
R1(config)#no ip route 192.168.2.0 255.255.255.0 172.16.2.2
R1(config)#ip route 192.168.2.0 255.255.255.0 serial 0/0/0
R1(config)#end
R1#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area
       * - candidate default, U - per-user static route, o - ODR
       P - periodic downloaded static route

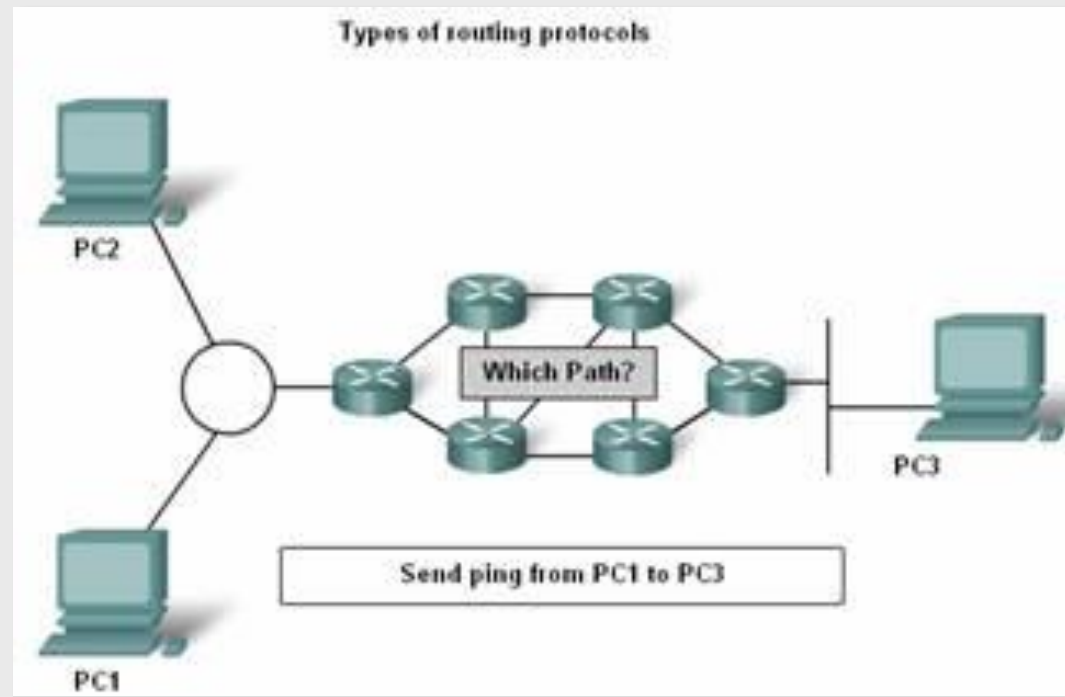
Gateway of last resort is not set

    172.16.0.0/24 is subnetted, 3 subnets
S       172.16.1.0 [1/0] via 172.16.2.2
C       172.16.2.0 is directly connected, Serial0/0/0
C       172.16.3.0 is directly connected, FastEthernet0/0
S       192.168.1.0/24 [1/0] via 172.16.2.2
S       192.168.2.0/24 is directly connected, Serial0/0/0
```

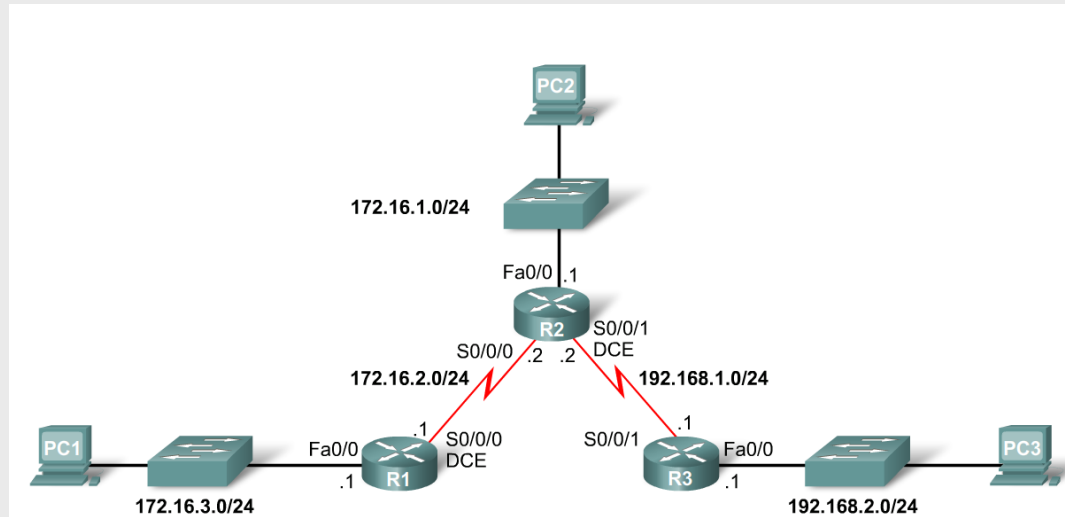
Exit interface now specified in the static route. No need for a recursive lookup.

# Routing table principles

- Every router makes its decisions **alone**, based on the information it has in its routing table.
- Different routing tables may contain **different** information
- A routing table can tell how to get to a destination but **not** how to get back



# Recursive route lookup

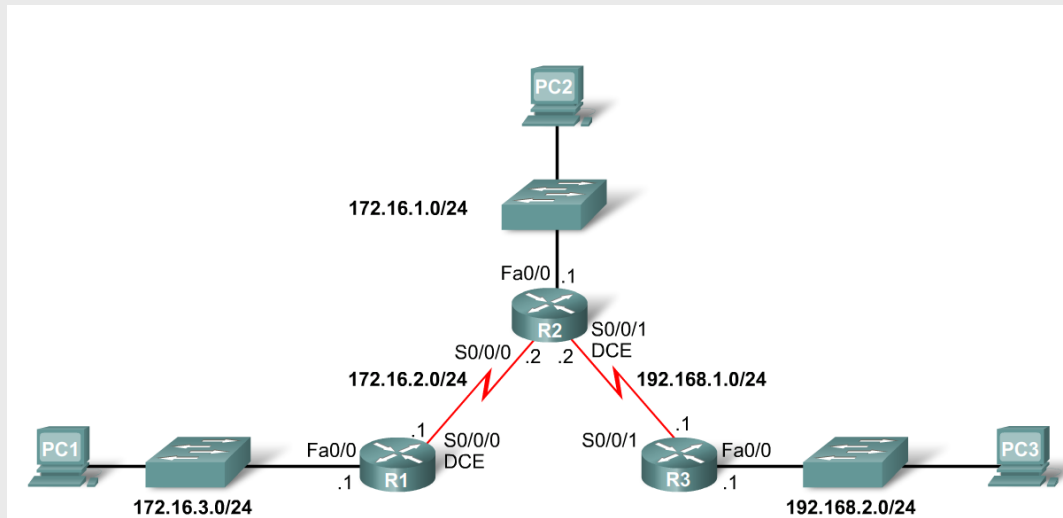


```
R1#show ip route
(**output omitted**)
  172.16.0.0/24 is subnetted, 3 subnets
S    172.16.1.0 [1/0] via 172.16.2.2
C    172.16.2.0 is directly connected, Serial0/0/0
C    172.16.3.0 is directly connected, FastEthernet0/0
S    192.168.1.0/24 [1/0] via 172.16.2.2
S    192.168.2.0/24 [1/0] via 172.16.2.2
```

Step 1: Find a route.

Step 2: Find an exit interface.

# Exit interface down



```
R1#debug ip routing
IP routing debugging is on
R1#config t
Enter configuration commands, one per line. End with CNTL/Z.
R1(config)#int s0/0/0
R1(config-if)#shutdown
R1(config-if)#end

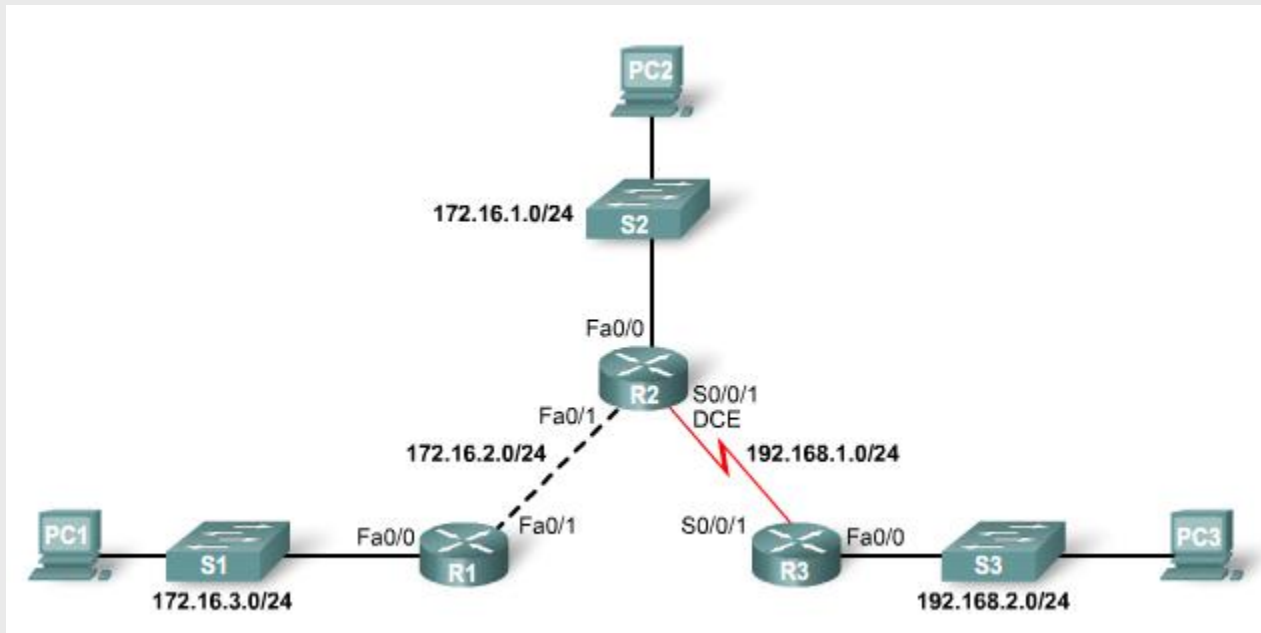
is_up: 0 state: 6 sub state: 1 line: 0
RT: interface Serial0/0/0 removed from routing table
RT: del 172.16.2.0/24 via 0.0.0.0, connected metric [0/0]
RT: delete subnet route to 172.16.2.0/24
RT: del 192.168.1.0 via 172.16.2.2, static metric [1/0]
RT: delete network route to 192.168.1.0
RT: del 172.16.1.0/24 via 172.16.2.2, static metric [1/0]
RT: delete subnet route to 172.16.1.0/24

R1#show ip route
***output omitted***
Gateway of last resort is not set
  172.16.0.0/24 is subnetted, 1 subnets
C    172.16.3.0 is directly connected, FastEthernet0/0
```

# Static route configuration

- Configure a static route with an exit interface
  - Issue with Ethernet exit interfaces

```
R1(config)#ip route 192.168.2.0 255.255.255.0 fastethernet 0/1
```



```
R1(config)#ip route 192.168.2.0 255.255.255.0 fastethernet 0/1 172.16.2.2
```

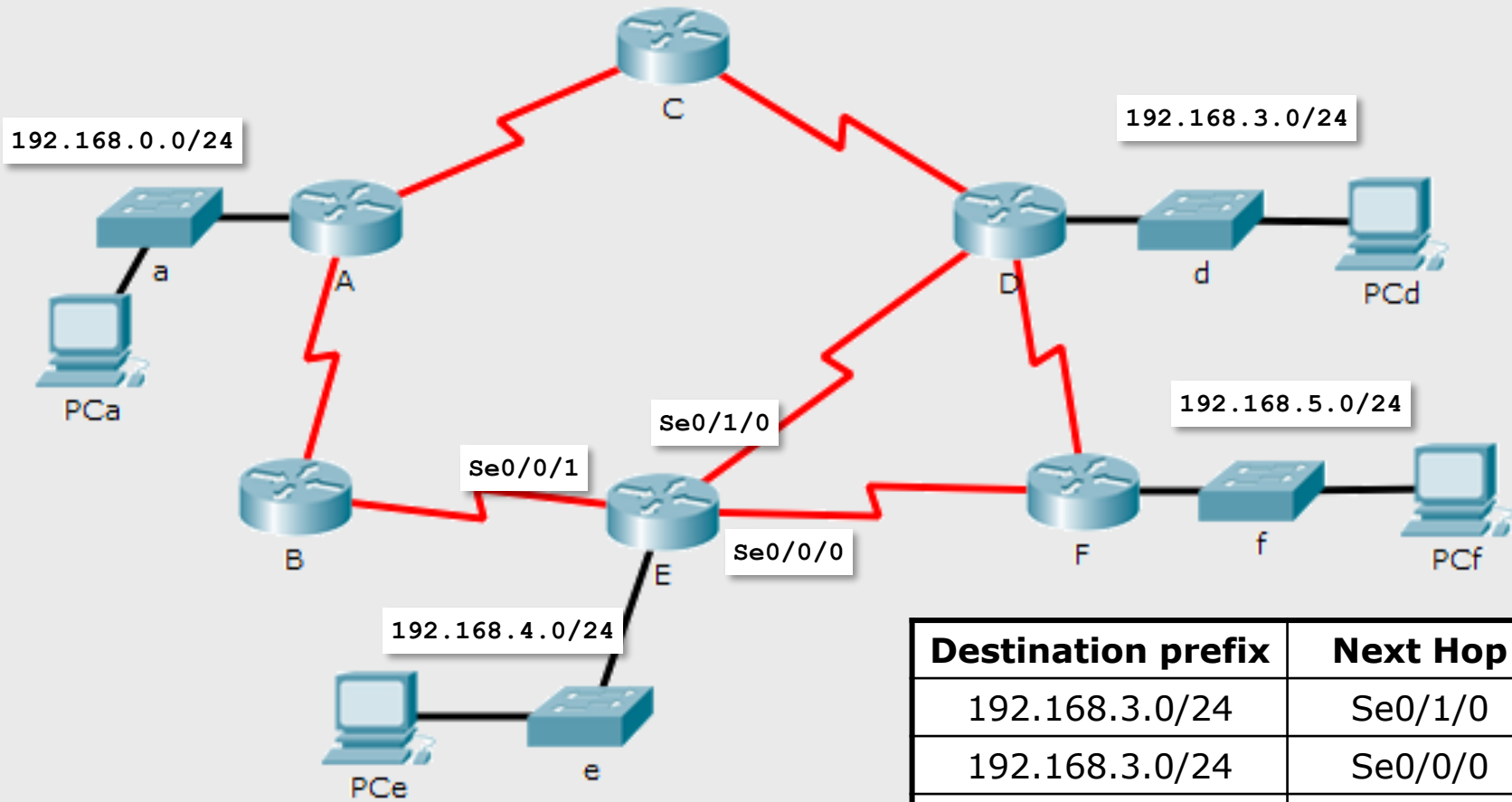


# Static routing – when to use

---

- Dynamic routing is not preferred for security reasons
  - Routing protocol can be a means to compromise network operation
  - Static routing enforces routes
    - To pass through firewalls
    - To pass through safe portions of the network
- Routing policies are in place
  - Service level agreements
  - Load balancing

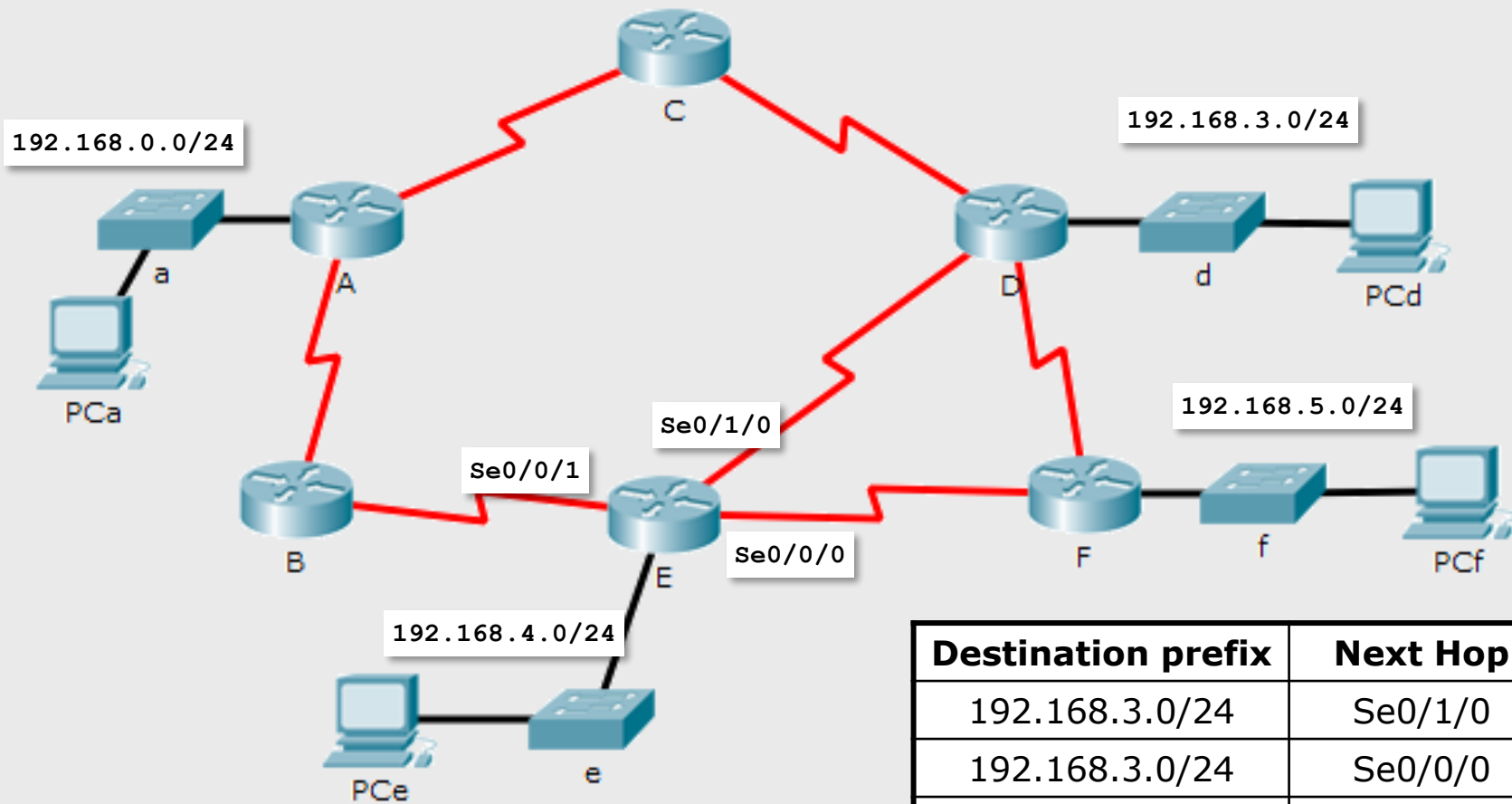
# Static routing – design phase



Routes to destinations must be carefully planned on each router **to avoid routing loops**

Destination prefix	Next Hop	Cost
192.168.3.0/24	Se0/1/0	30
192.168.3.0/24	Se0/0/0	40
192.168.0.0/24	Se0/0/1	30
192.168.0.0/24	Se0/1/0	40
192.168.5.0/24	Se0/0/0	30

# Static routing – configuration phase

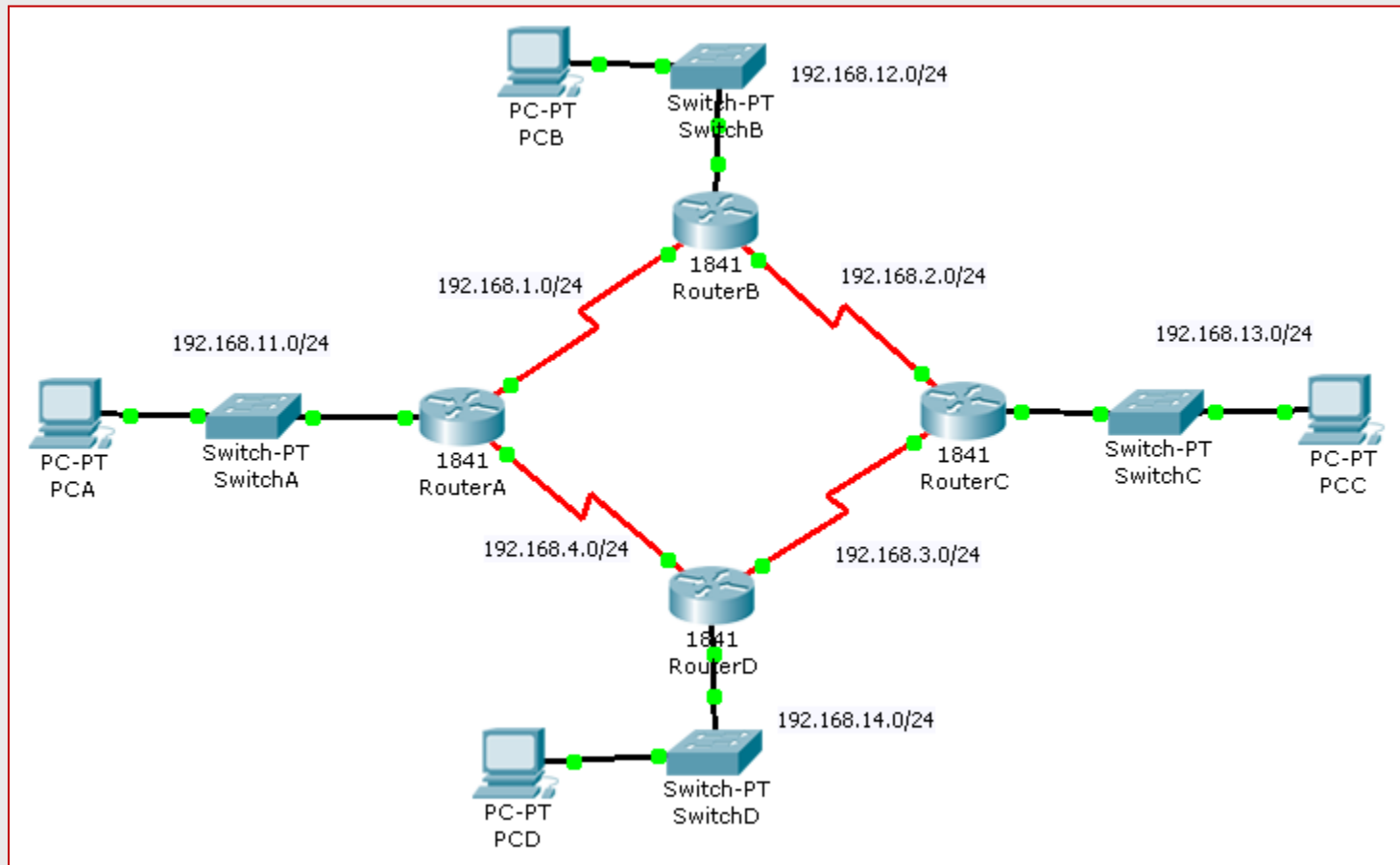


Routing table entries are manually configured by the network manager (already covered)

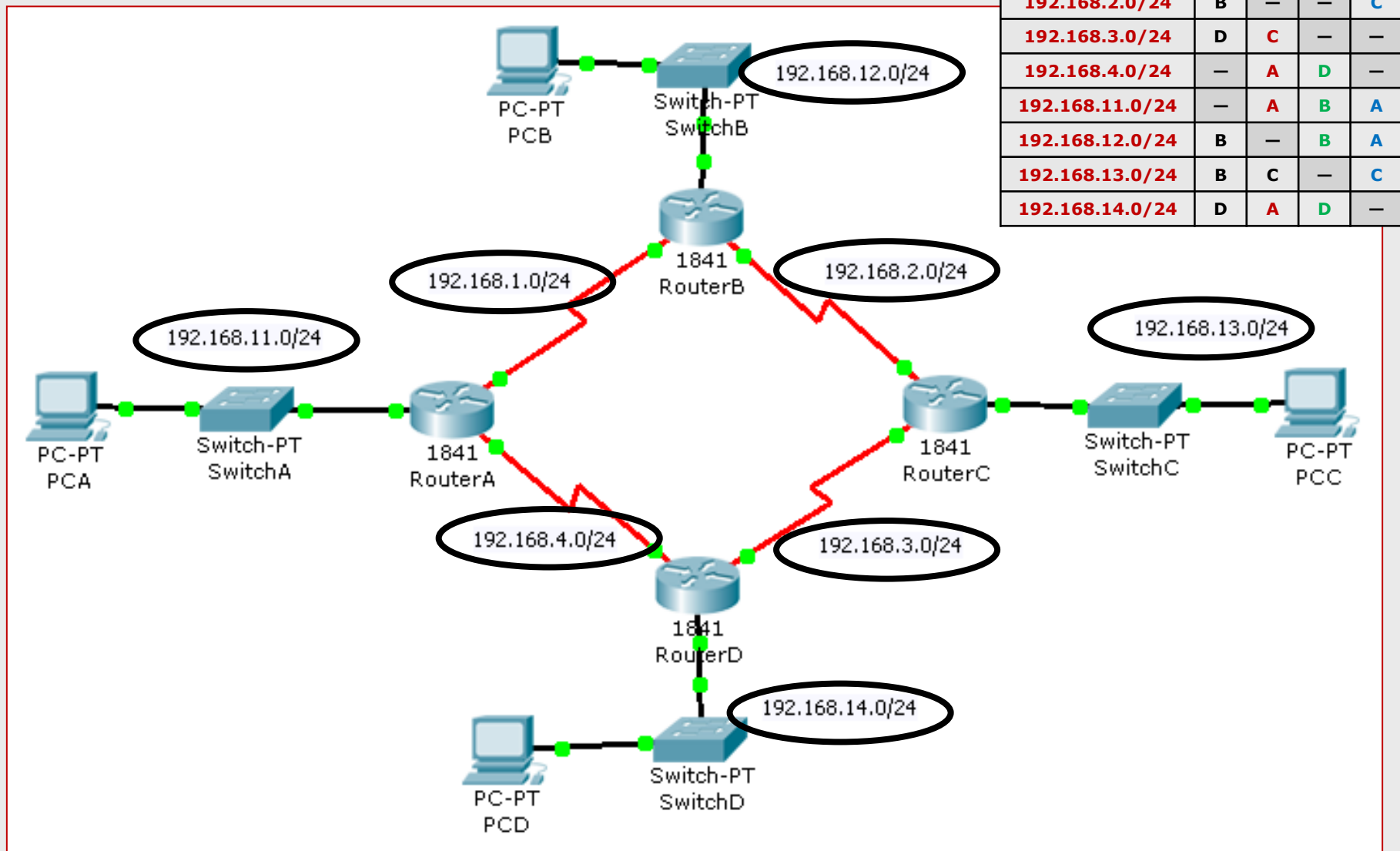
Destination prefix	Next Hop	Cost
192.168.3.0/24	Se0/1/0	30
192.168.3.0/24	Se0/0/0	40
192.168.0.0/24	Se0/0/1	30
192.168.0.0/24	Se0/1/0	40
192.168.5.0/24	Se0/0/0	30

# Static routing – design phase

- Use of a “design table” to keep track of planned routes and identify loops



# Static routing – design phase

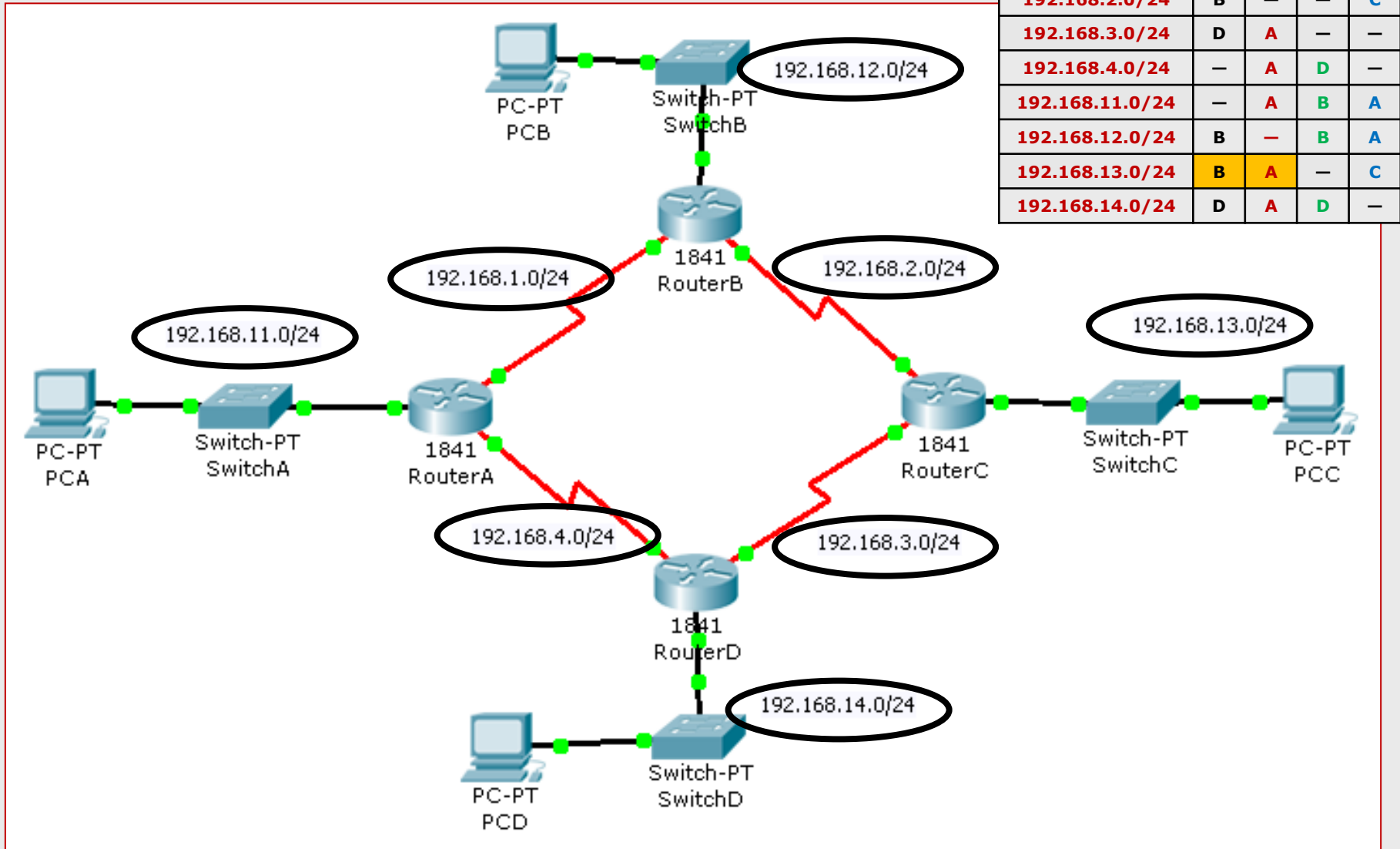


	A	B	C	D
192.168.1.0/24	—	—	B	A
192.168.2.0/24	B	—	—	C
192.168.3.0/24	D	C	—	—
192.168.4.0/24	—	A	D	—
192.168.11.0/24	—	A	B	A
192.168.12.0/24	B	—	B	A
192.168.13.0/24	B	C	—	C
192.168.14.0/24	D	A	D	—

# Static routing – design phase

## ■ RouterB

### Routing Loop

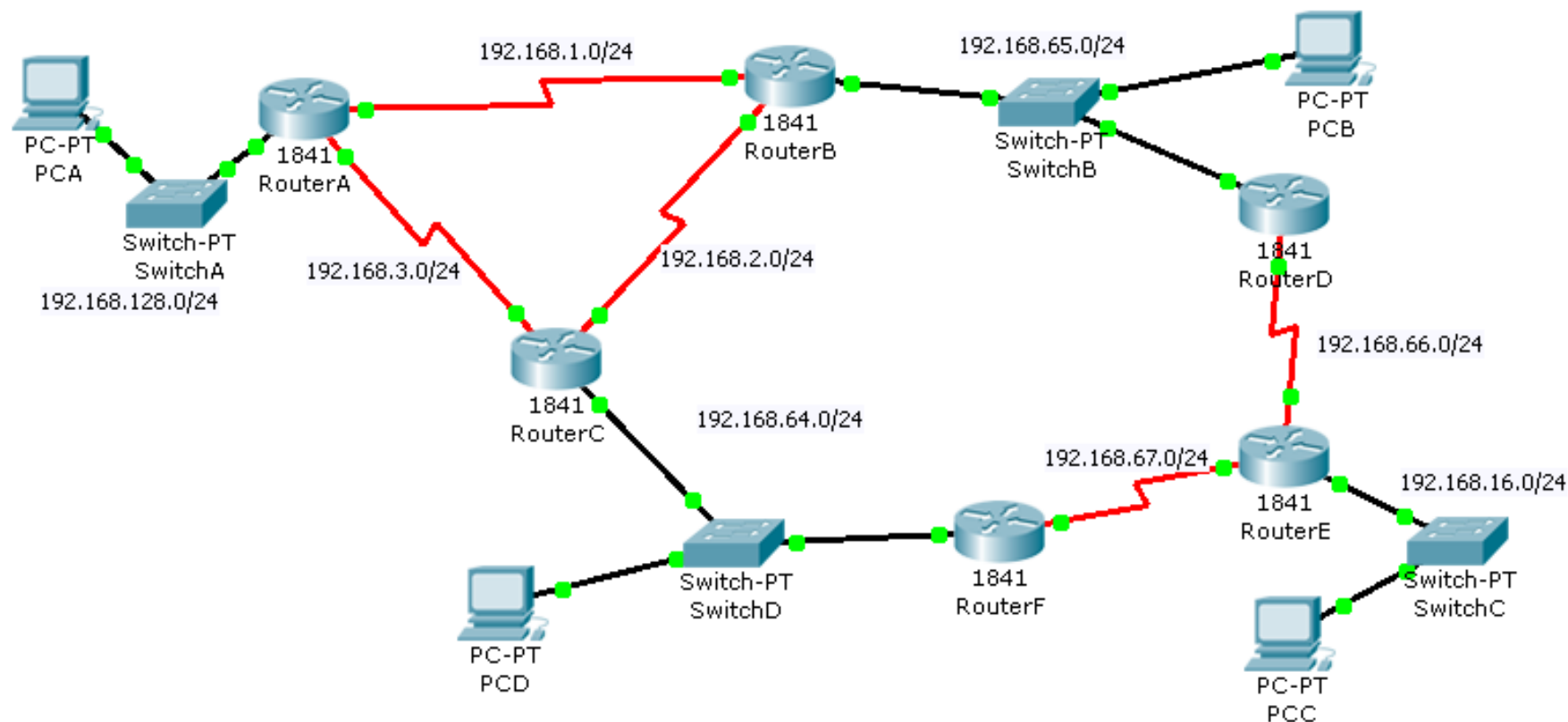


# Static routing – design phase

---

- How to avoid loops?
  - Loops are **guaranteed** to be avoided if the shortest-path tree to each destination network is used for each router
  - For directed graphs with non-negative weights, the shortest-path tree is computed by the **Dijkstra's algorithm**
- What if additional constraints are specified?
  - e.g., do not use a specific link for primary paths, ...
  - A constrained shortest-path tree is defined
    - out of scope of this class

# Static routing – design phase





# Static routing – design phase

- Use of a “design table” to keep track of planned routes and identify loops

Network	RA	RB	RC	RD	RE	RF
<b>192.168.128.0/24</b>	—					
<b>192.168.1.0/24</b>	—	—				
<b>192.168.2.0/24</b>		—	—			
<b>192.168.3.0/24</b>	—		—			
<b>192.168.16.0/24</b>					—	
<b>192.168.64.0/24</b>			—			—
<b>192.168.65.0/24</b>		—		—		
<b>192.168.66.0/24</b>				—	—	
<b>192.168.67.0/24</b>					—	—

# Static routing – design phase

- Use of a “design table” to keep track of planned routes and identify loops

Network	RA	RB	RC	RD	RE	RF
192.168.128.0/24	—	RA	RA	RB	RF	RC
192.168.1.0/24	—	—	RB	RB	RD	RC
192.168.2.0/24	RB	—	—	RB	RF	RC
192.168.3.0/24	—	RA	—	RB	RF	RC
192.168.16.0/24	RC	RD	RF	RE	—	RE
192.168.64.0/24	RC	RC	—	RB	RF	—
192.168.65.0/24	RB	—	RB	—	RD	RC
192.168.66.0/24	RB	RD	RB	—	—	RC
192.168.67.0/24	RC	RC	RF	RB	—	—