# Networks: The Routing

Ali Benzerbadj

University of Ain Temouchent Belhadj Bouchaïb (UAT-BB)

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# Plan

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# Routing

### What is Routing ?

Routing in networks involves finding the least costly paths to route data to their destinations. Routers act as guides that assist this data in reaching its destinations as efficiently as possible.

# Routing

## What is Routing ?

The main function of a router is to move an IP packet from one network to another, and for this, the router needs the following :

- The destination address
- Possible routes
- The best route

# Routing


Figure 1 – Routing [1]

# Routing

## Autonomous Systems

It should be noted that [2] :

- A network of interconnected routers and related systems managed by a common network administration is called an **Autonomous System (AS)** or routing domain (see Figure 2).
- The internet is composed of thousands of autonomous systems distributed worldwide.

# Autonmous Systems

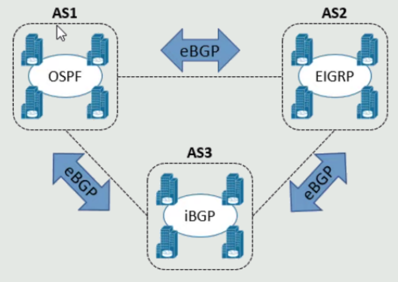



Figure 2 – Autonomous Systems (iBGP : Interior Gateway BGP, eBGP : Exterior Gateway BGP) [2]

# Routing

## Autonomous Sytems

- An Autonomous System (AS) is a collection of routers and networks under the same administration.
- Autonomous Systems are identified by 32-bit numbers called Autonomous System Numbers (ASNs) (originally, the number space was limited to 16 bits, but it has been expanded to 32 bits).

# Routing

## Autonomous Sytems

- IP packets are transmitted between Autonomous Systems over paths established by an Exterior Gateway Protocol (EGP).
- Within an Autonomous System, IP packets are transmitted over paths established by an Interior Gateway Protocol (IGP).

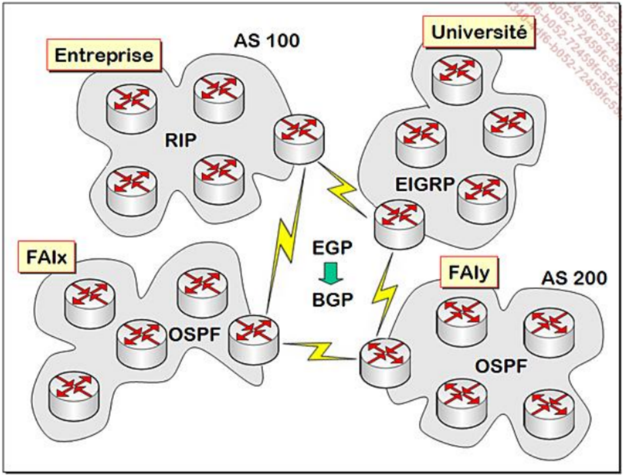



Figure 3 – Autonomous systems, IGP et EGP [3].

# Routing

## Types of Routing

There are two types of Routing :

- Static Routing
- Dynamic Routing

# Routing

## Static Routing

In this type of routing, the network administrator **manually** configures information about the remote network(s). It is worth noting that if a network is directly [a] connected to a router, it is automatically recognized by the router without the administrator's intervention.

*a*. A directly connected network is a network directly attached to one of the router's network interfaces.

# Routing

## Advantages of Static Routing

- Bandwidth conservation : Since no information about routes is exchanged between routers for them to stay updated, the bandwidth is not congested with information and routing exchange messages.
- No overload on the router's processor : The load is rather on the administrator.

# Routing

## Advantages of Static Routing

- Foreknowledge of the path : The administrator, having configured the entire topology, will know exactly through which path packets transit from one network to another. This could facilitate understanding of any errors that may occur during packet transmission.
- Security : Unlike dynamic routing protocols, static routing does not broadcast route information over the network since routes are manually configured by the administrator.

# Routing

## Disadvantages of Static Routing

- If a network is added to the initial topology, the administrator must add a route for it on all routers.
- Not feasible in large networks : For example, imagine an administrator who configures a certain number of routers $n$ (e.g., $n \geq 8$) one by one within the network to indicate remote routes.

# Routing

## Setting up a default static route in PacketTracer

A candidate default network (or default route) is a routing table entry that directs packets to a defined next hop when there is no explicit entry for the destination network. This type of route is used, for example, to redirect packets from a LAN to the Internet (see Figure 4).

# Routing

## Setting up a default static route in PacketTracer

Any packet that a router receives without an explicit or implicit entry (candidate default network or default route) in the routing table is discarded, and an ICMP (Internet Control Message Protocol) “Network Unreachable” message is sent by the router to the source station [4].

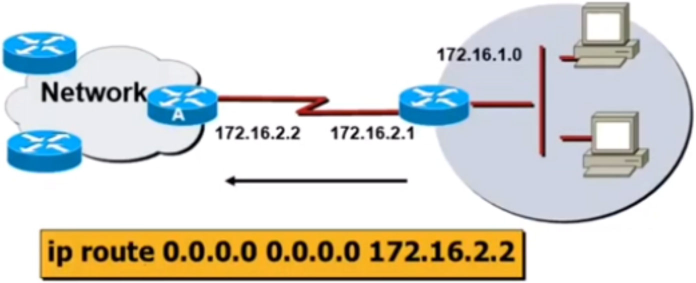



Figure 4 – Configuration of a default static route [1].

# Routing

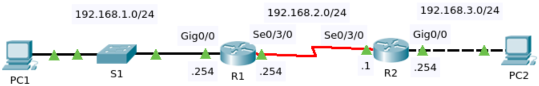
## Setting up a static route in PacketTracer

1. Adding a static route in Cisco Packet Tracer.
   - Router(config)# *ip route* network-address subnet-mask exit-interface
     For example, for the case of router R1 in Figure 5, we enter the following command :
     - Router(config)# *ip route* 192.168.3.0 255.255.255.0 192.168.2.1

# Routing

## Setting up a static route in PacketTracer

2. Adding a default static route in Cisco PacketTracer :
   - Router(config)# *ip route* 0.0.0.0 0.0.0.0 exit-interface
     For example, for the case of router R1 in Figure 4, we enter the following command :
     - Router(config)# *ip route* 0.0.0.0 0.0.0.0 172.16.2.2




```
R1#sh ip route
Codes: L - local, C - connected, S - static, 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

     192.168.1.0/24 is variably subnetted, 2 subnets, 2 masks
C       192.168.1.0/24 is directly connected, GigabitEthernet0/0
L       192.168.1.254/32 is directly connected,
GigabitEthernet0/0
     192.168.2.0/24 is variably subnetted, 2 subnets, 2 masks
C       192.168.2.0/24 is directly connected, Serial0/3/0
L       192.168.2.254/32 is directly connected, Serial0/3/0
S    192.168.3.0/24 [1/0] via 192.168.2.1
```

Figure 5 – Configuration of static routes.

# Routing

## Dynamic Routing

In this type of routing, information is learned from other routers, and routing protocols automatically adjust the routes. Among the common dynamic routing protocols are :

# Routing

## Dynamic Routing

- RIP (v1 & v2) [a]
- EIGRP [b]
- OSPF [c]
- IS-IS [d]
- BGP [e]

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a. Routing Information Protocol version 1 & version 2
b. Enhanced Interior Gateway Routing Protocol
c. Open Shortest Path First
d. Intermediate System-to-Intermediate System
e. Border Gateway Protocol

# Routing

## Advantages of Dynamic Routing

- Dynamic sharing of information about remote networks between routers.
- Discovery of remote networks and updating of routing tables as soon as a topology is modified.
- Searching for the best path (and backup path) to each destination.

# Routing

## Disdvantages of Dynamic Routing

- Consumption of processor time and network link bandwidth.
- Security issues

# Routing

## Classification of Dynamic Routing Protocols

- Figure 6 illustrates a classification of dynamic routing protocols according to their type, namely IGP (Interior Gateway Protocol) or EGP (Exterior Gateway Protocol), and the algorithm used for path selection, i.e., distance vector, link state, hybrid, or path vector.
- Figure 7 extends the classification to the addressing mode used by these protocols (classful or classless).

# Routing

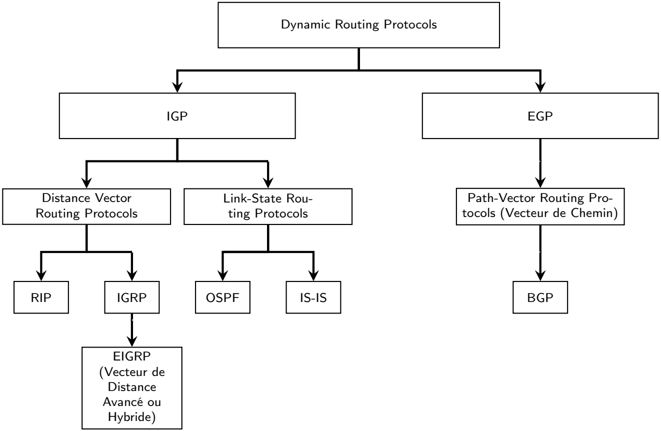


Figure 6 – Classification of dynamic routing protocols according to type and algorithm used.

# Routing

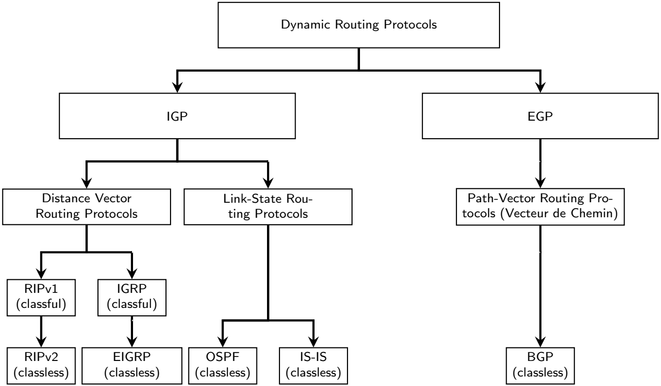


Figure 7 – Classification of dynamic routing protocols according to type, algorithm used, and addressing mode.

# Routing

**Algorithms for route selection**

The IGPs and EGPs protocols use different algorithms for route selection, as illustrated in Table 1.

Table 1 – Routing Protocols and Path Selection Algorithms.

| Routing protocol | Routing algorithm |
|---|---|
| RIP v1 & v2 | Distance vector |
| OSPF / IS-IS | Link-state |
| EIGRP | Advanced Distance Vector or Hybrid |
| BGP | Path vector |

# Routing

## Distance Vector Algorithm

- Routing protocols using distance vector, such as RIP, advertise routes in the form of distance vectors, where the distance is a metric such as the number of hops, and the vector is the IP address of the next-hop router used to reach the destination, as illustrated in Figures 8 and 9.

# Routing

## Distance Vector Algorithm

- When a router receives routing information from a neighbor, it stores it in a local routing database as it receives it. Then, it uses a distance vector-type algorithm such as the Bellman-Ford algorithm or the Ford-Fulkerson algorithm to determine the best loop-free paths to each reachable destination.

# Routing

## Distance Vector Algorithm

- When the best paths are determined, they are installed in the routing table and announced to each neighboring router.

# Routing

## Distance Vector Algorithm

- Routers running the distance vector protocol advertise routing information to their neighbors "from their own perspective," i.e., modified from the original routes received (after running Bellman-Ford or any similar algorithm). Therefore, a distance vector protocol does not have a complete map of the entire network, but its database indicates that a neighboring router knows how to reach the destination network and at what distance it is from that network.

# Routing

## Distance Vector Algorithm

- Distance vector protocols require fewer CPU [a] and memory resources and can therefore operate on entry-level routers.
- Distance vector protocols select paths based solely on the number of hops. They do not take into account other metrics such as link quality (bandwidth, delay, RSSI [b], etc.).

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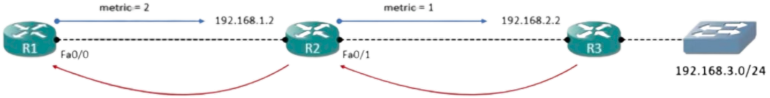
a. Central Processing Unit
b. Received Signal Strength Indicator




| Network | Metric | Next_Hop_IP |
|---|---|---|
| **192.168.3.0/24** | 2 | 192.168.1.2 |

| Network | Metric | Next_Hop_IP |
|---|---|---|
| **192.168.3.0/24** | 1 | 192.168.2.2 |

Figure 8 – Distance vector algorithm : Example 1 [2]

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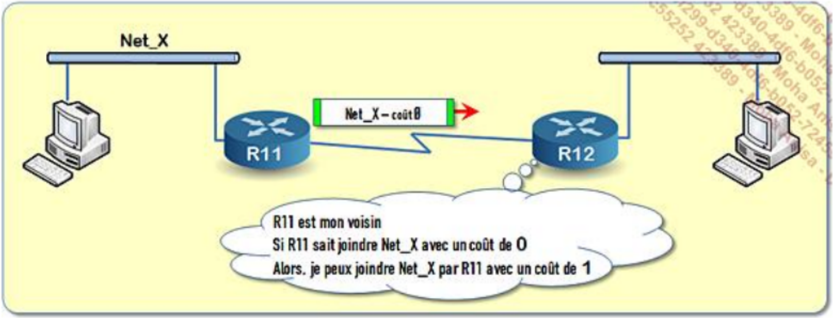


Figure 9 – Distance vector algorithm : Example 2 [3]

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# Routing

## Distance Vector Algorithm

In a distance vector routing protocol :

- The route is defined as a direction associated with a distance.
- Each router in the network relies on its neighbors to learn routes and contributes to its neighbors' learning by announcing the routes it knows. Topology information circulates from neighbor to neighbor in the network, which is sometimes referred to as "rumor routing".

# Routing

## Advanced Distance Vector or Hybrid Algorithm

DUAL [a] is an enhanced distance vector algorithm used by EIGRP, for example, to calculate the shortest path to a destination. Among the enhancements introduced in the DUAL algorithm compared to other distance vector algorithms are :

a. Diffusing Update ALgorithm

# Routing

## Advanced Distance Vector or Hybrid Algorithm

- Fast convergence time for changes in the network topology.
- Sending updates only when there is a change in the network topology. There is no periodic sending of complete routing table updates, as done by distance vector protocols like RIP, for example, which sends the entire routing table every 30 seconds (default period).
- Periodically using "hello" to form neighbor relationships, as done by link-state protocols like OSPF.

# Routing

## Advanced Distance Vector or Hybrid Algorithm

- Using bandwidth, delay, reliability, load, and MTU size [a] instead of the number of hops to calculate the path. For example, EIGRP is based on bandwidth and delay (see Figure 10).
- Ability to balance traffic load on equal or unequal cost paths.

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*a*. Maximum Transmission Unit

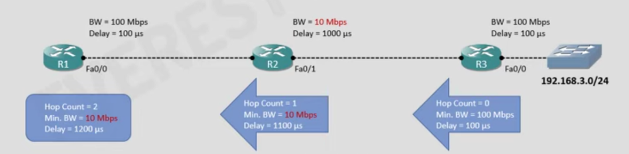


Figure 10 – EIGRP [2].

# Routing

## Link-State Algorithm

- OSPF and IS-IS are two examples of this type of protocols, commonly used in enterprise networks and service provider networks.
- OSPF announcements are called LSAs [a] while the announcement messages used by IS-IS are called LSPs [b].

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*a.* Link-state Advertisements
*b.* Link-State packets

# Routing

## Link-State Algorithm

- When a router receives an announcement from a neighbor, it stores the information in a local database called LSDB [a] and announces the link-state information to each of its neighboring routers exactly as it received them.

a. Link-State Data Base

# Routing

## Link-State Algorithm

- Link-state information is essentially broadcast throughout the network, unchanged from one router to another, exactly as the originating router announced it. This allows all routers in the network to have a synchronous and identical map of the network topology (Routers R1, R2, and R3 in Figure 11 each know the complete network topology.)

# Routing

## Link-State Algorithm

- Using the complete network map, each router in the network then runs the Dijkstra SPF [a] algorithm to calculate the best shortest loop-free paths. The link-state algorithm then populates the routing table with this information.

a. Shortest Path First

# Routing

## Link-State Algorithm

- Since routers running a link-state routing protocol each construct a complete map of the network topology, they therefore need more resources, in terms of CPU and memory, than routers running a distance vector protocol.
- Link-state protocols are less prone to routing loops and make better path decisions.

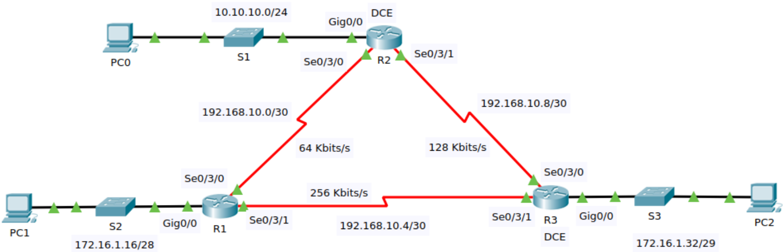


Figure 11 – OSPF.

IOS Command Line Interface

```
Router#
Router#
Router#show ip route
Codes: L - local, C - connected, S - static, 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

     10.0.0.0/24 is subnetted, 1 subnets
O       10.10.10.0/24 [110/1172] via 192.168.10.6, 01:07:44, Serial0/3/1
     172.16.0.0/16 is variably subnetted, 3 subnets, 3 masks
C       172.16.1.16/28 is directly connected, GigabitEthernet0/0
L       172.16.1.17/32 is directly connected, GigabitEthernet0/0
O       172.16.1.32/29 [110/391] via 192.168.10.6, 01:21:31, Serial0/3/1
     192.168.10.0/24 is variably subnetted, 5 subnets, 2 masks
C       192.168.10.0/30 is directly connected, Serial0/3/0
L       192.168.10.1/32 is directly connected, Serial0/3/0
C       192.168.10.4/30 is directly connected, Serial0/3/1
L       192.168.10.5/32 is directly connected, Serial0/3/1
O       192.168.10.8/30 [110/1171] via 192.168.10.6, 01:07:44, Serial0/3/1

Router#
Router#
```

Ctrl+F6 to exit CLI focus — Copy — Paste

Figure 12 – Router R1's routing table corresponding to the topology in Figure 11.

# Routing

## Path Vector Algorithm

- External BGP, which is the protocol used for external routing (inter-AS routing), uses this type of algorithm.

# Routing

## Path Vector Algorithm

- A router running External BGP does not announce a metric to its neighbors, as in the case of distance vector protocols, but rather the complete path that the announcement has taken before reaching the receiver. For example, in the topology of Figure 13, router S announces S, router A announces A-S, and router B announces B-A-S. The next-hop is defined as the node at the head of the path.

# Routing

## Path Vector Algorithm

- To prevent loops, each router, before accepting an announcement, checks if it is present in the announced path ; if so, it ignores the announcement. An announcement is preferred over another if the path it carries is shorter. It is the length of the path that serves as the metric.

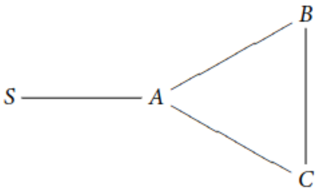


Figure 13 – Network Topology.

# Routing

**Routing table**

The routing table is the central component of a router. It is used by the routing function to determine the best path for each destination known to the router.

# Routing

## Routing table

The Routing table includes :

- Directly connected routes.
- Static routes configured by the administrator.
- Routes learned through a dynamic routing protocol.

# Routing

## Routing table

A routing table typically has the following fields :

- Destination : network to be reached + subnet mask
- Next Hop (Gateway) : the IP address of the next router on the path to reach the destination network.
- Metric
- Administrative Distance (AD)
- Means of learning the route

# Routing

## Routing table : The metric

In a routing protocol, the metric is a measure of the “distance” between a router and a destination network. It can correspond to :

# Routing

## Routing table : The metric

- The number of IP hops required to reach the destination network, as in the RIP protocol.
- A numerical cost that depends on the bandwidth of the traversed links, as in the OSPF protocol.
- The result of a more complex calculation, which takes into account load, delay, MTU, etc.

A metric with the smallest value reflects the best path.

# Routing

## Routing table : The Administrative Distance

- The Administrative Distance (AD) is an integer value between 0 and 255 indicating the origin of the route (connected route, static route, route learned via a dynamic routing protocol such as RIP, OSPF, etc.).
- The AD indicates the preference of one route over another. Indeed, the smaller the AD value, the better the route.

Table 2 – AD : Examples.

| Type of route | AD |
|---|---|
| Connected route | 0 (Absolute trust) |
| Static route | 1 (It is the administrator who configures the route. It is considered that he knows what he is doing.) |
| RIP | 120 |
| OSPF | 110 |
| IGRP | 100 (Replaced by EIGRP) |
| IS-IS | 115 |
| Internal BGP | 200 |
| External BGP | 20 |
| Internal EIGRP | 90 |
| External EIGRP | 170 |
| Unreliable | 255 (Unreliable source, the route is not installed in the routing table) |

# Routing

**Routing table : Means of Learning a Route**

It indicates the learning method for each entry in the routing table as illustrated in Table 3.

Table 3 – Means of Learning a Route.

| Code | Means of Learning a Route |
|---|---|
| C | Directly connected |
| S | Static |
| R | RIP |
| O | OSPF |
| I | IGRP |
| * | Default route |
| D | EIGRP |
| EX | external EIGRP |
| B | BGP |

# Routing

## How to fill a Routing table

A host's routing table is built as follows :

1. Specify the networks to which the host is directly connected.
2. Specify the default route.
3. Specify any other networks that the host cannot reach yet with the previous two steps.

# Routing

**Example**

Consider the network in Figure 14. Table 4 lists all the routes following the three rules for filling a routing table mentioned above. This is a $1^{st}$ solution where we considered a default route. Table 5 represents the $2^{nd}$ solution where we do not consider a default route since there is no access to the internet.

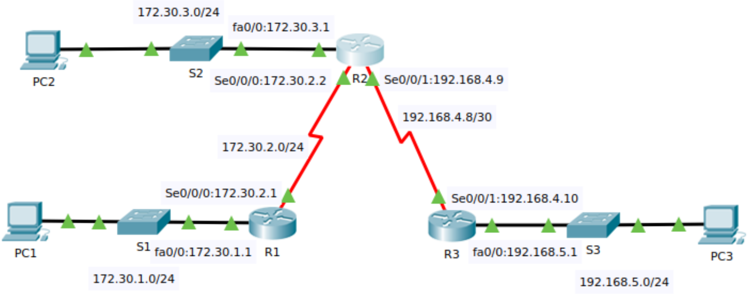


Figure 14 – Network topology

Table 4 – Routing Table of Router R2 : First Solution.

| Learning Method | Network to Reach | Mask | Gateway | AD | Metric |
|---|---|---|---|---|---|
| C | 172.30.2.0 | 255.255.255.0 | 172.30.2.2 | - | - |
| C | 172.30.3.0 | 255.255.255.0 | 172.30.3.1 | - | - |
| C | 192.168.4.8 | 255.255.255.252 | 192.168.4.9 | - | - |
| $S^*$ | 0.0.0.0 | 0.0.0.0 | 192.168.4.10 | 1 | 0 |
| S | 172.30.1.0 | 255.255.255.0 | 172.30.2.1 | 1 | 0 |

Table 5 – Routing Table of Router R2 : Second Solution.

| Learning Method | Network to Reach | Mask | Gateway | AD | Metric |
|---|---|---|---|---|---|
| C | 172.30.2.0 | 255.255.255.0 | 172.30.2.2 | - | - |
| C | 172.30.3.0 | 255.255.255.0 | 172.30.3.1 | - | - |
| C | 192.168.4.8 | 255.255.255.252 | 192.168.4.9 | - | - |
| S | 192.168.5.0 | 255.255.255.0 | 192.168.4.10 | 1 | 0 |
| S | 172.30.1.0 | 255.255.255.0 | 172.30.2.1 | 1 | 0 |

# Routing

## RIP

- RIP protocol is a distance vector IGP routing protocol.
- It is an open standard protocol, meaning it can be used with non-Cisco devices, including Juniper and other network equipment from various vendors.
- Generally, it is suitable for a small-sized network.

# Routing

## RIP

- It supports a maximum of 15 hops in a path.
- It uses hop count metric to calculate the best path from a source to a destination network.
- It sends routing updates (the entire routing table) every 30 seconds and when the network changes (such as a route going down or a new network appearing, routers do not wait for 30 seconds to exchange routing tables. This is called a triggered update).

# Routing

## RIP

- It uses UDP broadcast packets and port 520 to exchange routing information.
- The administrative distance (AD) value of the RIP protocol is 120.
- There are 3 versions of the RIP protocol : RIPv1, RIPv2, and RIPng which is an improvement over RIPv2 designed to support IPv6 networks.

# Routing

### RIP

The Tables 6 and 7 list the different types of timers used by the RIP protocol to optimize network performance.

Table 6 – Different types of timers used by the RIP protocol.

| Timer | Objective | Default value (seconds) | Description |
|---|---|---|---|
| Update Timer | Controls the frequency of sending updates | 30 | Specifies the interval between periodic updates. Each router sends its complete routing table to its neighbors at this interval. |
| Invalid Timer | Marks a route as invalid in the absence of updates. | 180 | If a router does not receive an update for a route within this timeframe, it marks the route as invalid, indicating that the destination is no longer reachable. |

Table 7 – Different types of timers used by the RIP protocol (Continue).

| | | | |
|---|---|---|---|
| Hold-down Timer | Prevents the use of invalid routes | 180 | After a route has been marked invalid, the router waits for the Hold-down Timer before accepting new updates for the same destination to prevent rapid changes. |
| Flush Timer | Deletes an unreachable route. | 240 | After a route has been marked invalid, the router waits for the Flush Timer before deleting the route from its routing table. |

# Routing

## RIP : Remark

If all routers were to use Update Timer timers set with the same value of 30 seconds, for example, a phenomenon of synchronization of their RIP announcements would occur after a certain time. To avoid this phenomenon, which would lead to packet bursts and risks of cyclic congestion, the actual timer values are randomly disturbed from 0 to 5 seconds.

# Routing

**Commands to implement RIP in PacketTracer**

- Router(config)# router rip $\rightarrow$ Activate the RIP process on the router
- Router(config-router)# version 2 $\rightarrow$ Activate version 2 of RIP

# Routing

## RIPv2

RIPv2 is an enhanced version of RIPv1. RIPv2 provides more features than RIPv1. Tables 8 and 9 list the main differences between RIPv1 and RIPv2 :

Table 8 – RIPv1 vs. RIPv2

| Feature | RIPv1 | RIPv2 |
|---|---|---|
| Protocol family | IGP | IGP |
| Addressing system | Classful :<br>The subnet mask<br>is not transmitted<br>in routing updates | Classless :<br>The subnet mask<br>is transmitted<br>in routing updates |
| Update interval | 30 seconds | 30 seconds |
| Basic algorithm | Bellman-Ford | Bellman-Ford |
| Routing update address | Broadcast<br>(255.255.255.255) | Multicast<br>(224.0.0.9) |
| Protocol and Port | UDP 520 | UDP 520 |

[a] Variable Length Subnet Mask
[b] Classless Inter Domain Routing

Table 9 – RIPv1 vs. RIPv2 (Continue)

| Feature | RIPv1 | RIPv2 |
|---|---|---|
| Metric unit | Hop (until 15) | Hop (until 15) |
| Update element | Entire table | Entire table |
| VLSM[a] | Does not support | Supports |
| CIDR[b] | Does not support | Supports |
| Authentication | Does not support | Supports |
| Non-contiguous networks | Does not support | Supports |

# Routing

## OSPF

- This is a standard protocol, i.e., non-proprietary, and therefore can operate on a CISCO, Juniper, Huawei router, etc.
- It is based on the Shortest Path First (SPF) algorithm, often referred to as the Dijkstra algorithm.
- There are two versions of OSPF, namely OSPFv2 (supports only IPv4) and OSPFv3 (supports only IPv6). Tables 10 and 11 list some characteristics of the OSPF protocol.

Table 10 – Characteristics of the OSPF protocol.

| | |
|---|---|
| Protocol family | IGP |
| Addressing system | Classless |
| Basic algorithm | Dijkstra |
| $IP_{v_4}$ Routing update address | Multicast (224.0.0.5) |
| $IP_{v_6}$ Routing update address | Multicast (FF02 : :5) |
| Metric unit | Cost= $\frac{10^8}{BandWidth}$ |
| Hop count | Unlimited |

Table 11 – Characteristics of the OSPF protocol (Continue).

| | |
|---|---|
| VLSM | Supports |
| Non-contiguous networks | Supports |
| Transport protocol | Does not use UDP or TCP. The protocol number used : 59(Hexa) 89 (Decimal) |
| Route summarization | Support |
| Authentication | Supports |
| Loop Free Topology | Yes (because each router has a complete map of the global topology of the network |

# Routing

## OSPF

- As soon as the OSPF protocol is activated on the routers in Figure 15, each of them will send a “hello” message to discover their direct neighbors.
- Each router will send a Link State Advertisement (LSA) message to the routers connected to its interfaces. An LSA message contains information about the router ID, the router’s interfaces (fa0/0, gig0/0, se0/1/0, etc.), and the IP addresses configured on these interfaces.

# Routing

## OSPF

- It is worth noting that routers configured with the OSPF protocol do not exchange entire routing tables as routers do with RIP. Instead, they exchange Link State Advertisements (LSAs).
- Each router that receives an LSA saves it in a database called LSDB (Link State Database) or Topological Database, and forwards it in turn to the routers connected to it.

# Routing

## OSPF

- Based on the LSDB, each router will create an SPF (Shortest Path First) tree with itself as the root, i.e., a kind of map of the global network topology.
- Based on the created SPF tree, each router will construct its routing table.

# Routing

## OSPF

- It is worth noting that each router has three types of tables :
  - Neighbor table (LSDB)
  - Topology table (SPF tree)
  - Routing table

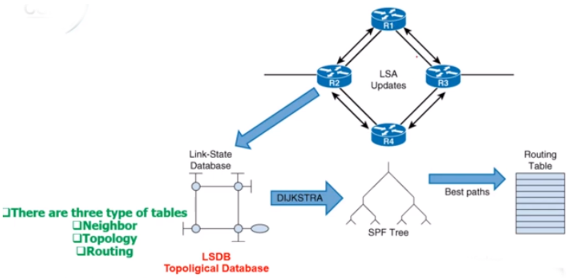


Figure 15 – OSPF : Operation [1]

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André Vaucamps. *Cisco : protocoles et concepts de routage : configuration avancée des routeurs*. ENI, 2010.

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