Day 24: Dynamic Routing Protocols

Dynamic Routing vs. Static Routing

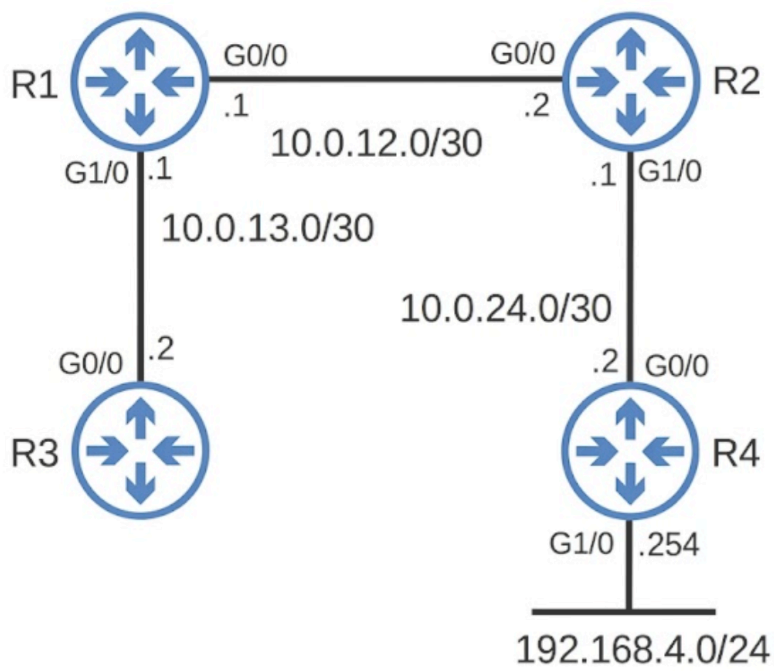
- **Static Routing:** Manually configuring routes to each destination with the `IP ROUTE` command (covered in Day 11).
- **Dynamic Routing:** Configuring a dynamic routing protocol on the router, letting the router find the best routes to destination networks.
    - Called "dynamic" because it is not fixed.
    - **Automatic Updates:** If you add a new LAN, routers automatically inform each other how to reach the new network.
    - **Automatic Failover:** If a path becomes unavailable, routers automatically start using the next-best path.

Lecture Overview

- **General Overview:** Demonstrate how dynamic routing protocols function and why they are preferred over static routes.
- **Types of Protocols:** Break down the different types of dynamic routing protocols.
- **Metrics:** A protocol's "metric" measures how "far" the destination is (similar to root cost in STP) and determines the best route.
- **Administrative Distance:** Another method used to determine the best route to a destination.

Demonstration Topology & Basic Concepts

Network Topology



- Four routers: R1, R2, R3, R4
- LAN connected to R4: 192.168.4.0/24
- Focus is on R1's perspective

Default Routing Table (No Static/Dynamic Routing Configured)

```
      10.0.0.0/8 is variably subnetted, 4 subnets, 2 masks
C        10.0.12.0/30 is directly connected, GigabitEthernet0/0
L        10.0.12.1/32 is directly connected, GigabitEthernet0/0
C        10.0.13.0/30 is directly connected, GigabitEthernet1/0
L        10.0.13.1/32 is directly connected, GigabitEthernet1/0
R1#
```

- Only **connected** and **local** routes are present
- These are automatically added when IP addresses are configured on interfaces

Route Types

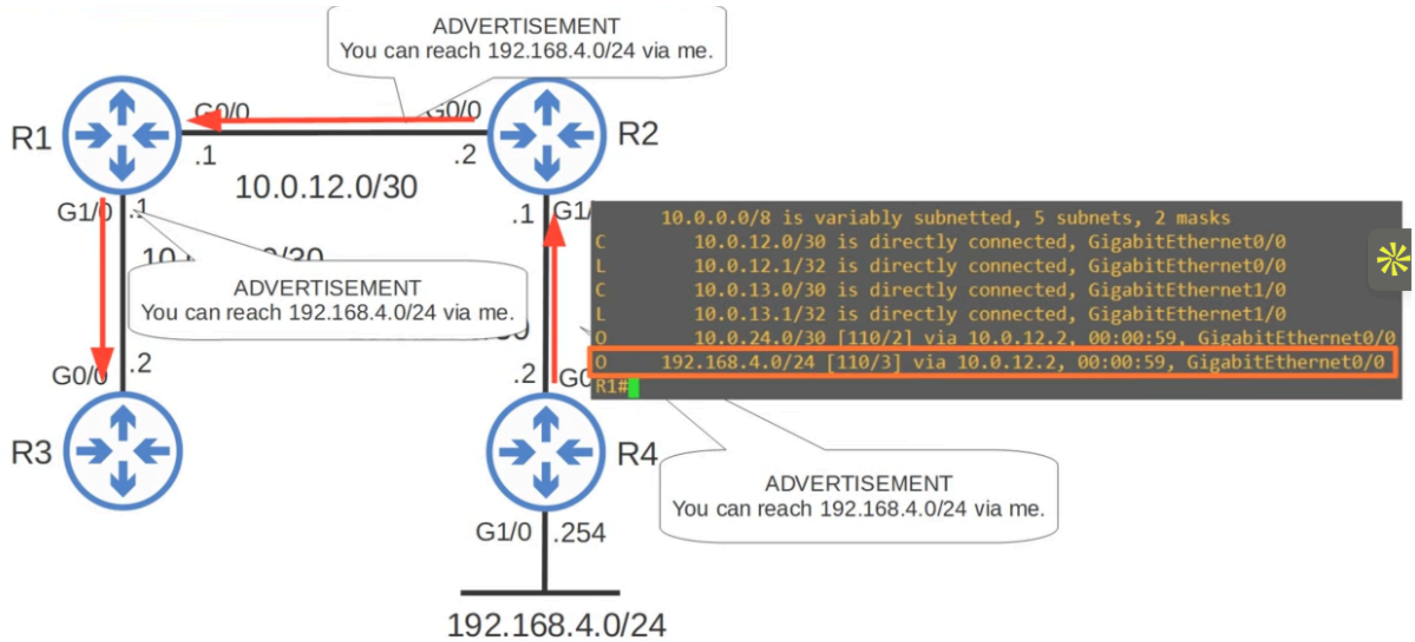
- **Network Route:** A route to a network or subnet (mask length less than /32)
  - Example: 10.0.12.0/30, 10.0.13.0/30, or 192.168.4.0/24
- **Host Route:** A route to a specific single address, specified with a /32 mask
  - Example: 10.0.12.1/32, 10.0.13.1/32
  - These are automatically added for the specific addresses configured on R1's G0/0 and G1/0 interfaces

Static Route to a Host

```
R1(config)# ip route [host's address] 255.255.255.255 [next-hop]
```

- Uses a /32 mask (255.255.255.255) to specify a single host

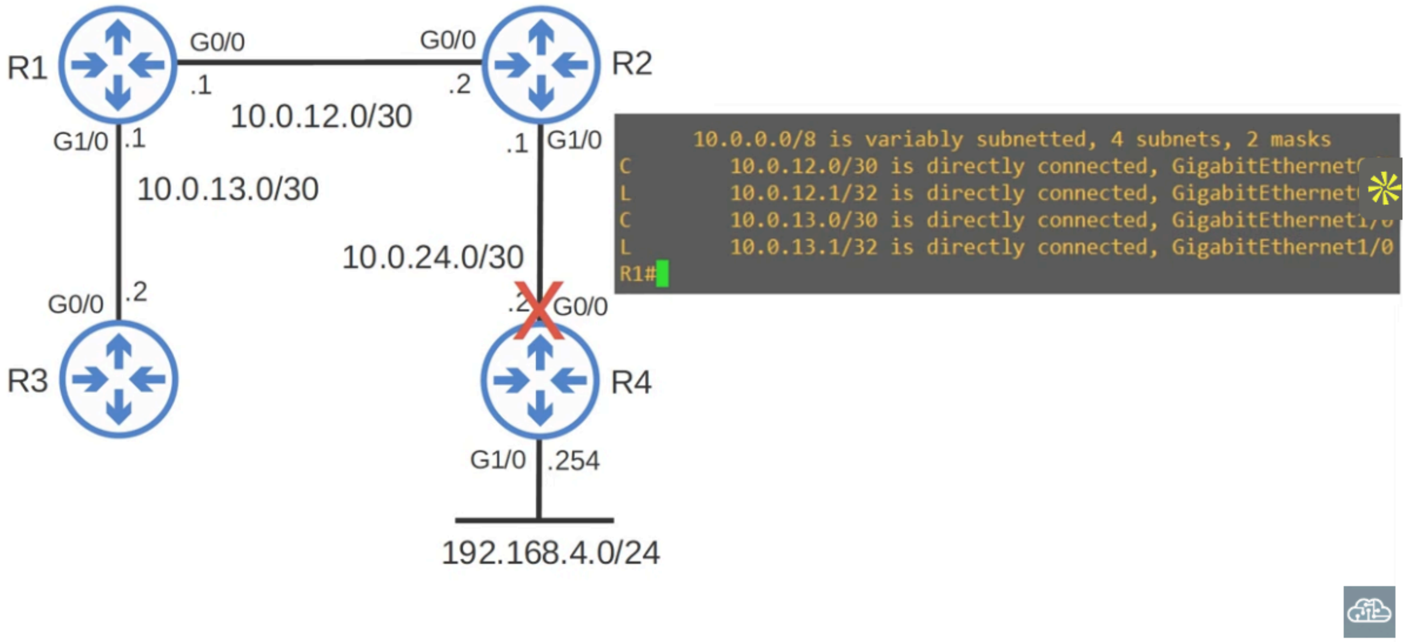
How Dynamic Routing Works (Demonstration)



Route Advertisement

- **R4** advertises its connected network 192.168.4.0/24 to its neighbor **R2**.
- **R2** adds 192.168.4.0/24 to its route table and advertises it to **R1**.
- **R1** adds the route to its route table and then advertises it to **R3**.
    - Routers advertise both connected routes and routes learned from other devices.

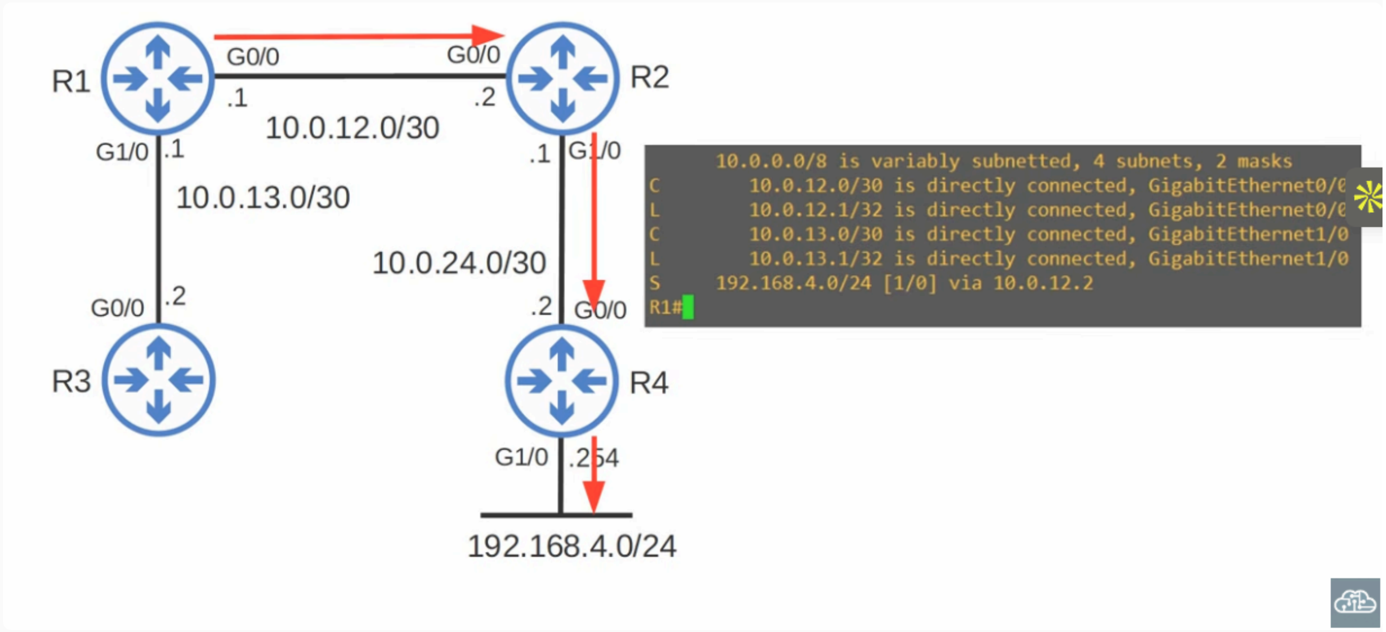
Automatic Failure Detection



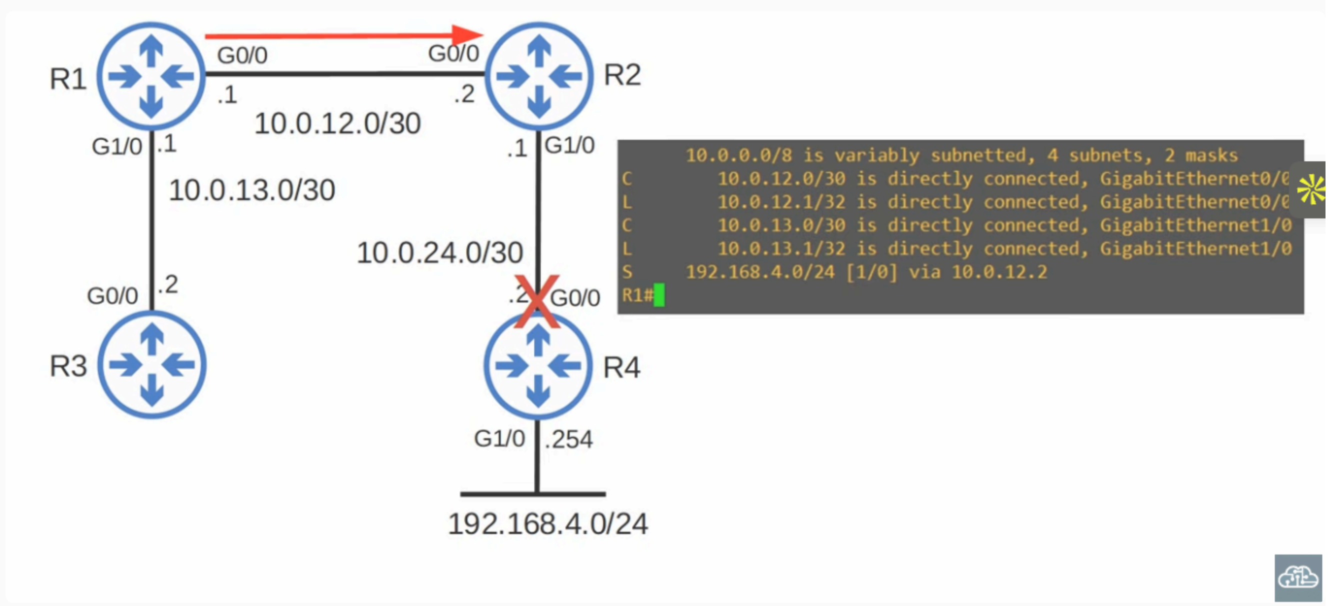
- If an interface fails (e.g., R4's G0/0 goes down), the routers automatically adapt.
- The route is removed from the routing tables of all routers.
- **Benefit:** Prevents routers from continuously sending traffic to a dead-end (blackholing traffic).

Static Routing vs. Dynamic Routing (Failure Behavior)

- **Static Routing Failure:**



  - R1 continues forwarding traffic to R2 for the 192.168.4.0 network even if the link is down.

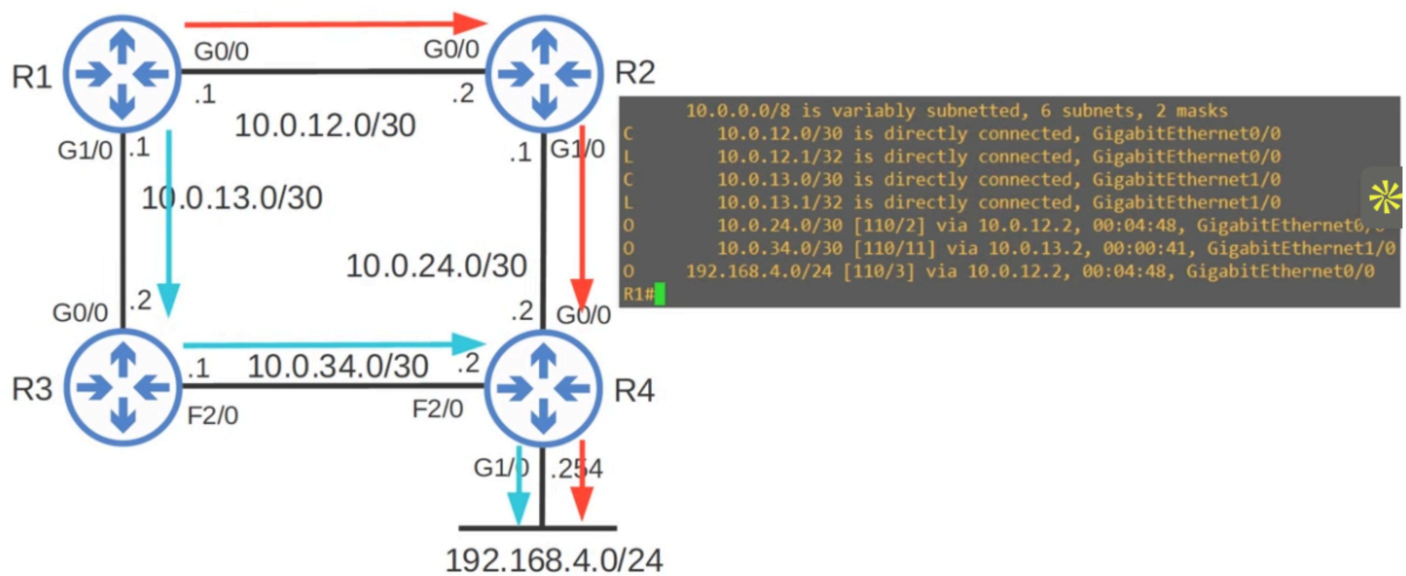


  - R1 is unaware of the failure because there is no dynamic protocol to notify it.
  - Traffic is sent to a dead-end.

- **Dynamic Routing Benefit:**
  - The router automatically removes invalid routes.
  - Ideally, a backup route is configured so the invalid route is replaced with the next-best route rather than being totally removed.

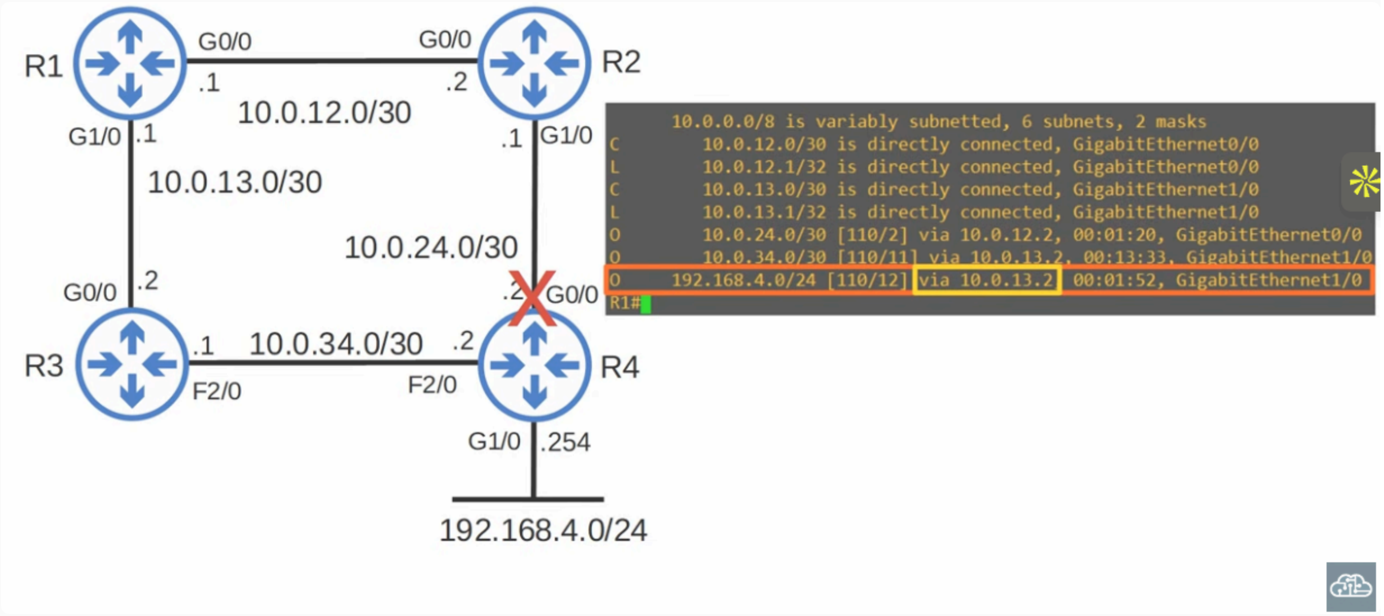
Automatic Failover and Path Selection

Redundant Path Demonstration

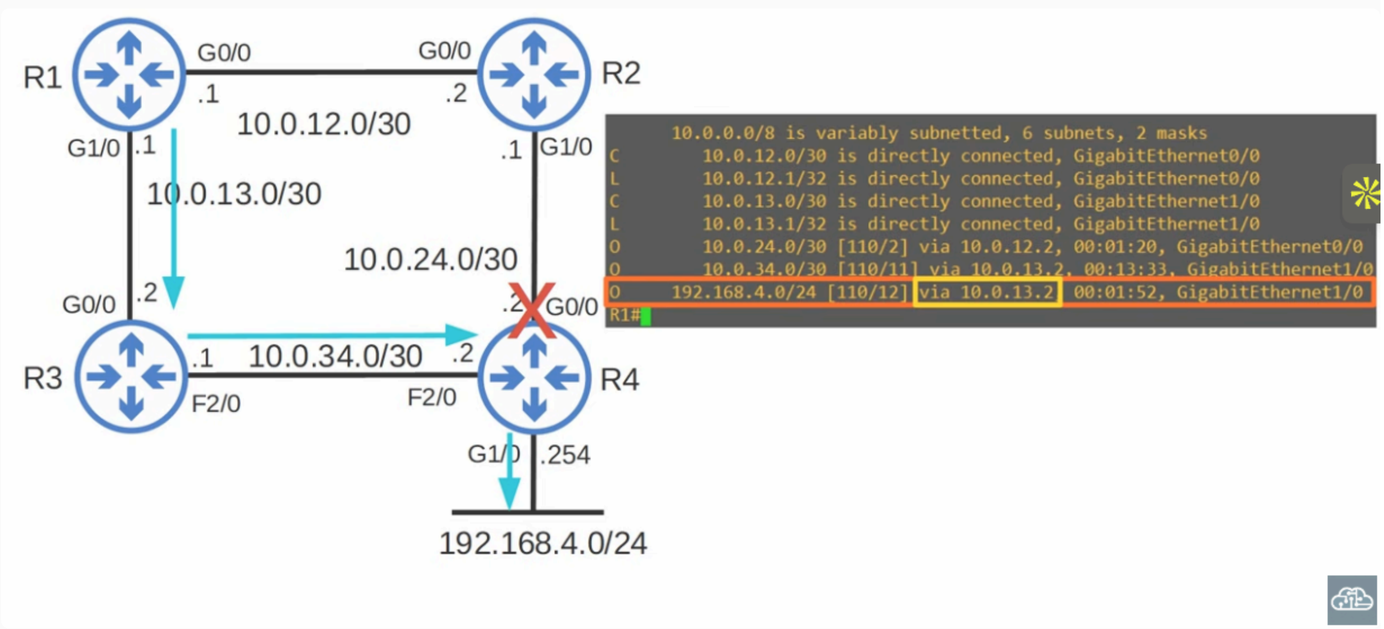


- Added another connection between R3 and R4, giving R1 two valid paths to 192.168.4.0/24: via R2 and via R3.

- R1's routing table shows the route via R2 (10.0.12.2) as the preferred route.

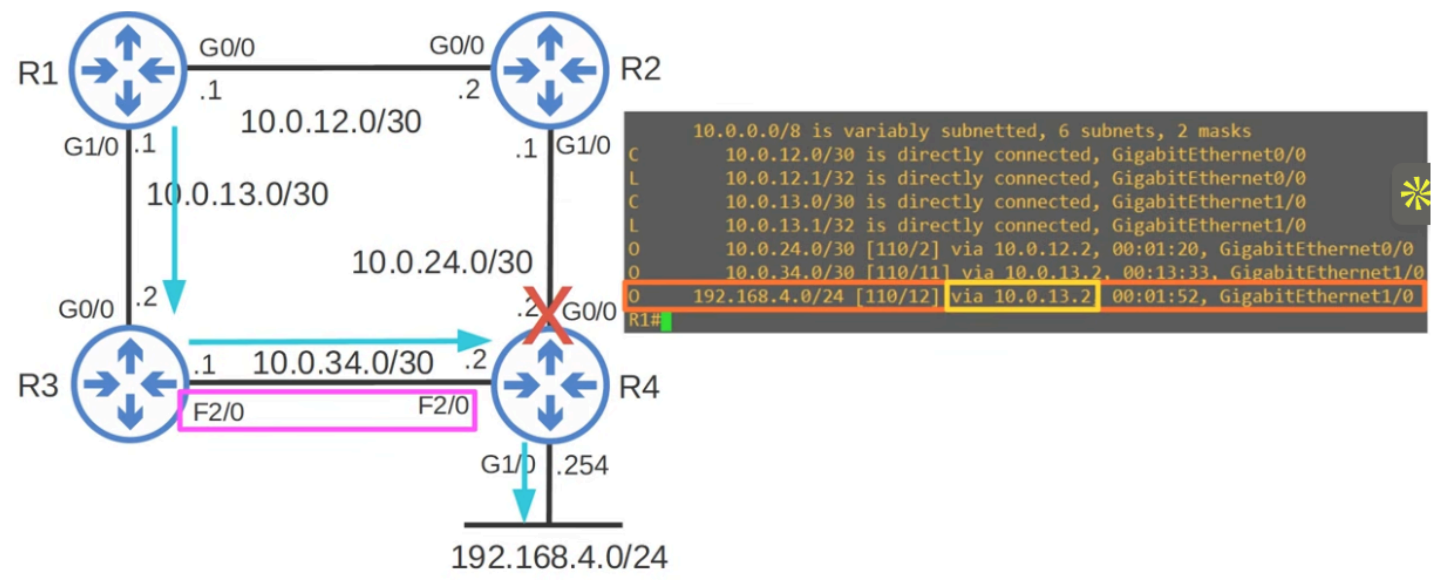


- When R4's G0/0 interface is disabled (simulating a failure), R1's route is automatically



- It's replaced with the route via R3 (10.0.13.2).
    - The preferred route is lost, but traffic can still reach the destination via the alternate path.

Path Selection Using Metric



- The route via R2 was preferred over the route via R3 because the connection between R3 and R4 is a **FastEthernet** connection (slower), not GigabitEthernet.
- Dynamic routing protocols use a concept similar to STP's **root cost** to determine the best path.
- R1 learned about 192.168.4.0/24 from both R2 and R3, but determined the path via R2 is superior because it **costs less**.

Key Points of Dynamic Routing Protocols

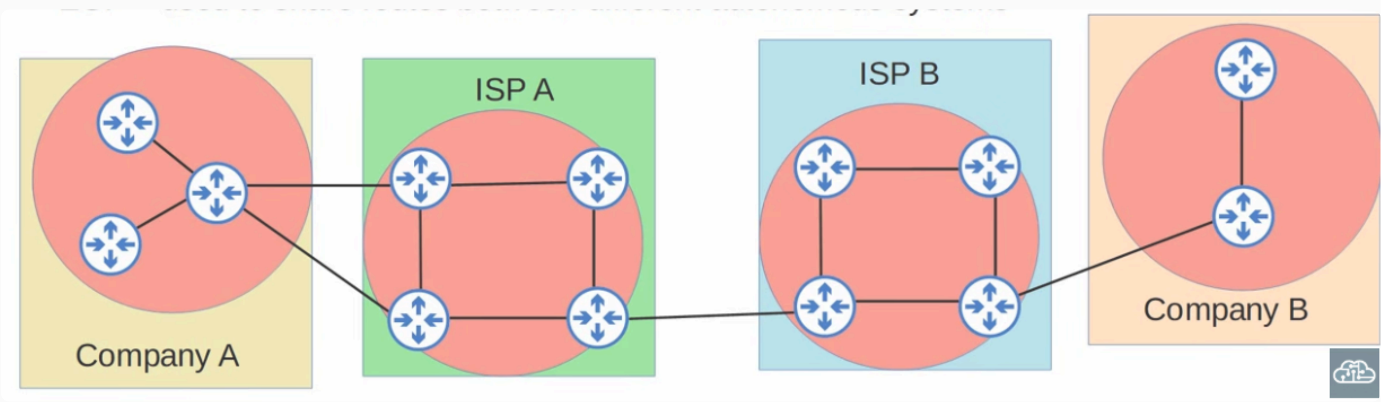
- Routers advertise information about:
  - Their connected routes.
  - Routes they have learned from other devices.
- **Adjacencies:** Routers form "adjacencies" (also known as "neighbor relationships" or "neighborships") with adjacent routers to exchange this information.
  - Example: R1 forms adjacencies with R2 and R3.

- **Route Selection:** If multiple routes to a destination are learned, the router determines which is superior using the route's **metric**.
  - The **lower metric is superior**.
  - Similar to STP, where a lower root cost is superior when determining the root port.

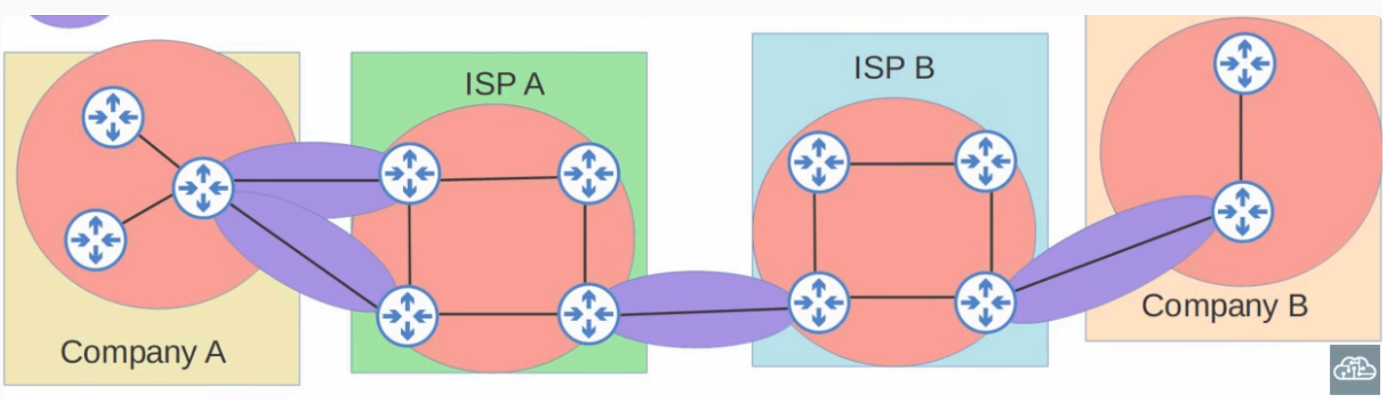
Types of Dynamic Routing Protocols

Categories: IGP vs. EGP

- **IGP (Interior Gateway Protocol):**



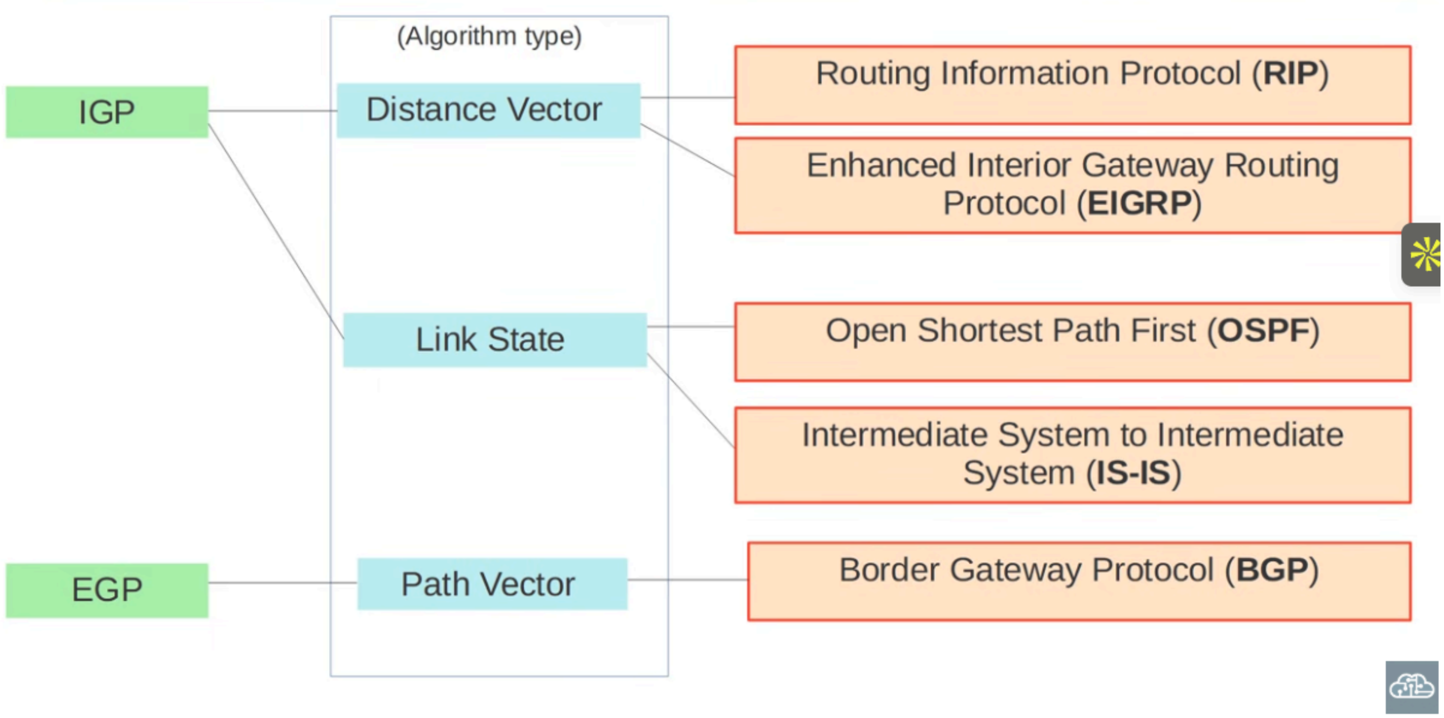
  - Used to share routes **within** a single autonomous system (AS).
  - An AS is a single organization (e.g., a company).
- **EGP (Exterior Gateway Protocol):**



  - Used to share routes **between** different autonomous systems.

- **Basic Purpose:** Both share information about routes to destinations, but they function differently.
- **CCNA Focus:** The course focuses mostly on OSPF (an IGP), but you must understand other IGPs and the one EGP in use to compare and contrast them with OSPF.

Algorithm Types and Protocol Mapping



- **Algorithm Type:** Refers to the processes used by each protocol to share route information and determine the best route.
- **EGP Algorithms:**
  - **Path Vector:** The only EGP algorithm type.
  - **Protocol: BGP** (Border Gateway Protocol). (Note: Only EGP in modern use; not deeply covered in CCNA).

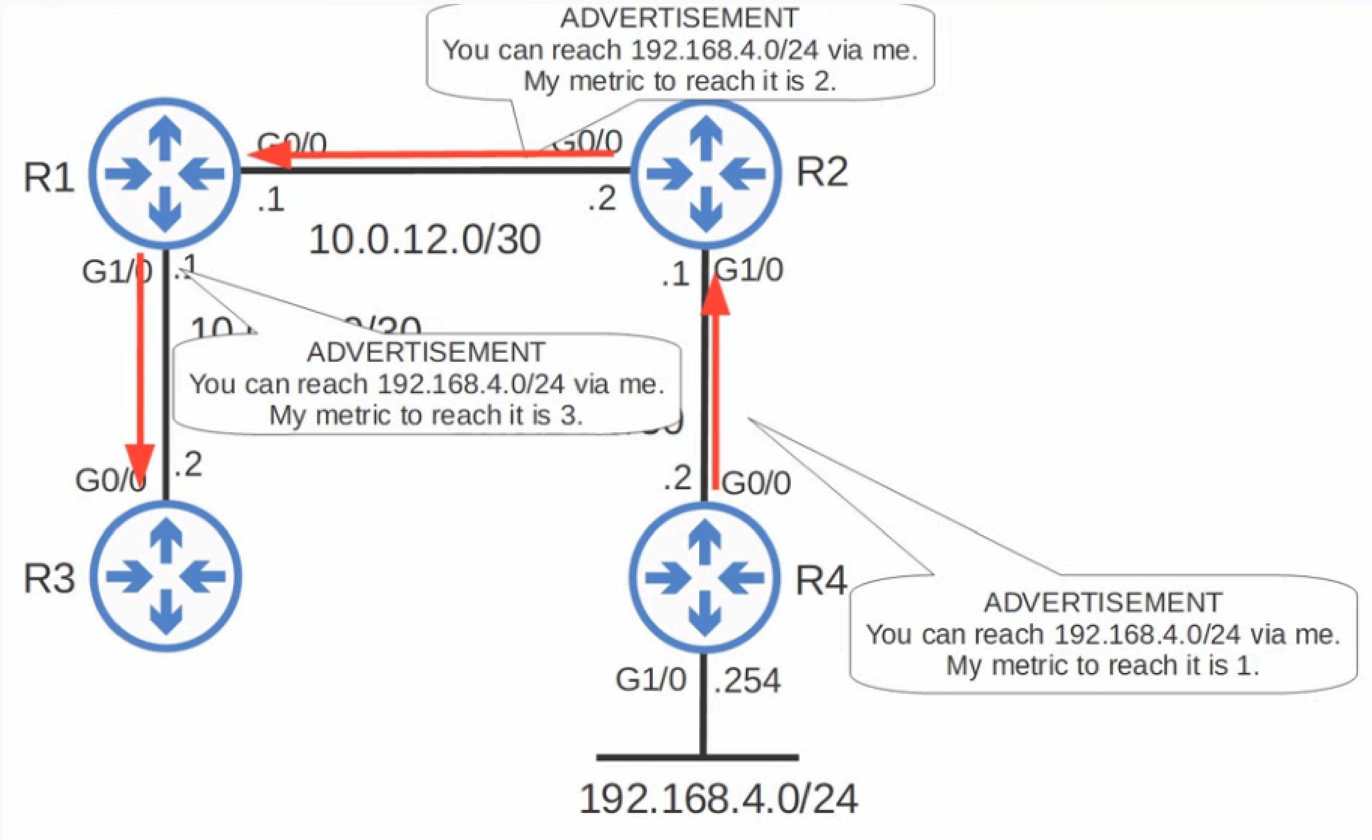
- **IGP Algorithms:**
  - **Distance Vector:**
    - Protocols: **RIP** (Routing Information Protocol) and **EIGRP** (Enhanced Interior Gateway Routing Protocol).
  - **Link State:**
    - Protocols: **OSPF** (Open Shortest Path First) and **IS-IS** (Intermediate System to Intermediate System).

Characteristics of Routing Protocols

Distance Vector Routing Protocols

- **Protocols:** RIP and EIGRP.
- **History:** Invented before link state protocols (early 1980s). Early examples include RIP and Cisco's IGRP (which was later updated to EIGRP).
- **Operation ("Routing by Rumor"):**
  - Routers send information about their known destination networks and their metrics to reach them **only to directly connected neighbors**.
  - The router does not know about the network beyond its neighbors; it only knows what neighbors tell it.
- **Name Origin:**
  - **Distance:** The metric.
  - **Vector:** The direction to send traffic (next-hop router).
- **How it works:** Basically, routers share their route table (or parts of it) with their neighbors.

- **Example:**



  - R4 tells R2: "You can reach 192.168.4.0/24 via me. My metric is 1."
  - R2 tells R1: "You can reach 192.168.4.0/24 via me. My metric is 2."
  - R1 does not have a detailed picture of the network, only that it can reach the destination via R2 with a metric of 2.

Link State Routing Protocols

- **Protocols:** OSPF and IS-IS.

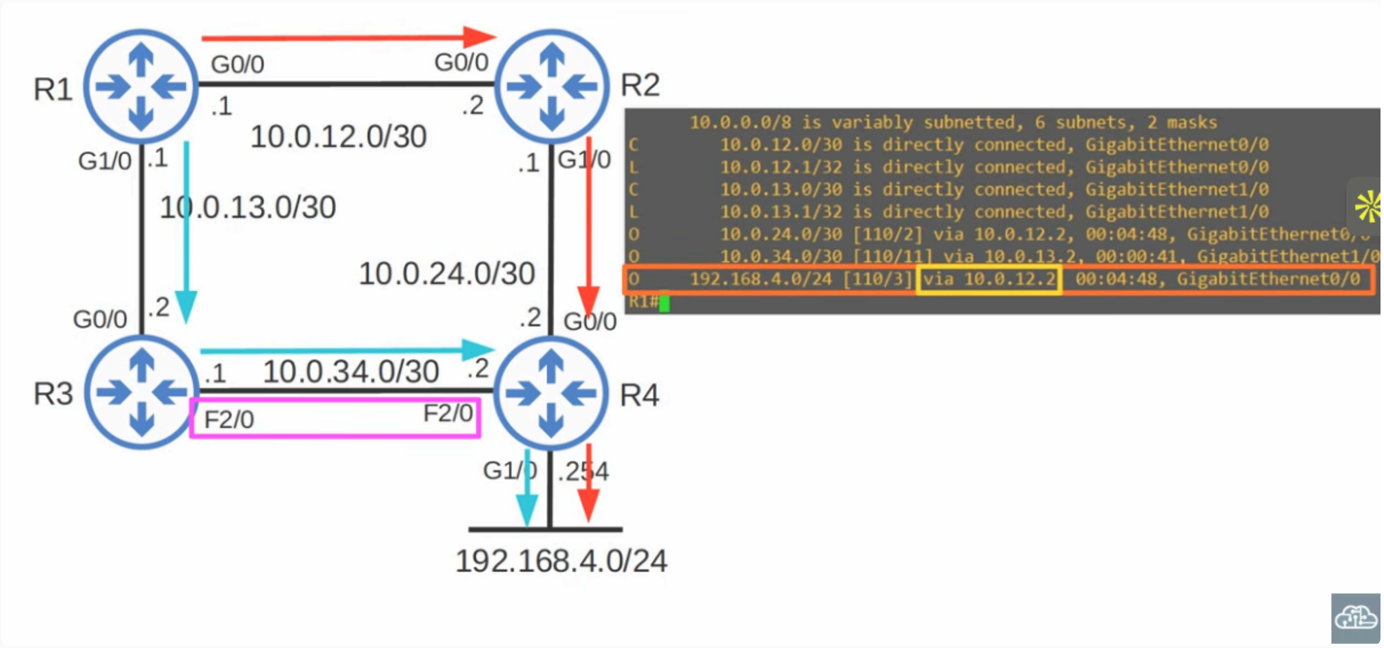
- **Operation:**
  - Every router creates a **connectivity map** of the network.
  - This map is the same on each router in the network.
  - Each router advertises information about its interfaces/connected networks to its neighbors.
  - Advertisements are passed along until all routers develop the same map.
  - Each router independently uses this map to calculate the best routes to each destination.
- **vs. Distance Vector:** Link state gives routers a complete picture of the network (not just neighbor info like "routing by rumor").
- **Resource Usage:** Uses more CPU power and memory because more information is shared.
- **Convergence:** Tends to be faster in reacting to changes in the network than distance vector protocols.

Metrics

- **Purpose:** Determines the best path to a destination when multiple routes exist from the **same** routing protocol.
- **Selection Rule:** Lower metric = better route.
  - Similar to STP, where a lower root cost is superior.
- **Usage:** If a router learns two different routes to the same destination via the same protocol, the route with the lowest metric is entered into the routing table.

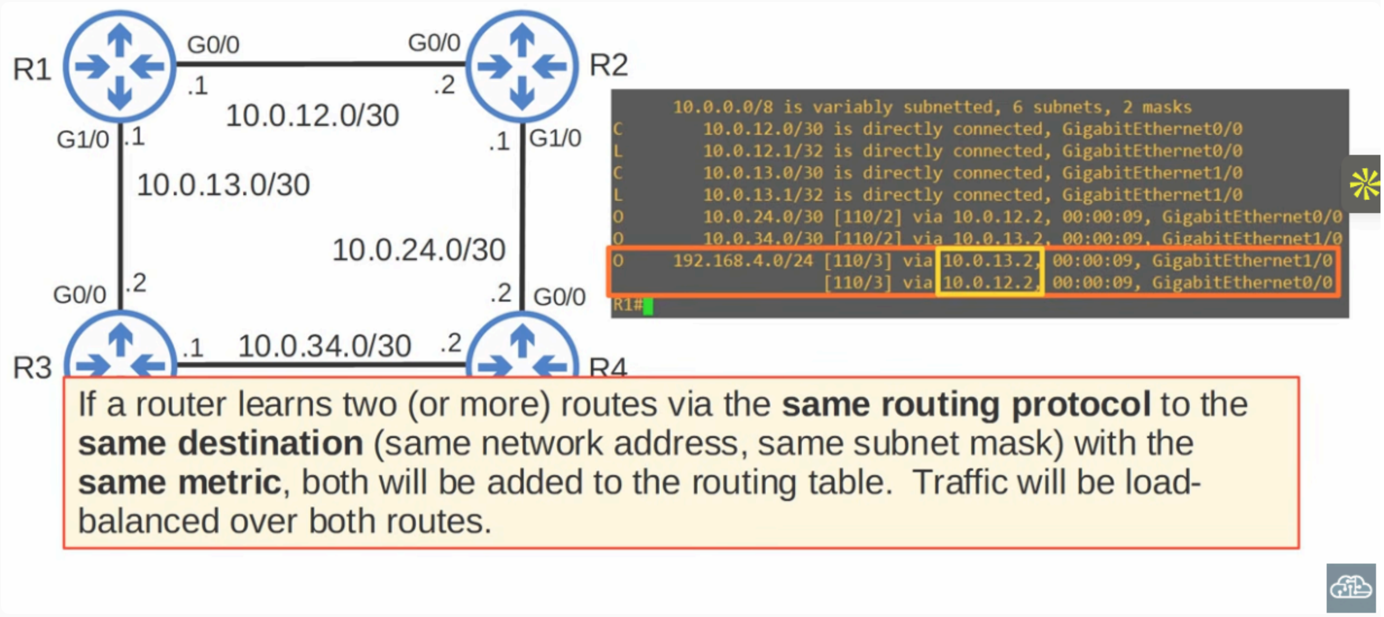
Equal Cost MultiPath (ECMP) Load-Balancing

- **Unequal Cost Example:**



  - R1 learns two paths to 192.168.4.0/24, one via R2 and one via R3.
  - The connection between R3 and R4 is **FastEthernet** (slower), resulting in a **higher metric**.
  - **Result:** Only the route **via R2** is added to the routing table (lower metric).

- **Equal Cost Example:**



  - The connection between R3 and R4 is changed to **GigabitEthernet** (same speed as the other links).
  - Both routes now have the **same metric**.
  - **Result: BOTH** routes are added to the routing table.
    - via 10.0.13.2 (R3)
    - via 10.0.12.2 (R2)
  - Traffic will be **load-balanced** over both routes.
- **Key Condition:** Routes must be to the **exact same destination** (same network address and same prefix length).

- **Route Table Indicators:**

```
R1#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
       i - IS-IS, su - IS-IS summary, 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, H - NHRP, l - LISP
       + - replicated route, % - next hop override

Gateway of last resort is not set

      10.0.0.0/8 is variably subnetted, 6 subnets, 2 masks
C        10.0.12.0/30 is directly connected, GigabitEthernet0/0
L        10.0.12.1/32 is directly connected, GigabitEthernet0/0
C        10.0.13.0/30 is directly connected, GigabitEthernet1/0
L        10.0.13.1/32 is directly connected, GigabitEthernet1/0
O        10.0.24.0/30 [110/2] via 10.0.12.2, 00:00:09, GigabitEthernet0/0
O        10.0.34.0/30 [110/2] via 10.0.13.2, 00:00:09, GigabitEthernet1/0
O     192.168.4.0/24 [110/3] via 10.0.13.2, 00:00:09, GigabitEthernet1/0
                     [110/3] via 10.0.12.2, 00:00:09, GigabitEthernet0/0
R1#
```

  - **Code:** Routes learned via OSPF are indicated by the code **O**.
  - **Metrics:** Located in the **second** value inside the square brackets `[AD/Metric]`. Both routes have a metric of **3**.
  - **Administrative Distance (AD):** Located in the **first** value inside the square brackets (OSPF is **110**).
- This is called **Equal Cost MultiPath (ECMP)** load-balancing.

ECMP with Static Routes

- ECMP load-balancing can also be done with **static routes**.

- **Configuration:**
  - Disable OSPF on R1.

```
R1(config)#ip route 192.168.4.0 255.255.255.0 10.0.12.2
R1(config)#ip route 192.168.4.0 255.255.255.0 10.0.13.2
```

  - Configure two static routes to 192.168.4.0, one via R2 and one via R3.
- **Result:**
  - Both routes are added to the routing table and traffic is load-balanced.
- **Route Table Indicators:**

```
R1(config)#ip route 192.168.4.0 255.255.255.0 10.0.12.2
R1(config)#ip route 192.168.4.0 255.255.255.0 10.0.13.2
R1(config)#do 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
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L        10.0.12.1/32 is directly connected, GigabitEthernet0/0
C        10.0.13.0/30 is directly connected, GigabitEthernet1/0
L        10.0.13.1/32 is directly connected, GigabitEthernet1/0
S     192.168.4.0/24 [1/0] via 10.0.13.2
                     [1/0] via 10.0.12.2
```

  - **Metric:** Both routes show a metric of **0** (static routes don't use the concept of metric).
  - **Administrative Distance (AD):** The AD value of static routes is **1**.

Per-Protocol Metric Details

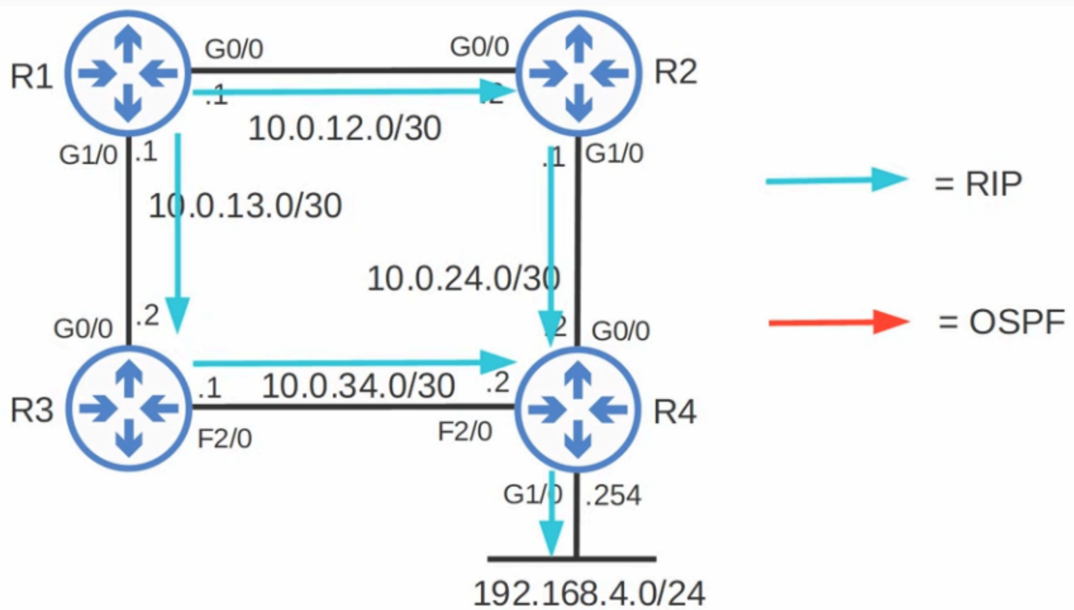
IGP	Metric	Explanation
RIP	Hop count	Each router in the path counts as one 'hop'. The total metric is the total number of hops to the destination. **Links of all speeds are equal.**
EIGRP	Metric based on bandwidth & delay (by default)	Complex formula that can take into account many values. By default, the bandwidth of the **slowest link in the route** and the total delay of all links in the route are used.
OSPF	Cost	The cost of each link is calculated based on bandwidth. The total metric is the total cost of each link in the route.
IS-IS	Cost	The total metric is the total cost of each link in the route. The cost of each link is **not** automatically calculated by default. All links have a cost of 10 by default.

- **RIP Metric: Hop Count**
  - Each router in the path counts as one "hop".
  - **Downside:** Primitive; links of all speeds are treated equally (a 10Mbps link = 1 hop, a 10Gbps link = 1 hop).
- **EIGRP Metric: Bandwidth and Delay**
  - The most complicated metric of the IGPs.
  - Calculated based on the bandwidth of the **slowest** link and the **total delay** of all links in the path.
  - *Note: The "delay" value is assigned to the interface based on its bandwidth.*
- **OSPF Metric: Cost**
  - The cost of each link is calculated based on bandwidth.
  - Better than RIP because it accounts for link speed.

- **IS-IS Metric: Cost**
  - Cost is **not** automatically calculated based on bandwidth.
  - All links have a default cost of 10 (functions like hop count unless configured).

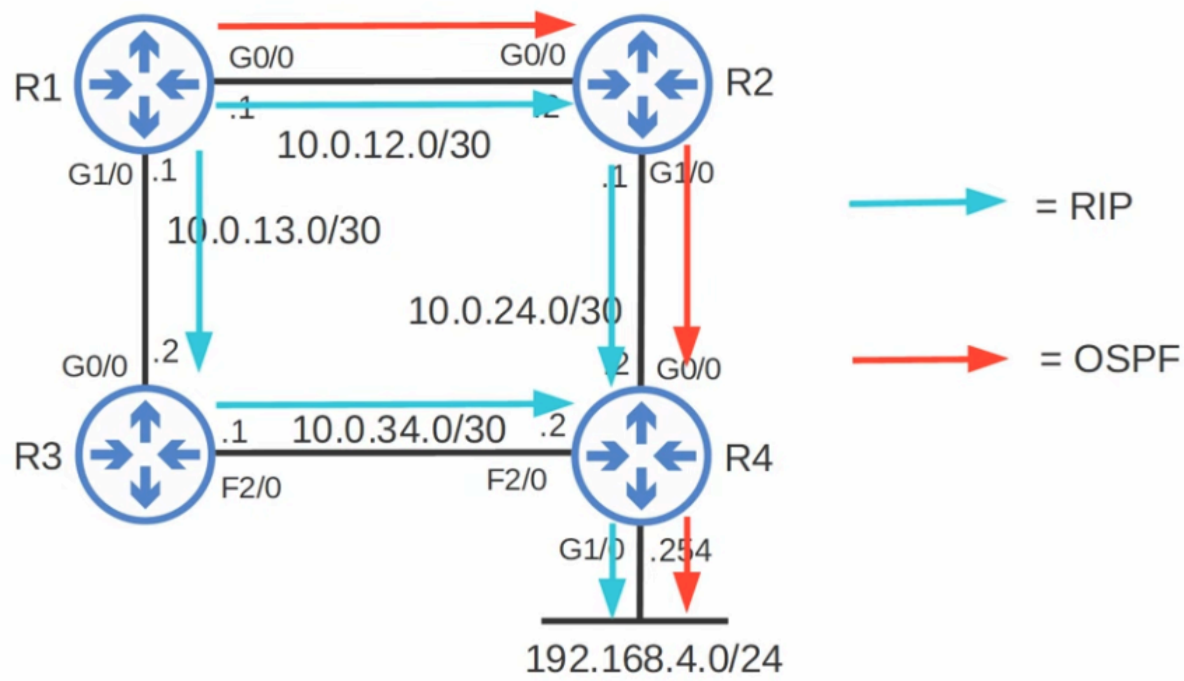
Metric Comparison Demonstration (R1's Perspective to 192.168.4.0/24)

- **Using RIP (Hop Count):**



  - Path via R2: 2 hops (R1 → R2 → R4).
  - Path via R3: 2 hops (R1 → R3 → R4).
  - **Result:** RIP treats both routes as equal, even though the R3-R4 link is slower (FastEthernet). Both routes are added to the table for load balancing.

- **Using OSPF (Cost/Bandwidth):**

  - OSPF calculates cost based on bandwidth.
  - The slower FastEthernet connection between R3 and R4 results in a **higher metric**.
  - **Result:** The route via R3 is less favorable. Only the route via R2 is added to the routing table.
- **Conclusion:** Some routing protocols (like OSPF) make better path decisions than others (like RIP) because they account for link speed.

Administrative Distance (AD)

Overview

- **Definition:** Administrative Distance (AD) is used to determine the best route when routes are learned from **different** routing protocols (e.g., OSPF vs. EIGRP).
- **Selection Rule:** Lower AD = more trustworthy = better route.

- **Why it's needed:**
    - **Metric** compares routes learned via the **same** routing protocol.
    - Different routing protocols use totally different metrics (e.g., OSPF cost vs. EIGRP bandwidth/delay), so they **cannot be compared** directly.
    - Example: An OSPF route with a metric of 30 cannot be directly compared to an EIGRP route with a metric of 33280.
- **Trustworthiness:** A lower AD indicates the routing protocol is considered more "trustworthy" (more likely to select good routes).
    - Example: RIP has a high AD because its hop count-based metric is not very good (doesn't account for link speed).

Common Administrative Distance Values

Route protocol/type	AD
Directly connected	0
Static	1
External BGP (eBGP)	20
EIGRP	90
IGRP	100
OSPF	110

Route protocol/type	AD
IS-IS	115
RIP	120
EIGRP (external)	170
Internal BGP (iBGP)	200
Unusable route	255

- **Most Preferred to Least Preferred:**
  - **AD - 0: Directly Connected**
    - **Meaning:** The destination is physically attached to the router's own interface.
    - **Trust Level:** Highest possible trust. The router knows this path is real because the cable is plugged directly into it.
  - **AD - 1: Static Route**
    - **Meaning:** A human administrator manually typed in the command to create this route.
    - **Trust Level:** Extremely high trust. Because a person configured it intentionally, the router trusts it over almost any automated protocol.
  - **AD - 20: eBGP (External BGP)**
    - **Meaning:** Routes learned from a *different* organization (Autonomous System), usually an ISP.
    - **Trust Level:** Very high. Used to route traffic across the global Internet.
  - **AD - 90: EIGRP**
    - **Meaning:** Routes learned from Cisco's proprietary routing protocol.
    - **Trust Level:** High (among IGPs). It is trusted more than OSPF or RIP.
  - **AD - 100: IGRP**
    - **Meaning:** Routes learned from the older, obsolete version of EIGRP.
    - **Trust Level:** Lower than modern protocols.
  - **AD - 110: OSPF**
    - **Meaning:** Routes learned from the Open Shortest Path First protocol (the industry standard).
    - **Trust Level:** Medium-High. It is trusted less than EIGRP but more than RIP.
  - **AD - 115: IS-IS**
    - **Meaning:** Routes learned from Intermediate System to Intermediate System (commonly used in massive ISP networks).
    - **Trust Level:** Medium. Slightly less preferred than OSPF.

- **AD - 120: RIP**
  - **Meaning:** Routes learned from the Routing Information Protocol.
  - **Trust Level:** Low. The router considers this protocol less "smart" (it uses simple hop counts), so it trusts it the least among the standard interior protocols.
- **AD - 170: EIGRP External**
  - **Meaning:** This is a specific type of route that originally came from *outside* the EIGRP network but was injected *into* the EIGRP network (Outside the Scope of the CCNA).
  - **Trust Level:** Low. Even though it is EIGRP, the router is suspicious of the route because it didn't originate inside the trusted EIGRP system.
- **AD - 200: iBGP (Internal BGP)**
  - **Meaning:** Routes learned from BGP within the *same* organization.
  - **Trust Level:** Very Low (usually). In specific complex network designs, administrators prefer that internal routing protocols (like OSPF) handle internal traffic, so iBGP is given a very high (bad) number to prevent loops and conflicts.
- **AD - 255: Unusable**
  - **Meaning:** This is a "ghost" route.
  - **Trust Level:** Zero. If a router sees an AD of 255, it assumes the information is invalid or the source is unknown. It will throw the route away and never use it.

- **Note:** Values are specific to Cisco devices; other vendors may differ.
- **Comparison of IGPs:** EIGRP (90) is most preferred, followed by OSPF (110), IS-IS (115), and RIP (120).

Quiz Demonstration: AD vs. Metric

Which route to 10.1.1.0/24 will be added to the route table?

- **Scenario:** Three routes are learned to 10.1.1.0/24:
    1. Via RIP (Next hop: 192.168.1.1) - Metric: 5
    2. Via RIP (Next hop: 192.168.2.1) - Metric: 3
    3. Via OSPF (Next hop: 192.168.3.1) - Metric: 10
- **Answer:** The **OSPF route** is added to the routing table.
- **Reasoning:**
    - **Step 1:** Compare Administrative Distance (AD) first.
    - OSPF (AD 110) is preferred over RIP (AD 120) because 110 < 120.
    - **Step 2:** Metric is only used to compare routes learned via the **same** protocol.
    - Since OSPF has the best AD, the RIP metrics (5 and 3) are irrelevant.

- **AD of 1: Static Routes Display**

```
R1(config)#ip route 192.168.4.0 255.255.255.0 10.0.12.2
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L        10.0.12.1/32 is directly connected, GigabitEthernet0/0
C        10.0.13.0/30 is directly connected, GigabitEthernet1/0
L        10.0.13.1/32 is directly connected, GigabitEthernet1/0
S     192.168.4.0/24 [1/0] via 10.0.13.2
                     [1/0] via 10.0.12.2
R1(config)#
```

  - **What they are:** Routes manually configured by a human administrator using the `IP ROUTE` command.
  - **Route Table Display:** The professor shows that in the `show ip route` output, static routes display an AD of **1** inside the square brackets (e.g., `[1/0]`).
  - **Trust:** They are the second most preferred routes. The router trusts them highly because a person intentionally configured them.

- **Route Table Display:** `[AD/Metric]` (e.g., `[110/10]`)

```
R1#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
       i - IS-IS, su - IS-IS summary, 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, H - NHRP, l - LISP
       + - replicated route, % - next hop override

Gateway of last resort is not set

      10.0.0.0/8 is variably subnetted, 6 subnets, 2 masks
C        10.0.12.0/30 is directly connected, GigabitEthernet0/0
L        10.0.12.1/32 is directly connected, GigabitEthernet0/0
C        10.0.13.0/30 is directly connected, GigabitEthernet1/0
L        10.0.13.1/32 is directly connected, GigabitEthernet1/0
O        10.0.24.0/30 [110/2] via 10.0.12.2, 00:00:09, GigabitEthernet0/0
O        10.0.34.0/30 [110/2] via 10.0.13.2, 00:00:09, GigabitEthernet1/0
O     192.168.4.0/24 [110/3] via 10.0.13.2, 00:00:09, GigabitEthernet1/0
                     [110/3] via 10.0.12.2, 00:00:09, GigabitEthernet0/0
R1#
```

  - **Route Code:** OSPF routes are identified by the code **O** at the beginning of the line in the route table.
  - **Format:** `[AD/Metric]`
    - **AD (Left number):** OSPF has an AD of **110**.
    - **Metric (Right number):** The cost value is calculated based on bandwidth.
  - **Example from the demonstration:**
    - Two routes to 192.168.4.0/24 were learned via OSPF.
    - Both routes appeared in the route table with **[110/3]**.
    - AD = 110, Metric = 3.
    - Because both routes had the **same metric** (3), both were installed in the routing table for **ECMP load-balancing**.

Changing Administrative Distance & Floating Static Routes

- **Changing AD:**
  - You can change the AD of a routing protocol (covered later in OSPF configuration).
  - You can also change the AD of a static route.
  - **Command Example:**

    ```
    R1(config)# ip route [destination] [subnet mask] [next-hop] [AD value]
    ```

    - Note: The option is labeled "distance metric" in the CLI help, but this refers to **Administrative Distance**, not the routing metric.
    - Example: Setting the AD to 100 makes the static route less trusted than the default AD of 1.
- **Floating Static Routes:**
  - **Purpose:** A backup route that sits inactive ("floating") until the primary dynamic route fails.
  - **How it works:**
    - Configure a static route with an AD **higher** than the dynamic routing protocol (e.g., AD 100 or higher, while OSPF is 110, EIGRP is 90).
    - As long as the dynamic route exists, the static route is not in the routing table.
    - If the dynamic route is lost (e.g., interface failure, adjacency lost), the static route is installed as the backup.
  - **Exam Topic:** Floating static routes are explicitly listed in the CCNA exam topics.

Lecture Summary / Review

- **Dynamic Routing Purpose:** Automatically learn routes without manual static configuration (impractical in large networks).

- **Protocol Categories:**
  - **IGP (Interior Gateway Protocol):** Routing *within* an organization.
  - **EGP (Exterior Gateway Protocol):** Routing *between* organizations (Internet). Only modern EGP is **BGP**.
- **Algorithm Types:**
  - **Path Vector:** Used by BGP.
  - **Distance Vector:** Used by RIP and EIGRP.
  - **Link State:** Used by OSPF and IS-IS.
- **Metric vs. Administrative Distance:**
  - **Metric:** Compares routes learned via the **same** routing protocol (lower is better).
  - **Administrative Distance (AD):** Compares routes learned via **different** routing protocols (lower is better/more trustworthy).