Routing Operations in Cisco IOS Routers

BRKRST-2350

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Routing Operation in Cisco IOS Routers

Topics Covered:

- The Routing Table (RIB)
- Overriding the Routing Table
- Load Sharing
- Routing Segmentation and Separation
- Routing and Router Resources

The Routing Table

The Routing Table

- Basic Structure
- Route Selection
- Interface Down Events
- Backup Routes
- Static Routes
- Discard Routes

The Routing Table

Basic Structure

- The Routing Information Base or RIB
- Routing Protocols*

    Install routes into the RIB

- Interfaces

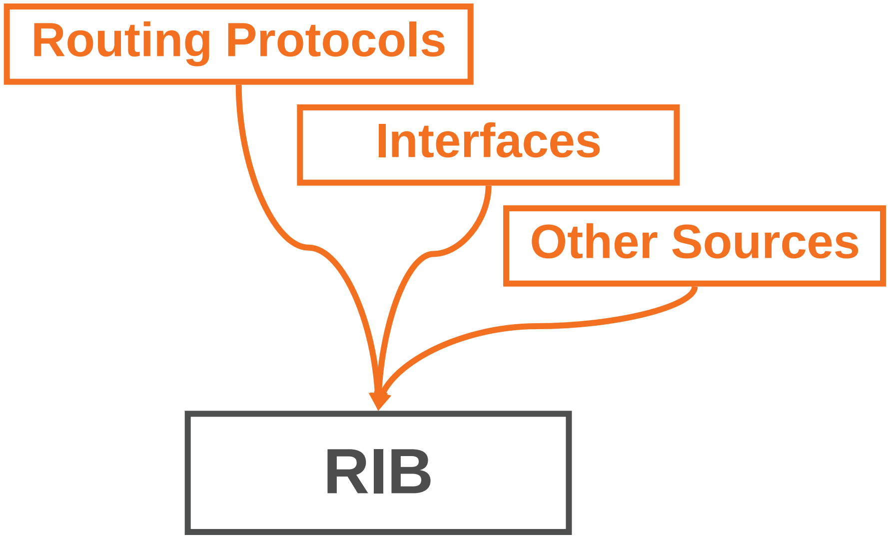
    Install routes into the RIB

- Other Sources

    Install routes into the RIB

    -Performance Routing (PFR)

    -Reverse-Route Injection (RRI)



Basic Structure

- Routing Protocols

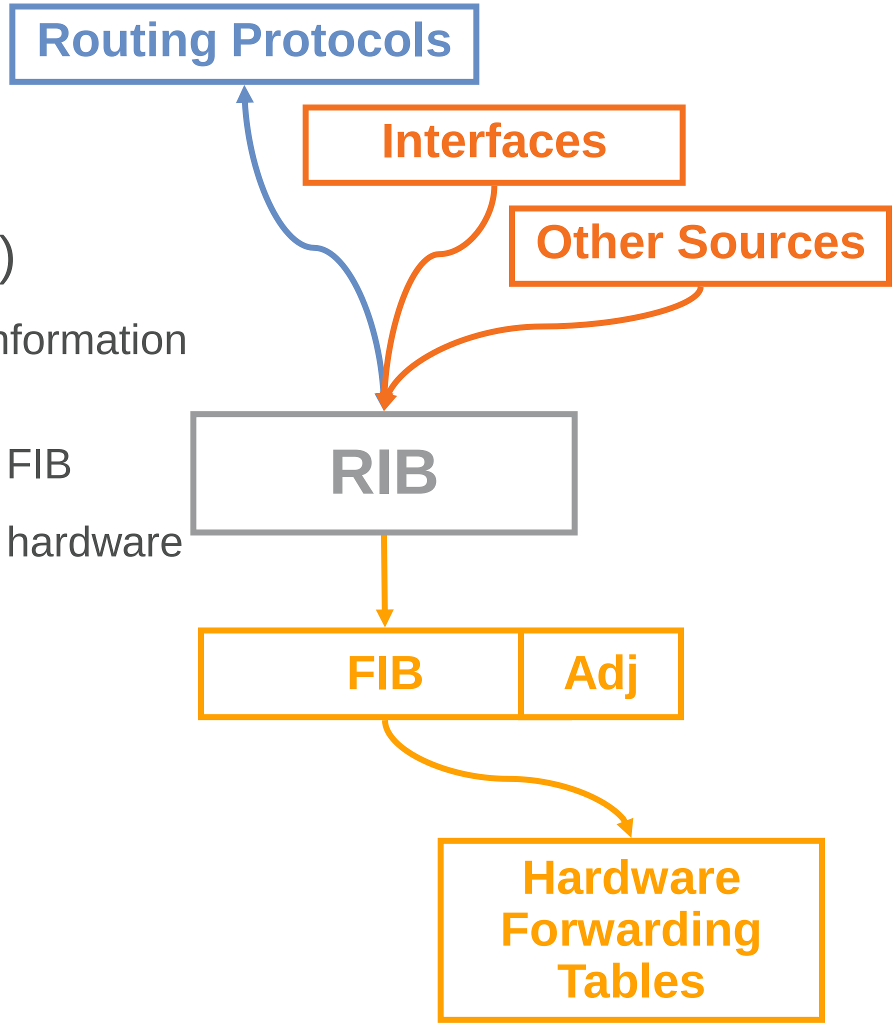
  Pull routes from the RIB
  for redistribution

- Cisco Express Forwarding (CEF)

  CEF maintains the FIB, Forwarding Information Base, and the Adjacency tables

  A copy of the RIB is sent down to the FIB

  A copy of the RIB is sent down to the hardware forwarding component



Basic Structure

```
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
       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, + - replicated route
```

```
      10.0.0.0/8 is variably subnetted, 2 subnets, 2 masks
C        10.1.20.0/25 is directly connected, Ethernet1/0
L        10.1.20.1/32 is directly connected, Ethernet1/0
C     172.0.0.0/8 is directly connected, Ethernet0/0
      172.16.0.0/16 is variably subnetted, 2 subnets, 2 masks
L        172.16.13.1/32 is directly connected, Ethernet0/0
D        172.16.24.0/24 [90/307200] via 10.1.20.2, 00:23:36, Ethernet1/0
      192.168.10.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.10.0/24 is directly connected, Serial2/0
L        192.168.10.1/32 is directly connected, Serial2/0
S     200.15.0.0/16 is directly connected, Null0
```

Basic Structure

```
router#show ip route
```

Network

```
        10.0.0.0/8 is variably subnetted, 2 subnets, 2 masks
C          10.1.20.0/25 is directly connected, Ethernet1/0
L          10.1.20.1/32 is directly connected, Ethernet1/0
C       172.0.0.0/8 is directly connected, Ethernet0/0
        172.16.0.0/16 is variably subnetted, 2 subnets, 2 masks
L          172.16.13.1/32 is directly connected, Ethernet0/0
D          172.16.24.0/24 [90/307200] via 10.1.20.2, 00:23:36, Ethernet1/0
        192.168.10.0/24 is variably subnetted, 2 subnets, 2 masks
C          192.168.10.0/24 is directly connected, Serial2/0
L          192.168.10.1/32 is directly connected, Serial2/0
S       200.15.0.0/16 is directly connected, Null0
```

Basic Structure

```
router#show ip route
```

Route

```
        10.0.0.0/8 is variably subnetted, 2 subnets, 2 masks
C          10.1.20.0/25 is directly connected, Ethernet1/0
L          10.1.20.1/32 is directly connected, Ethernet1/0
C       172.0.0.0/8 is directly connected, Ethernet0/0
        172.16.0.0/16 is variably subnetted, 2 subnets, 2 masks
L          172.16.13.1/32 is directly connected, Ethernet0/0
D          172.16.24.0/24 [90/307200] via 10.1.20.2, 00:23:36, Ethernet1/0
        192.168.10.0/24 is variably subnetted, 2 subnets, 2 masks
C          192.168.10.0/24 is directly connected, Serial2/0
L          192.168.10.1/32 is directly connected, Serial2/0
S       200.15.0.0/16 is directly connected, Null0
```

Basic Structure

```
router#show ip route
```

Network + Route

```
      10.0.0.0/8 is variably subnetted, 2 subnets, 2 masks
C        10.1.20.0/25 is directly connected, Ethernet1/0
L        10.1.20.1/32 is directly connected, Ethernet1/0
C     172.0.0.0/8 is directly connected, Ethernet0/0
      172.16.0.0/16 is variably subnetted, 2 subnets, 2 masks
L        172.16.13.1/32 is directly connected, Ethernet0/0
D        172.16.24.0/24 [90/307200] via 10.1.20.2, 00:23:36, Ethernet1/0
      192.168.10.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.10.0/24 is directly connected, Serial2/0
L        192.168.10.1/32 is directly connected, Serial2/0
S     200.15.0.0/16 is directly connected, Null0
```

Basic Structure

```
router#show ip route
```

Major networks with subnets show up under a single network with multiple routes

```
C     172.0.0.0/8 is directly connected, Ethernet0/0
      172.16.0.0/16 is variably subnetted, 2 subnets, 2 masks
L        172.16.13.1/32 is directly connected, Ethernet0/0
D        172.16.24.0/24 [90/307200] via 10.1.20.2, 00:23:36, Ethernet1/0
      192.168.10.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.10.0/24 is directly connected, Serial2/0
L        192.168.10.1/32 is directly connected, Serial2/0
S     200.15.0.0/16 is directly connected, Null0
S     200.15.100.0/24 is directly connected, Null0
```

Native mask routes and supernets show up as separate networks

Basic Structure

Administrative distance **Metric** **Last Modification Time**

```
D EX 192.168.254.0/24 [170/3072256] via 208.0.246.10, 00:58:45, Serial3/0
```

- The administrative distance is locally significant
- The metric is a protocol specific measure
- The time shown is the amount of time since the route was last touched
    - EIGRP recalculation of any type, including losing an alternate path, resets this timer
    - OSPF SPF run resets this timer
    - IS-IS SPF run resets this timer

Admin Distance

Route Source	Default Distance Values
Connected interface	0
Static route	1
Enhanced Interior Gateway Routing Protocol (EIGRP) summary route	5
External Border Gateway Protocol (BGP)	20
Internal EIGRP	90
IGRP	100
OSPF	110
Intermediate System-to-Intermediate System (IS-IS)	115
Routing Information Protocol (RIP)	120
Exterior Gateway Protocol (EGP)	140
On Demand Routing (ODR)	160
External EIGRP	170
Internal BGP	200
Unknown (infinity)	255

Learn. Connect. Collaborate. together.

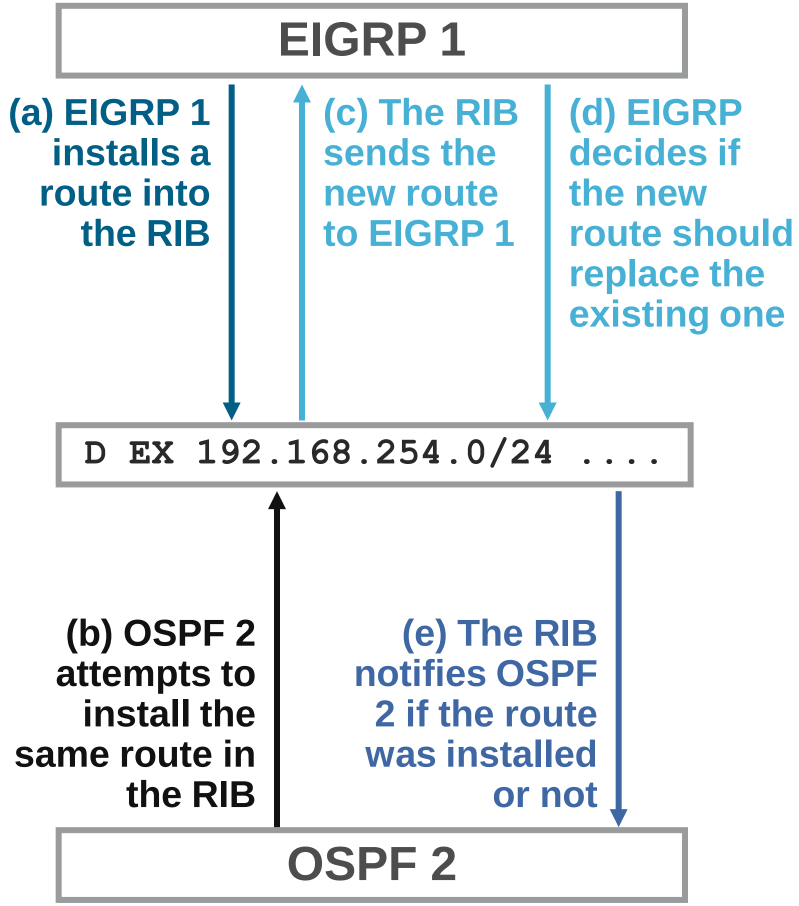
Routing Table:

Route Selection

Route Selection

How does the RIB decide which route is best among various sources?

Actually, it doesn't.



Route Selection

- Each route is marked with the installing routing process
- When another process attempts to install an overlapping route in the RIB, the RIB allows the owner of the current route to decide if it should be installed or not
- Generally, this decision is made using the administrative distance of the two routing processes

Route Selection

The RIB receives OSPF's new route, calls into EIGRP, and EIGRP determines if the OSPF route should be installed

The RIB receives the EIGRP reply and flushes the EIGRP route

```
RT: closer admin distance for 192.168.254.0, flushing 1 routes
EIGRP-IPv4(1):Callback: lostroute 192.168.254.0/24
RT: add 192.168.254.0/24 via 208.0.245.11, ospf metric [110/65]
```

EIGRP receives a callback stating the RIB has removed one of its routes

The RIB installs OSPF's route

The RIB notifies OSPF its route has been installed

Route Selection

How is administrative distance used to determine which route should be installed?

RIPv2 → 10.1.1.0/24

EIGRP → 10.1.1.0/24

EIGRP → 10.1.1.0/25

These two routes are identical

EIGRP internal AD = 90

RIP AD = 120

EIGRP internal route is installed

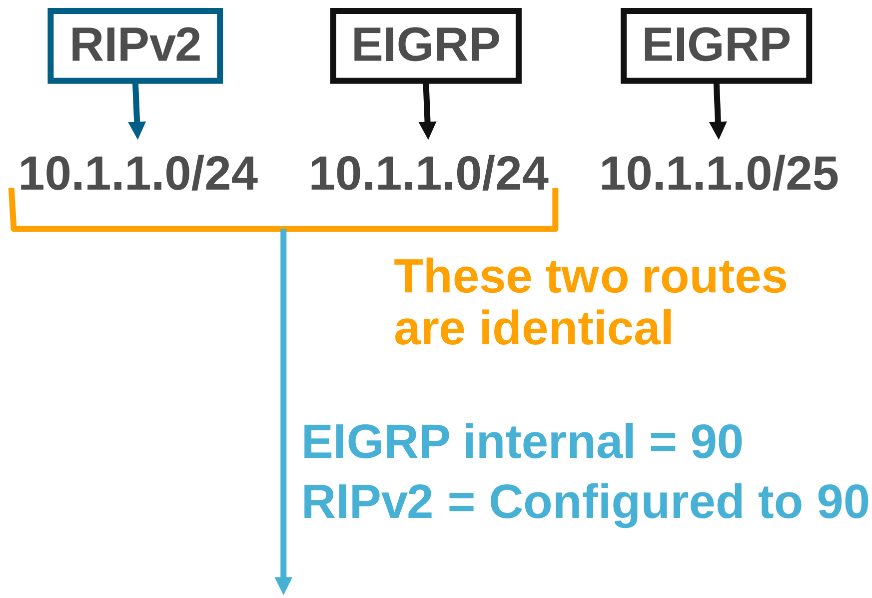
The lowest administrative distance wins.

Route Selection

- Only identical routes are compared
- Identical prefixes with different prefix lengths are not the same route
- The route from the protocol with the lower administrative distance is installed

Route Selection

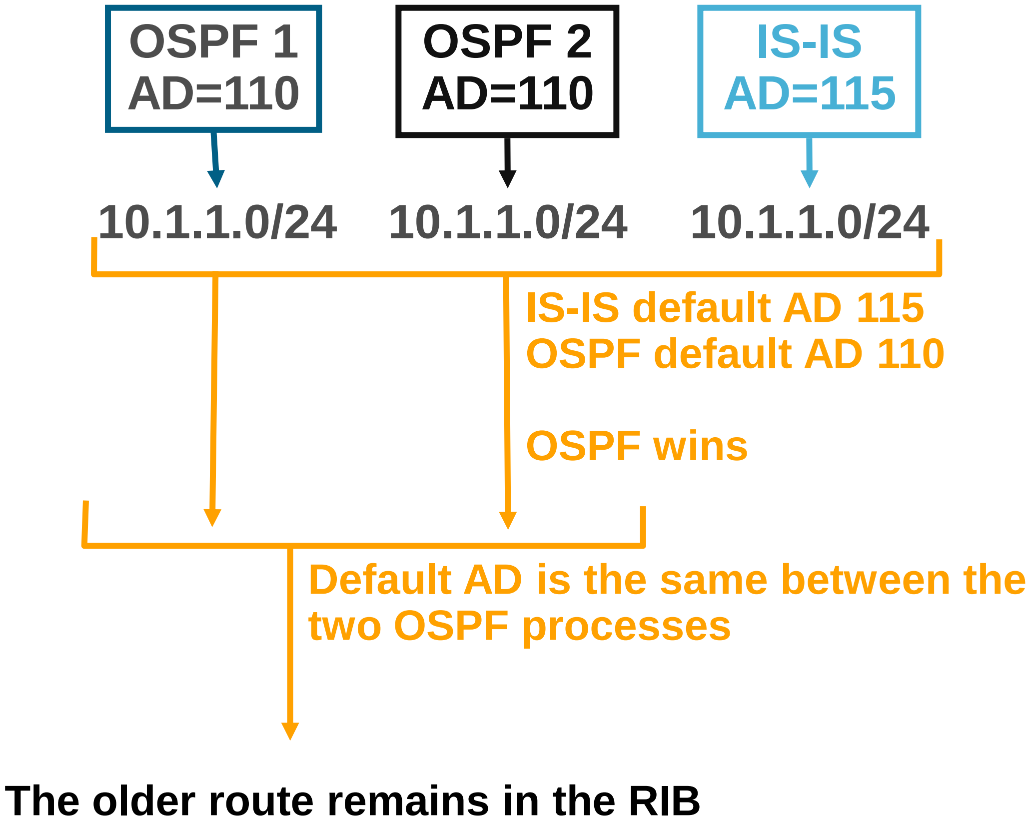
- What happens if the administrative distance of the two routes are equal?
- It depends on the routing protocol



It depends. Usually the route with the default AD is installed into the RIB

Route Selection

OSPF and IS-IS



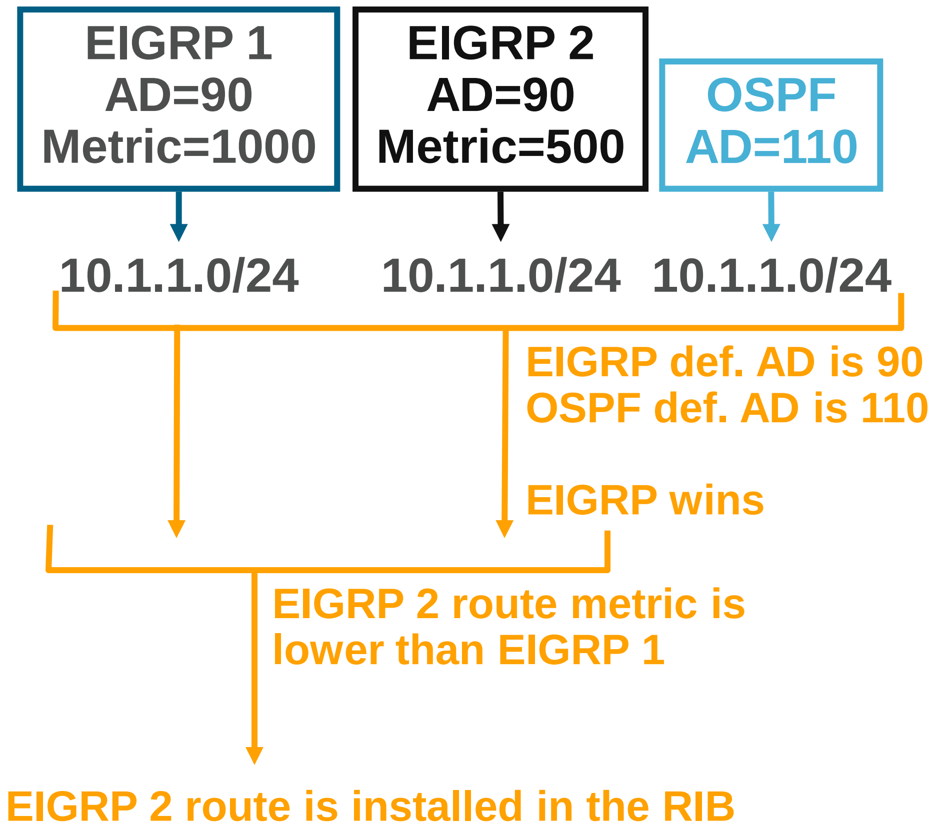
Route Selection

OSPF and IS-IS

- The default administrative distance of each route is compared
- If these are the same, the older route remains in the routing table

Route Selection

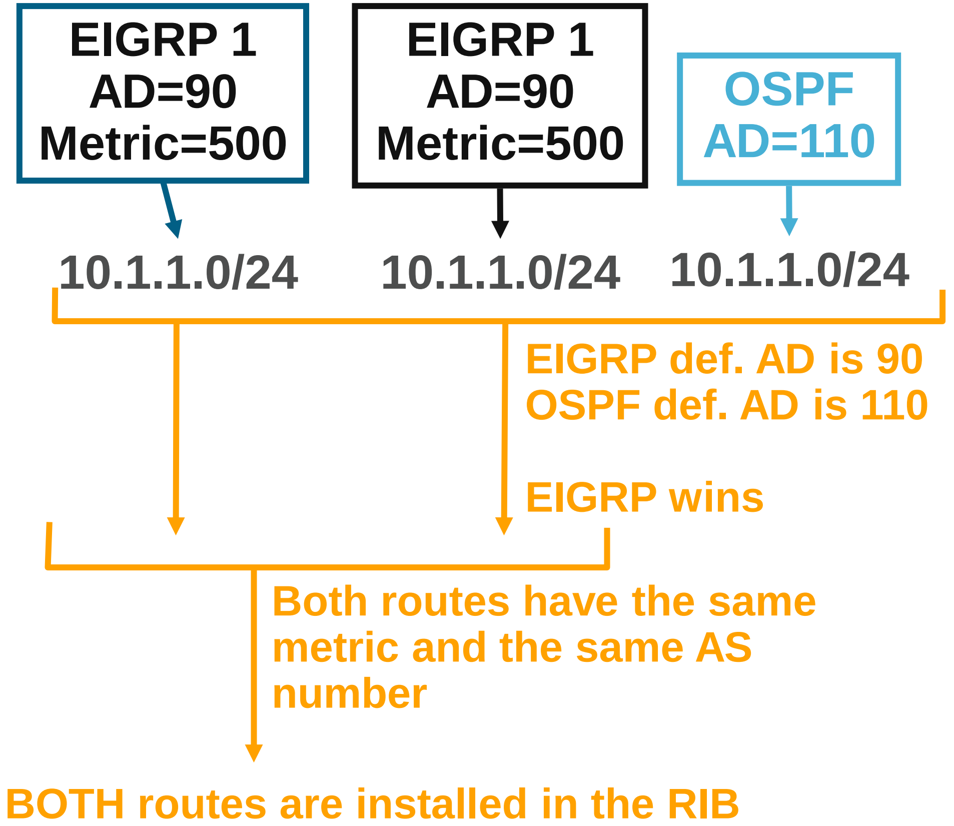
EIGRP



Tie breaker is the lowest AS number

Route Selection

- What happens if the same routing process has multiple identical routes with the same metric?



When multiple paths exist within the same routing process with equal cost, both are presented to the RIB for equal cost load-sharing

Route Selection

EIGRP

- Default administrative distance of each route’s protocol is compared
- If these are the same, both routes must be EIGRP
- Compare the metric type and metric, the lower cost route is installed
- If the metric and metric type are the same, compare the EIGRP AS number
- The lower AS number wins

The Routing Table:

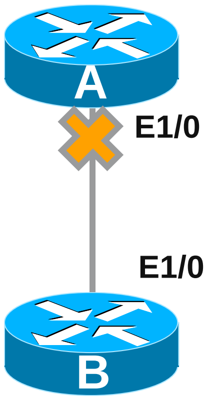
Interface Down Events

Interface Down Events

How does the RIB interact with the routing protocol when an interface fails?

```
interface Ethernet1/0
 ip address 10.1.20.1 255.255.255.128

router eigrp 1
 network 10.0.0.0
```




```
interface Ethernet1/0
 ip address 10.1.20.2 255.255.255.128

router eigrp 1
 network 10.0.0.0
```

Interface Down Events

```
A#show ip route

 10.0.0.0/8 is variably subnetted, 2 subnets, 2 masks
C       10.1.20.0/25 is directly connected, Ethernet1/0
L       10.1.20.1/32 is directly connected, Ethernet1/0
     172.16.0.0/16 is variably subnetted, 2 subnets, 2 masks
D       172.16.24.0/24 [90/307200] via 10.1.20.2, 00:00:05, Ethernet1/0....
```

The RIB tells EIGRP the interface is down

10.1.20.0, connected, is removed from the RIB

172.16.24.0, learned through EIGRP, is removed from the RIB (before EIGRP takes the neighbor down)

The EIGRP neighbor goes down

The interface changes to down state

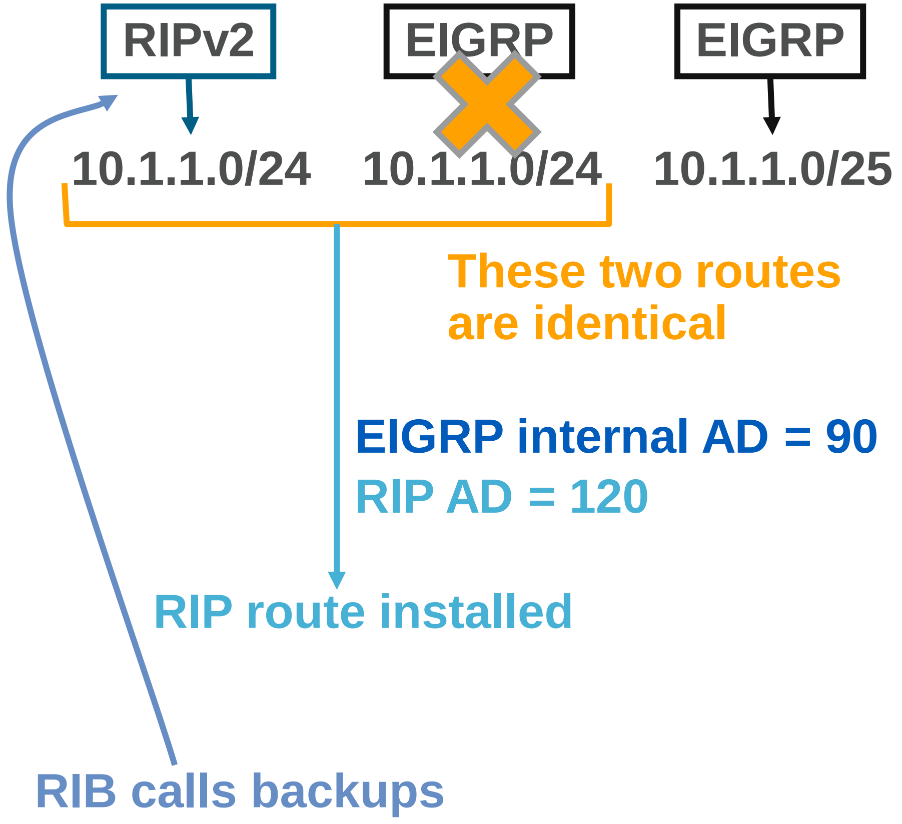
```
20:46:58.151: EIGRP-IPv4(1): Callback: route_adjust Ethernet1/0
20:46:58.151: RT: interface Ethernet1/0 removed from routing table
20:46:58.151: RT: del 10.1.20.0 via 0.0.0.0, connected metric [0/0]
20:46:58.151: RT: delete subnet route to 10.1.20.0/25
20:46:58.151: RT: delete route to 10.1.20.1 via 0.0.0.0, Ethernet1/0
20:46:58.151: RT: no routes to 10.1.20.1, flushing
20:46:58.151: RT: delete route to 172.16.24.0 via 10.1.20.2, Ethernet1/0
20:46:58.151: RT: no routes to 172.16.24.0, flushing
20:46:58.151: %DUAL-5-NBRCHANGE: EIGRP-IPv4 1: Neighbor 10.1.20.2 (Ethernet1/0) is down: interface down
20:47:00.139: %LINK-5-CHANGED: Interface Ethernet1/0, changed state to administratively down
20:47:01.139: %LINEPROTO-5-UPDOWN: Line protocol on Interface Ethernet1/0, changed state to down
```

The Routing Table:

Backup, Static, and Discard Routes

Backup Routes

Backup Routes



Backup Routes

- If a route with a low administrative distance fails…
- The routing table calls each routing process asking for backup routes
- Each routing process attempts to install its matching routes
- The route with the lowest administrative distance wins

Backup Routes

```
router-b#show ip route
Codes: D - EIGRP, EX - EIGRP external, O - OSPF....
....
O    10.0.16.0/24 [110/1064] via 10.0.12.10, Serial0/3
```

The route is installed by OSPF

```
router-b#show ip eigrp topo
IP-EIGRP Topology Table for AS(100)/ID(208.0.17.11)
....
P 10.0.16.0/24, 0 successors, FD is Inaccessible
```

EIGRP has the same route in its topology table, but it's not installed because it has a higher AD (170)

```
router-b#debug ip routing
router-b#debug ip eigrp notifications

....
RT: delete route to 10.0.16.0/24
IP-EIGRP: Callback: callbackup_routes 10.0.16.0/24

IP-EIGRP: Callback: reload_iptable
RT: add 10.0.16.0/24 via 10.0.12.10, eigrp metric [170/3072256]
```

The OSPF route fails…

EIGRP gets a callback for 10.0.16.0/24, which is the OSPF route that failed

EIGRP installs the existing 10.0.16.0/24 route from its topology table

```
router-b#show ip route
Codes: D - EIGRP, EX - EIGRP external, O - OSPF....
....
D EX   10.0.16.0/24 [170/3072256] via 10.0.12.10, Serial0/3
....
```

The route is now installed by EIGRP

Learn. Connect. Collaborate. together.

Static Routes

Static Routes

Static Routes Can Have a Next Hop of an IP Address

- `ip route 10.1.1.0 255.255.255.0 10.1.2.1`

- This causes the RIB and CEF to do a recursive lookup to find the correct Layer 2 header to rewrite onto the packet
- Recursive lookup: For each packet destined to 10.1.1.0/24:

    1) Look up the destination (10.1.1.0/24)
    2) Find the next hop is 10.1.2.1
    3) Look up how to get to 10.1.2.1
    4) Find 10.1.2.1 is via connected interface
    5) Look up the layer 2 header out connected interface to next-hop 10.1.2.1

- As long as the next hop is reachable, the router assumes the destination through that next hop is reachable

Static Routes

Static Routes Can Have a Next Hop of a Point-to-Point interface

- **`ip route 10.1.1.0 255.255.255.0 serial0`**

- The RIB and forwarding tables point the route directly out the point-to-point interface
  - No need to do a recursive lookup
- For each packet destined to 10.1.1.0/24, the Layer 2 rewrite header is set up to reach the other end of the point-to-point link
- Faster, less complicated lookup
- As long as the interface is up, the router assumes the destination is reachable through that interface

Static Routes

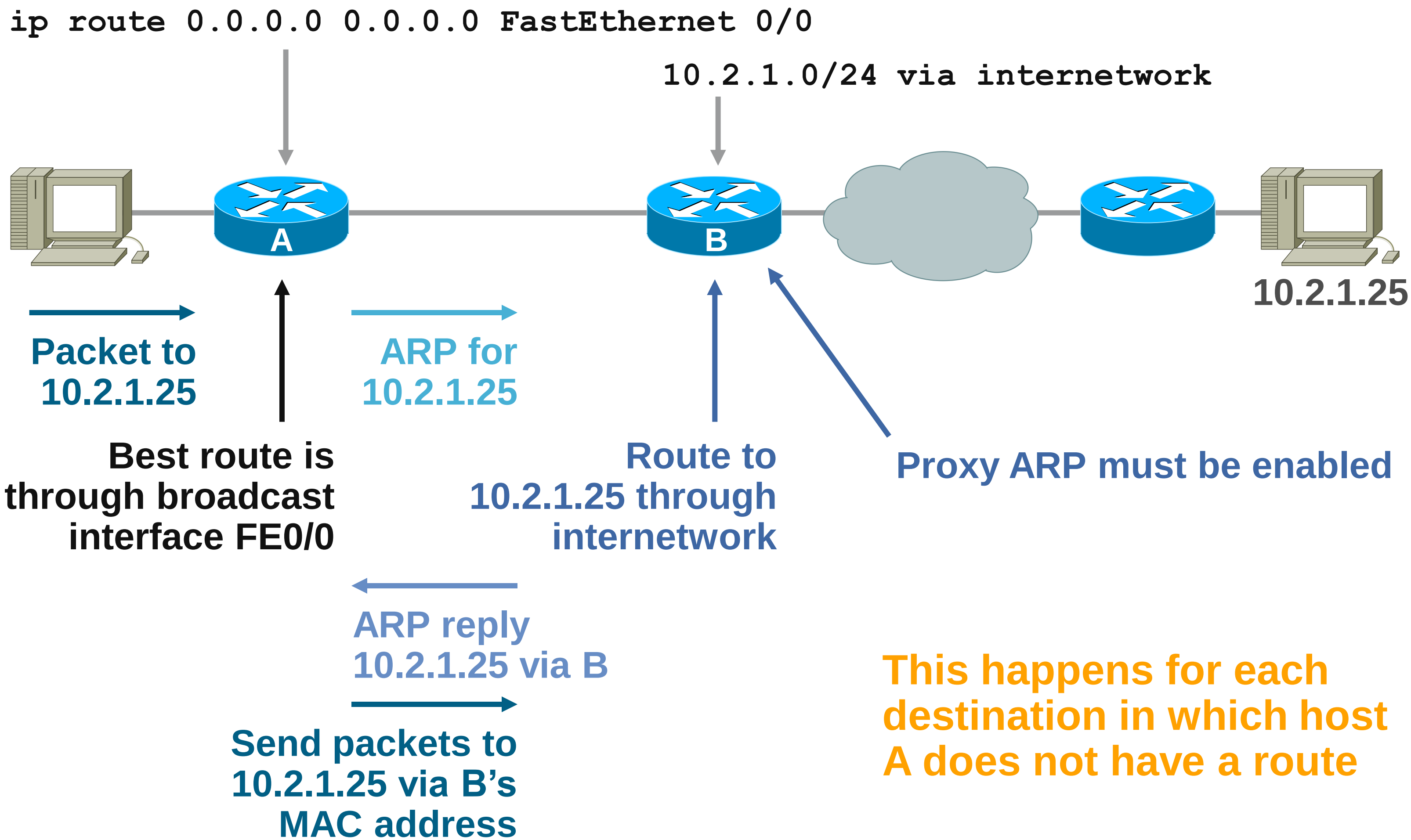
Static Routes Can Have a Next Hop of a broadcast interface

- **`ip route 10.1.0.0 255.255.0.0 fa0/0`**

- The RIB and CEF will point this route directly to the broadcast interface

```
router#show ip route
....
10.0.0.0/16 is subnetted, 1 subnets
S      10.1.0.0 is directly connected, FastEthernet0/0
```

Static Routes



Note: Proxy ARP disabled by default

Static Routes

- For a default route (0.0.0.0/0), this could result in 2^{32} ARP entries in A's local tables
  - This would overflow the ARP cache, and crash A
- Control static routes to broadcast interfaces
  - Small range of reachable addresses
  - Don't use with proxy ARP, just for reaching hosts actually connected to that segment
- Static routes to point-to-point interfaces don't have this problem

Static Routes

- For a static route to an interface, the destination network is shown in the routing table as connected:

```
router(config)#ip route 10.1.0.0 255.255.0.0 fa 0/1

router#show ip route
....
10.0.0.0/16 is subnetted, 1 subnets
S       10.1.0.0 is directly connected, FastEthernet0/1
```

- Static routes to interfaces will be included if you configure redistribute connected
- How do routing protocols handle this in relation to the network statement?

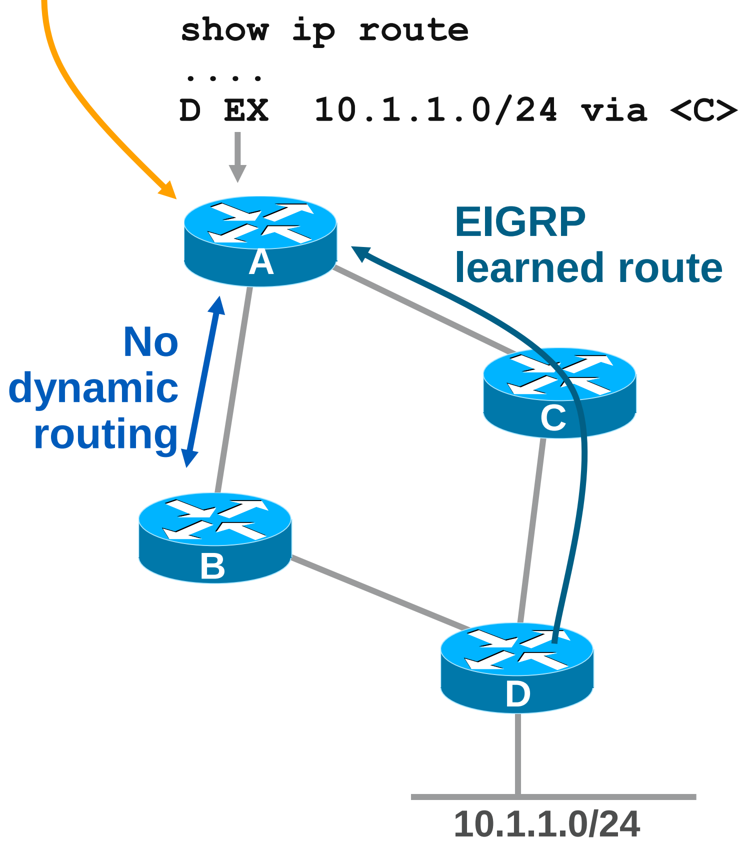
Static Routes

- OSPF:
  - Static routes to interfaces are not advertised as a result of a network statement
- IS-IS:
  - IS-IS doesn’t use network statements, so static routes to interfaces are not advertised without redistribution
- EIGRP:
  - Static routes to interfaces are considered connected routes
  - They will be picked up and advertised if they are contained within a network statement
- BGP:
  - Static routes to interfaces are installed in the routing table
  - They will be picked up and advertised if they match a network statement

Static Routes

Floating Static Routes

`ip route 10.1.1.0 255.255.255.0 <B> 250`



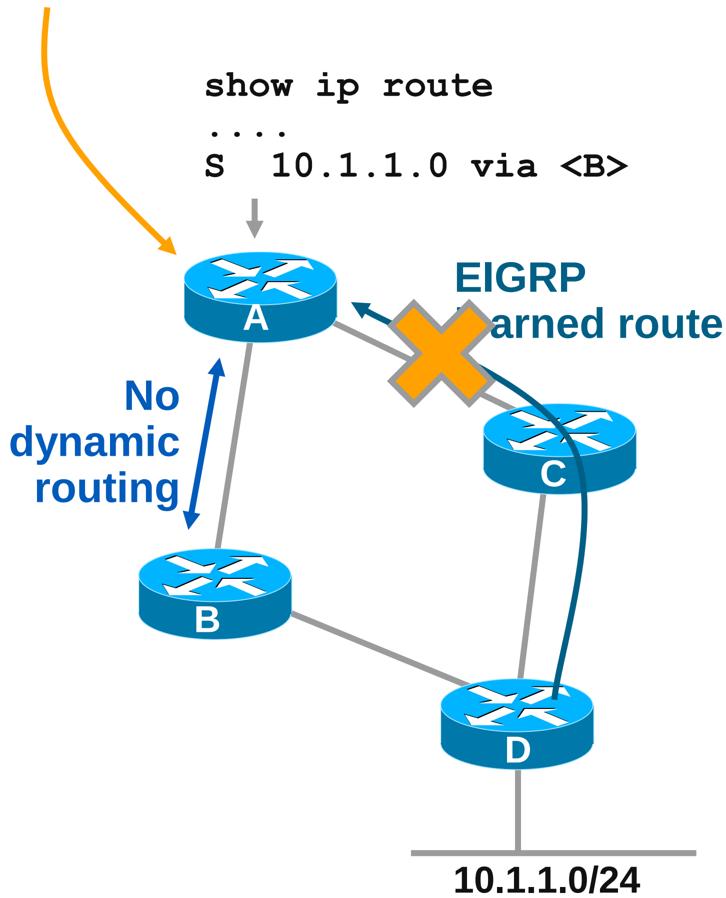
Static Routes

- The concepts of administrative distance and backup routes are used to create floating static routes
- Configuring a static route with a very high administrative distance ensures it won't be installed as long as there is a dynamically learned route installed in the RIB using the default AD
- 255 = unreachable

Static Routes

Floating Static Routes

ip route 10.1.1.0 255.255.255.0 <B> 250



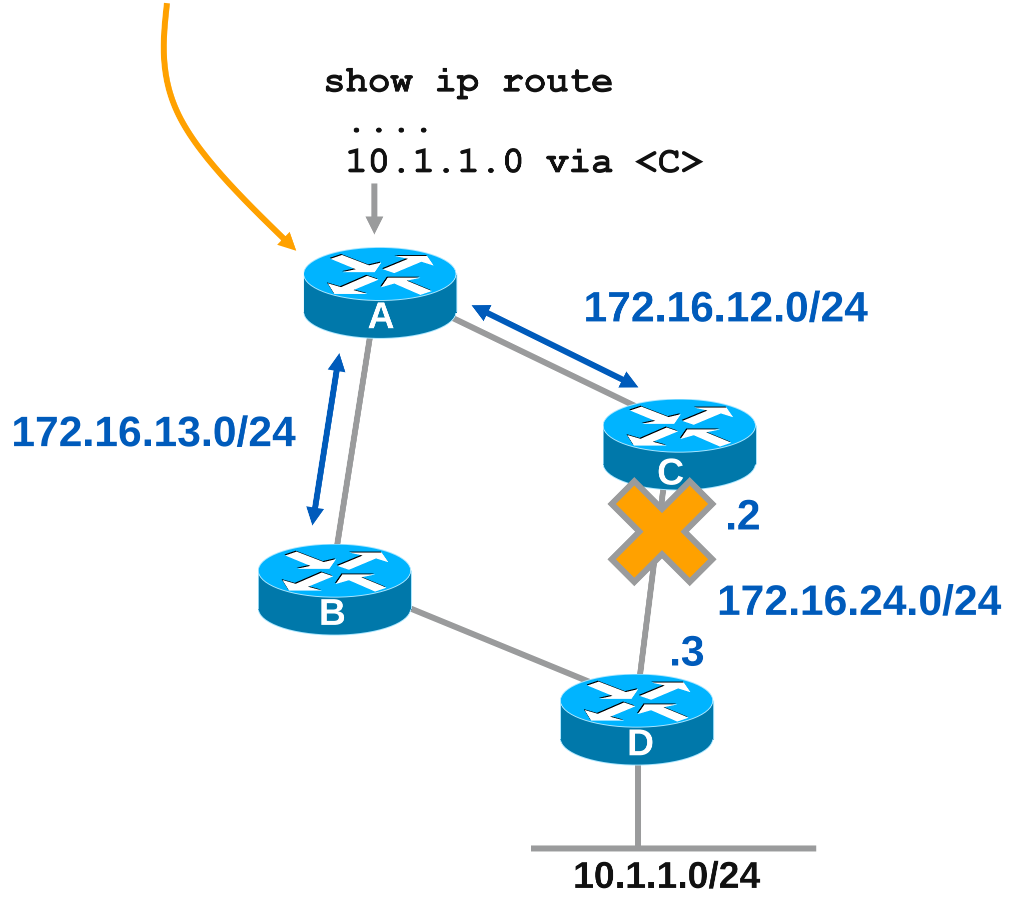
Static Routes

- When the dynamically learned route fails, the RIB calls the processes looking for a backup route
- Since no other processes have routes to install, the static route with an administrative distance of 250 wins
- This assumes that the primary route will be removed from the table in a failure event. If a failure event will not remove the primary route from the RIB then the floating static backup will not be installed.

Static Routing with Object Tracking

How can we get dynamic failover with no dynamic routing?

```
ip route 10.1.1.0 255.255.255.0 <C>
ip route 10.1.1.0 255.255.255.0 <B> 10
```



Static Routing with Object Tracking

```
ip route 10.1.1.0 255.255.255.0 172.16.12.2 track 1
ip route 10.1.1.0 255.255.255.0 172.16.13.3 10

track 1 ip sla 1 reachability

ip sla 1
 icmp-echo 172.16.24.2 source-interface Ethernet1/0
 frequency 5
ip sla schedule 1 life forever start-time now
```

Probes are being sent to 172.16.24.2

The track object goes down when reachability fails

The routing table is updated to remove the route to the destination through the tracked path

The floating static route is installed into the routing table

Probes are still sent to determine when this path is available again

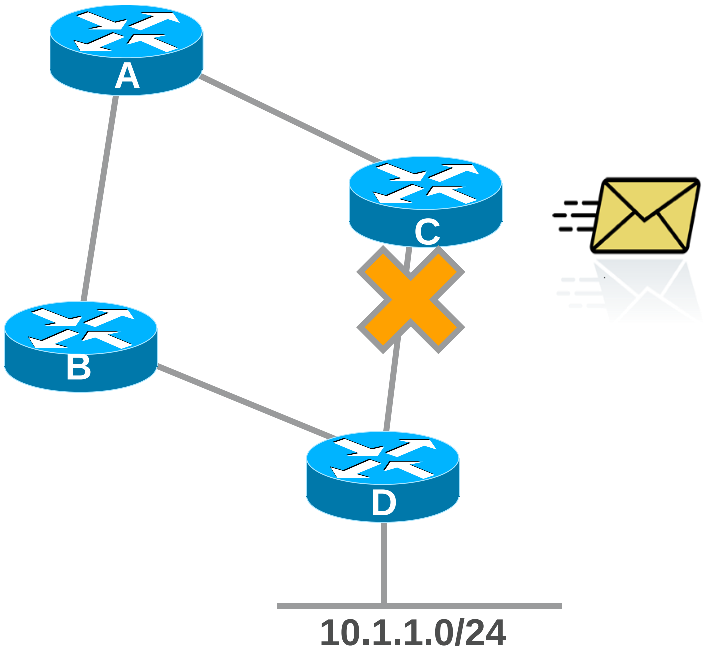
```
02:34:12.106: ICMP: echo reply rcvd, src 172.16.24.2, dst 172.16.12.1, topology BASE, dscp 0 topoid 0
02:34:17.114: ICMP: dst (172.16.12.1) host unreachable rcv from 172.16.12.2
02:34:17.306: Track: 1 Change #9 ip sla 1, reachability Up->Down
02:34:17.306: %TRACKING-5-STATE: 1 ip sla 1 reachability Up->Down
02:34:17.306: RT: del 10.1.1.0 via 172.16.12.2, static metric [1/0]
02:34:17.306: RT: delete subnet route to 10.1.1.0/24
02:34:17.306: RT: updating static 10.1.1.0/24 (0x0) via 172.16.13.3
02:34:17.306: RT: add 10.1.1.0/24 via 172.16.13.3, static metric [10/0]
02:34:17.310: RT: updating static 10.1.1.0/24 (0x0) via 172.16.13.3
02:34:22.114: ICMP: dst (172.16.12.1) host unreachable rcv from 172.16.12.2
```

Object Tracking Tip - Use EEM

```
event manager applet static_tracking
event syslog pattern "%TRACKING-5-STATE: 1 ip sla 1 reachability Up->Down"
action 1 wait 3
action 2 cli command "enable"
action 3 cli command "term len 0"
action 4 cli command "term exec prompt timestamp"
action 5 cli command "show log | append flash:log_output"
action 6 mail server "<mail_server_ip>" to "<email_address>" from "<sender>" subject "Link C-D is down."
end
```

Connectivity is unstable.
Any helpful tools?

We can use Embedded Event Manager (EEM) to notify us of the issue



www.cisco.com/web/go/eem

Static Routing with BFD

- BFD – Bidirectional Forwarding Detection

    BFD builds its own neighbor relationship with adjacent routers to provide fast peer failure detection independent of media type, encapsulation, or routing protocols

- Static routing has no method of peer discovery

    Can use BFD to track the reachability of the peer

- Static route only installed in RIB if BFD session is up allowing us to consider the Gateway reachable

```
Interface GigabitEthernet0
   ip address 2.2.2.1 255.255.255.252
   bfd interval 500 min_rx 500 multiplier 5

ip route static bfd GigabitEthernet0 2.2.2.2
ip route 192.168.1.1 255.255.255.255 GigabitEthernet0 2.2.2.2
```

Discard Routes

Discard Routes

- Discard routes are created when a router aggregates routing information

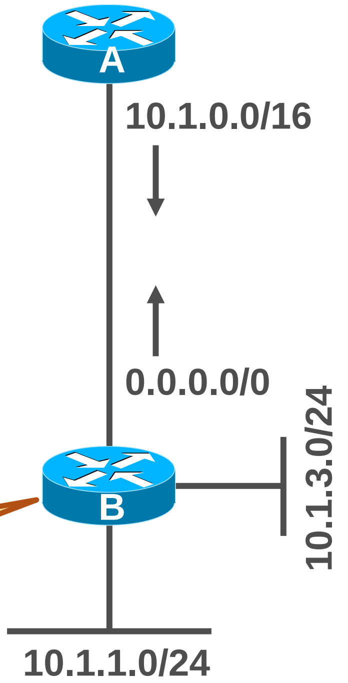
```
(EIGRP) ip summary-address eigrp 100 10.1.0.0 255.255.0.0 5
(OSPF)  area 1 range 10.1.0.0 255.255.0.0
(IS-IS) summary-address 10.1.0.0 255.255.0.0 level-2
....
Router_A#show ip route
....
D       10.1.0.0/16 is a summary, 00:04:03, Null0
```

- A discard route has an administrative distance of five by default

Discard Routes

Why is this discard route created?

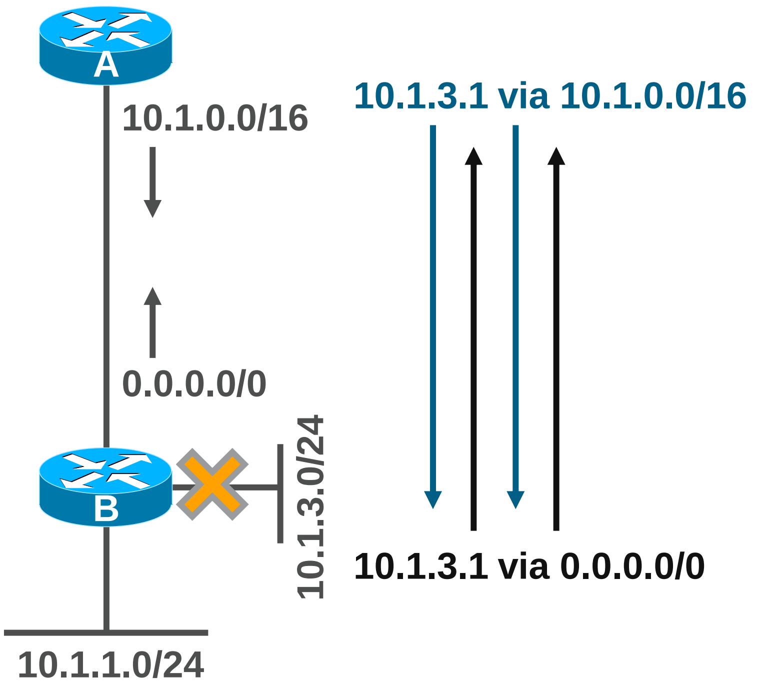
- Suppose
  - A is advertising a default route to B
  - B is advertising the summary 10.1.0.0/16 to A
  - B is not building a discard route for this summary




```
interface eth 0/0
   ip summary-address eigrp 100 10.1.0.0 255.255.0.0
…
ip route 0.0.0.0 0.0.0.0 <A>
```

Discard Routes

A receives a packet for 10.1.3.1



We have a permanent routing loop.

Routing Loop avoided if B had a discard route for 10.1.0.0/16

Discard Routes

- A receives a packet for 10.1.3.1
    - A examines its local routing table, and finds the best path is through B, using the route to 10.1.0.0/16
    - A forwards the packet to B
- B receives the packet for 10.1.3.1
    - B examines its local routing table, and finds the best path is through A, using the default route
    - B forwards the packet to A
- We have a permanent routing loop!
- If B builds a discard route for 10.1.0.0/16, it will discard the packet, rather than forwarding it through the default route back to A

Discard Routes

- Can you prevent the routing protocol from creating a discard route?

  OSPF

  ```
  router ospf 100
   no discard route
  ```

  EIGRP

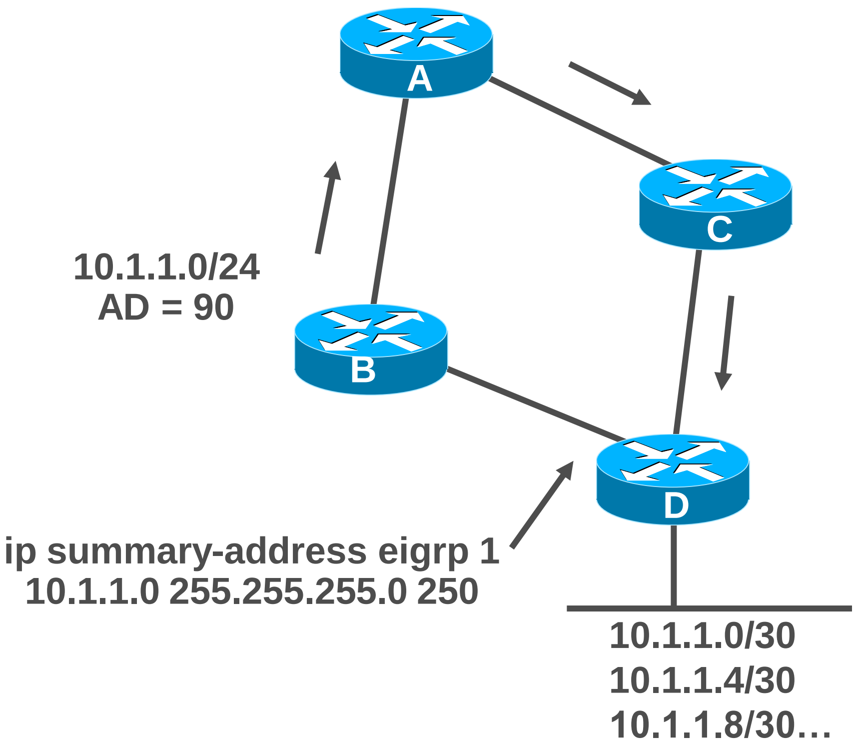
  ```
  interface serial0
   ip summary-address 10.1.0.0 255.255.0.0 255
  ```

- Why would you want to get rid of the discard route?

  Be very careful with removing discard routes—this can create routing loops

Discard Routes

Be careful when using non default AD values for summary routes.




```
D#show ip route 10.1.1.0
Routing entry for 10.1.1.0/24
  Known via "eigrp 1", distance 250, type internal
  Redistributing via eigrp 1
  Routing Descriptor Blocks:
  * directly connected, via Null0
```

D receives the route from C via EIGRP with an AD of 90. This is better than the installed route to Null with an AD of 250.

Learn. Connect. Collaborate. together.

Overriding the Routing Table

Overriding the Routing Table

What if I do not want to route my traffic based only on destination?

- Policy-Based Routing (PBR)
    - Route-map
- Performance Routing (PfR)
    - Source IP
    - ToS
    - Application
    - Link Utilization

Overriding the Routing Table:

Policy Based Routing

Route Maps

- Route maps allow you to:
  - Combine more than one type of filter into a single phrase
  - Use some rudimentary forms of logical “AND” and “OR” to filter routes
  - Set some route attributes, rather than just permitting or denying routes
- Route maps can be used to:
  - Set IP next-hop
  - Filter BGP updates
  - Filter EIGRP updates
  - Filter routes being redistributed between two protocols
  - Etc.

Route Maps

One of the two results of a route map is whether the route is permitted or denied through the filter

Type of phrase (permit or deny) **Phrase sequence**

Phrase 1
```
route-map networkers permit 10
 match ip address 10
```
Phrase 2
```
route-map networkers permit 20
 match ip address 20
 set ip next-hop 10.1.1.1
```
Phrase 3
```
route-map networkers permit 30
 set ip next-hop 10.2.2.2
```

If this match succeeds, the route map exits with *permit*

If not, the route map continues with the next phrase

If this match succeeds, *set next-hop* is executed, and the route map exits with *permit*

If not, the route map continues with the next phrase

If the route map makes it to this phrase, *set next-hop* is executed, and the route map exits with *permit*

Route Maps

Phrase type	Match result	Route map result
Permit	Permit	Set statements within the phrase are executed and the route map exits with *permit*
Deny	Permit	Set statements within the phrase are not executed and the route map exits with deny
Permit/ Deny	Deny	Set statements within the phrase are not executed and route map continues with the next phrase *If there is no next phrase, route map exits with deny*

Route Maps

- PBR proceeds through the route map until a match is found. If no match is found in the route map, the packet will be forwarded according to normal destination-based routing
- If the route-map statement is marked as a deny, the packets meeting the match criteria are forwarded according to normal destination-based routing
- If the statement is marked as permit and the packets do not meet the match criteria, the packets are forwarded according to normal destination-based routing
- If the route-map statement is marked as permit and the packets meet the match criteria, the set clauses are applied and policy routing is performed

Route Maps

Match	Description
`metric`	Metric of the route *In BGP's case, this is the MED* *Must match exactly!*
`route-type`	OSPF or EIGRP route type *Internal, External OSPF external type 1 or 2*
`tag`	Route tag
`ip address`	Standard or extended access list *Applied against the prefix* *Numbered or named*
`ip address prefix-list`	Prefix list *Applied against the prefix and prefix length*
`ip next-hop`	Standard or extended access list *Applied against the next hop (via in the routing table)* *Numbered or named*
`length`	Packet length
`ip route-source`	Standard or extended access list *Applied against the neighbor this route was learned from (from in the routing table)* *Numbered or named*

Route Maps

- Not all set statements work with all protocols or in all situations
- It is recommended to test what you want to do before you try to use it

Set	Description
`ip next-hop`	Set the next hop in the routing table or transmitted route
`ip next-hop recursive`	Set the next hop to a subnet which is not directly connected
`ip next-hop verify`	Set the next hop and verify availability using tracking
`interface`	Set the output interface
`metric`	Set the metric of the redistributed or transmitted route
`metric-type`	Set the type of external route *External type 1 or type 2 for OSPF*
`tag`	Sets the route tag

Route Map Logic (AND)

```
route-map networkers permit 10
  match ip address 10
  match tag 1000
  set ip next-hop 10.1.1.1
```

Must match BOTH 'match' conditions to successfully match route-map phrase

Logical AND

Some types of matches cannot co-exist in the same route map phrase, such as an access list and a prefix list

Route Map Logic (OR)

```
route-map networkers permit 10
  match ip address 10 20
  set ip next-hop 10.1.1.1
```

Can match any ACL in the ACL list under the single ‘match’ statement

Logical OR

Route Map Logic (NOT)

```
route-map networkers permit 10
  match ip address 10
route-map networkers permit 20
  match ip address 20
route-map networkers permit 30
  set ip next-hop 10.1.1.1
```

If we match either ACL in phrase 10 or phrase 20 then we exit the route-map and don’t fall to catch-all phrase 30.

Therefore we must NOT match either ACL 10 nor 20 in order for the ‘set’ to apply

Logical NOT

Route Maps

Route map	Logic	Notes

`route-map networkers permit 10`
`  match ip address 10`
`  match tag 1000`
`  set ip next-hop 10.1.1.1`
	AND	Both matches must succeed for the set to be executed
		
		Some types of matches cannot co-exist in the same route map phrase, such as an access list and a prefix list

`route-map networkers permit 10`
`  match ip address 10 20`
`  set ip next-hop 10.1.1.1`
	OR	If the route matches either access list 10 or 20, the set will be executed

`route-map networkers permit 10`
`  match ip address 10`
`route-map networkers permit 20`
`  match ip address 20`
`route-map networkers permit 30`
`  set ip next-hop 10.1.1.1`
	NOT	The route must not match access list 10 or 20 for the set to execute
		If the access lists deny routes, then the routes must not exist for a specific action to be taken (useful in conditional advertisement)

Route Maps

- Route map AND and OR rules
  - If two different types of matches are configured in the same phrase, they must both succeed for the set to be executed and the route map to exit (logical AND)
  - If two of the same type of match are configured (where permitted) in the same phrase, either one can succeed for the set to be executed and the route map to exit (logical OR)
  - All matches in a single phrase must fail for the route map to fall through to the next phrase (logical NOT)
- Route maps can become very complicated based on these parsing rules

Route Maps

Gathering Policy with Continue

```
route-map networkers permit 10
 match ip address 10
 set ip next-hop 10.1.1.1
 continue 30
route-map networkers permit 20
 match ip address 20
 set ip next-hop 10.1.2.1
 continue 30
route-map networkers permit 30
 set ip precedence critical
 set ip df 0
```

If this match succeeds

Execute this set

Continue to 30

Execute this set

If this match succeeds

Execute this set

Continue to 30

Execute this set

Route Maps

- In normal processing, if all matches fail, the route map falls through to the next phrase
- Route map continue allows you to continue to another phrase if the matches succeed
- Sets are executed before the continue is followed
- Use for:
  - Gathering policy (matches and sets) into a single phrase
  - More complex logical constructions

Policy Based Routing

- Allows packets to be filtered through route maps containing policies that selectively determine the next hop to which packets are to be forwarded
- Policy routes can be determined based on such things as the source of the packet, protocol types, port numbers, and the size of the packet
- Must be applied on the interface on which the packet is received. “ip policy route-map <name>” in interface configuration mode

Policy Based Routing

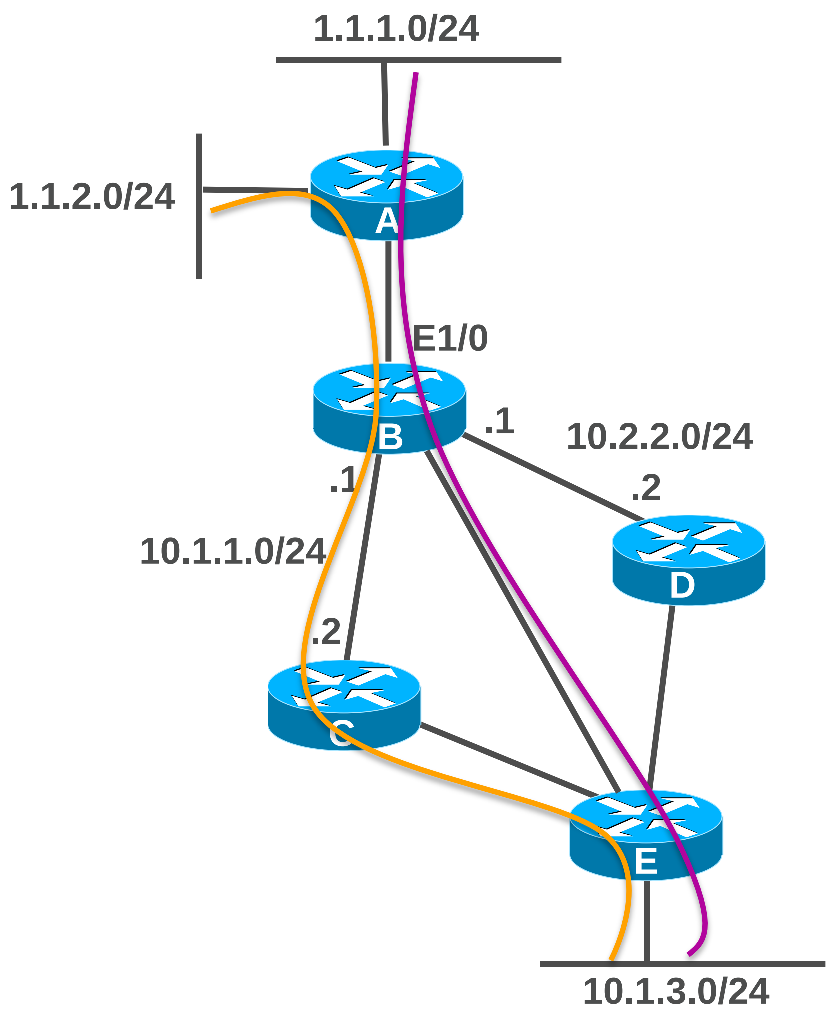
```
Router_B#show ip route
....
D  10.1.3.0/24 via <E>

Router_B#show run

interface Ethernet1/0
 ip policy route-map networkers

access-list 10 permit 1.1.1.0 0.0.0.255
access-list 20 permit 1.1.2.0 0.0.0.255


route-map networkers permit 10
 match ip address 10
route-map networkers permit 20
 match ip address 20
 set ip next-hop 10.1.1.2
route-map networkers permit 30
 set ip next-hop 10.2.2.2
```



Policy Based Routing

- PBR applied to an interface only affects traffic that comes in that interface
- Can configure a PBR policy local to the router

```
Router#show run

ip local policy route-map networkers

access-list 101 permit ip any 1.1.1.0 0.0.0.255

route-map networkers permit 10
  match ip address 101
  set ip next-hop 10.1.1.2
```

- Local PBR policy only affects traffic generated from the router itself

Policy Based Routing

- Can PBR be Dynamic?

  You can use Object Tracking with PBR to track the availability of the next-hop

```
track 1 ip sla 1 reachability
track 2 ip sla 2 reachability

ip sla 1
   icmp-echo 10.10.10.2 source-interface Ethernet1/0
ip sla 2
   icmp-echo 10.10.10.3 source-interface Ethernet1/0
ip sla schedule 1 life forever start-time now
ip sla schedule 2 life forever start-time now

route-map networkers permit 10
  match ip address 101
  set ip next-hop verify-availability 10.10.10.2 1 track 1
  set ip next-hop verify-availability 10.10.10.3 2 track 2
```

- Tracking object tied to IP SLA object
- Route-map ties next-hop to tracking object so next-hop is only valid if the tracking object is UP
- If both tracking objects are DOWN, normal routing is used

Sequence number determines priority of next-hops

Policy Based Routing

- Load sharing—Supplemental to dynamic load-sharing capabilities offered by Cisco IOS, PBR allows traffic to be administratively distributed among multiple paths based on the traffic characteristics
- Quality of Service (QoS)—Using IP Precedence or type of service (ToS) values to prioritize differentiated traffic
- Source-sensitive routing—Route traffic originating from different users through different paths
- Cost—Route traffic across low-bandwidth, low-cost permanent paths or high-bandwidth, high-cost,
switched paths
- Security—Route certain types of traffic (like http) to firewall/IPS/content filtering device and allow other traffic to follow normal routing

Overriding the Routing Table:

Performance Routing

Performance Routing

- Traditional routing based on destination of packet
- Policy-based routing allows routing based on more information about the packet

  Source IP, Protocol, Ports Used, QoS markings, etc

- Performance Routing (PFR) allows for routed path decisions to be made on path characteristics (like reachability, delay, packet loss, jitter, Mean opinion Score) so application traffic can be given the optimum path given it’s path requirements

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Performance Routing

- Learn traffic and applications
  - Discovers traffic going through network via Netflow
- Measure traffic and application performance
  - Tracks characteristics like loss/delay/jitter about paths either passively (via netflow) or actively (via IP SLA probes)
- Apply policies to the traffic based on measurements
  - Allows definitions of policies so certain applications or traffic classes given required network service
- Reroute traffic
  - Dynamically alters path of application traffic if current service not in line with specified policy to sustain performance

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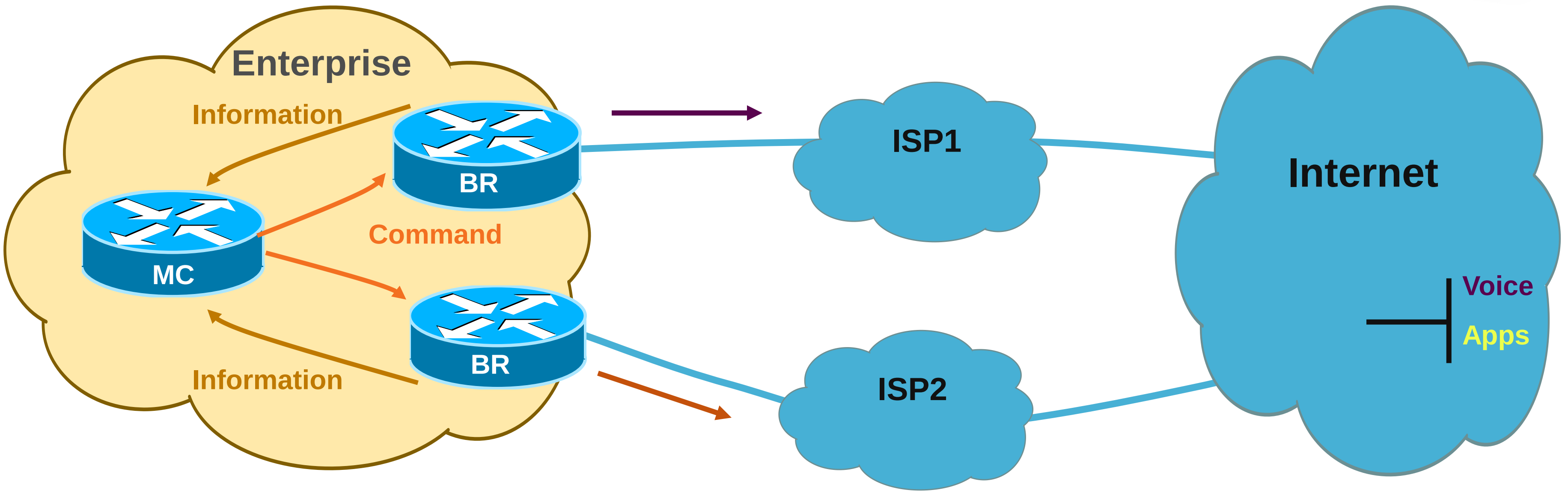
Performance Routing



- Border Routers collect traffic information and pass the information to a central router (called a Master Controller)
- Master Controller receives information about flows and determine if they are within configured policy for traffic class
- If measurements of traffic class is out of policy or less-optimum, Master controller can send commands to the borders to re-route traffic

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Load Sharing

Load Sharing

- Assume the same routing process attempts to install two routes for the same destination in the RIB
- The routing process may allow the second route to be installed based on its own rules

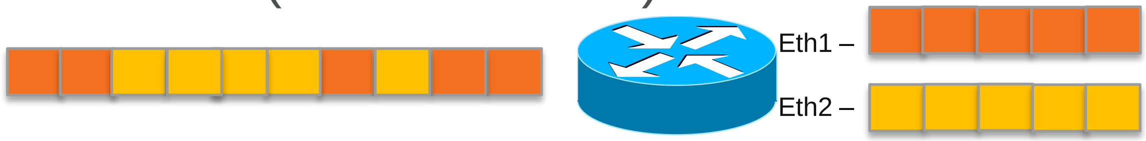
	OSPF	IS-IS	EIGRP
Route cost	Must be equal to installed route	Must be equal to installed route	Must be less than or equal to the lowest cost route times the variance
Maximum Paths	Must be less than or equal to the *maximum-paths* configured under the routing process		

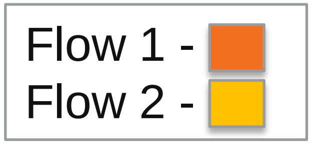
Load Sharing

Load sharing performed in the CEF (Cisco Express Forwarding) path

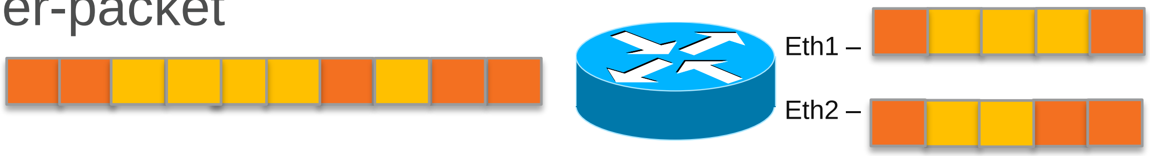
CEF has 2 forms of load sharing

- Per-session (Per-destination)





- Per-packet



Load Sharing

Per-Session Load Sharing

- Often referred to as per-destination load sharing, even within Cisco IOS
- This method is the default behavior and does not require any additional configuration
- A session is a flow that shares the same source and destination. Traffic with different source to destination pairs tend to take different paths
- This method ensures that traffic for a given session arrive in order
- Has the potential for traffic polarization and is more effective as the number of source to destination pairs increase

Load Sharing

Per-Packet Load Sharing

- To utilize this method, configure “ip cef load-sharing per-packet” in interface configuration mode. Each outgoing interface must have this command configured
- Uses a round-robin method to determine which path each packet takes to the destination without consideration of source to destination sessions
- Ensures traffic is more evenly distributed over multiple paths
- Packets for a given source to destination session may take different paths, introducing a greater potential for packets to arrive out of sequence. Not advisable for all types of traffic
- Method used when process-switching

Load Sharing

```
router#show ip route 192.168.239.0
Routing entry for 192.168.239.0/24
  Known via "eigrp 100", distance 170, metric 3072256, type external
  Redistributing via eigrp 100
  Last update from 192.168.245.11 on Serial3/1, 00:18:17 ago
  Routing Descriptor Blocks:
  * 192.168.246.10, from 192.168.246.10, 00:18:17 ago, via Serial3/0
      Route metric is 3072256, traffic share count is 1
      ....
    192.168.245.11, from 192.168.245.11, 00:18:17 ago, via Serial3/1
      Route metric is 3072256, traffic share count is 1
      ....
```

The *traffic share count* is critical to understanding the actual load sharing of packets using these two routes

How is this calculated?

Load Sharing

```
router#show ip route 192.168.239.0
Routing entry for 192.168.239.0/24
  Known via "eigrp 100", distance 170, metric 3072256, type external
  Redistributing via eigrp 100
  Last update from 192.168.245.11 on Serial3/1, 00:18:17 ago
  Routing Descriptor Blocks:
  * 192.168.246.10, from 192.168.246.10, 00:18:17 ago, via Serial3/0
      Route metric is 3072256, traffic share count is 1
      ....
    192.168.245.11, from 192.168.245.11, 00:18:17 ago, via Serial3/1
      Route metric is 3072256, traffic share count is 1
      ....
```

The metric of each route is divided into the highest metric among the available metrics

3072256/3072256 == 1

The resulting number is the traffic share count

Load Sharing

```
router#show ip route 192.168.239.0
Routing entry for 192.168.239.0/24
  Known via "eigrp 100", distance 170, metric 3072256, type external
  Redistributing via eigrp 100
  Last update from 192.168.245.11 on Serial3/1, 00:18:17 ago
  Routing Descriptor Blocks:
  * 192.168.246.10, from 192.168.246.10, 00:18:17 ago, via Serial3/0
      Route metric is 1536128, traffic share count is 2
      ....
    192.168.245.11, from 192.168.245.11, 00:18:17 ago, via Serial3/1
      Route metric is 3072256, traffic share count is 1
      ....
```

If one metric is less than another metric, the traffic share count will be something other than 1 (only for EIGRP and requires variance to be configured)

3072256/3072256 == 1

3072256/1536128 == 2

The resulting number is the traffic share count

Load Sharing

```
router#show ip route 192.168.239.0
Routing entry for 192.168.239.0/24
  Known via "eigrp 100", distance 170, metric 3072256, type external
  Redistributing via eigrp 100
  Last update from 192.168.245.11 on Serial3/1, 00:18:17 ago
  Routing Descriptor Blocks:
  * 192.168.246.10, from 192.168.246.10, 00:18:17 ago, via Serial3/0
      Route metric is 3072256, traffic share count is 1
      ....
    192.168.245.11, from 192.168.245.11, 00:18:17 ago, via Serial3/1
      Route metric is 3072256, traffic share count is 1
      ....
```

When process switching, *traffic share count* packets is sent down one path, and then the process moves to the next available path

The route with the * beside it is the current in use path for process-switching

Load Sharing

- CEF uses 16 hash buckets and assigns hash buckets to each next-hop

```
Router#sh ip route 1.1.1.3
Routing entry for 1.1.1.3/32
  Known via "ospf 10", distance 110, metric 20, type extern 2, forward metric 30
  Last update from 10.3.3.2 on Ethernet1/0, 00:01:04 ago
  Routing Descriptor Blocks:
    10.3.3.2, from 70.70.70.70, 00:01:04 ago, via Ethernet1/0
      Route metric is 20, traffic share count is 1
  * 10.3.3.1, from 70.70.70.70, 00:01:24 ago, via Ethernet1/0
      Route metric is 20, traffic share count is 1
```

Each packet that comes in gets measured against the HASH, and the HASH result determines which hash bucket the packet uses

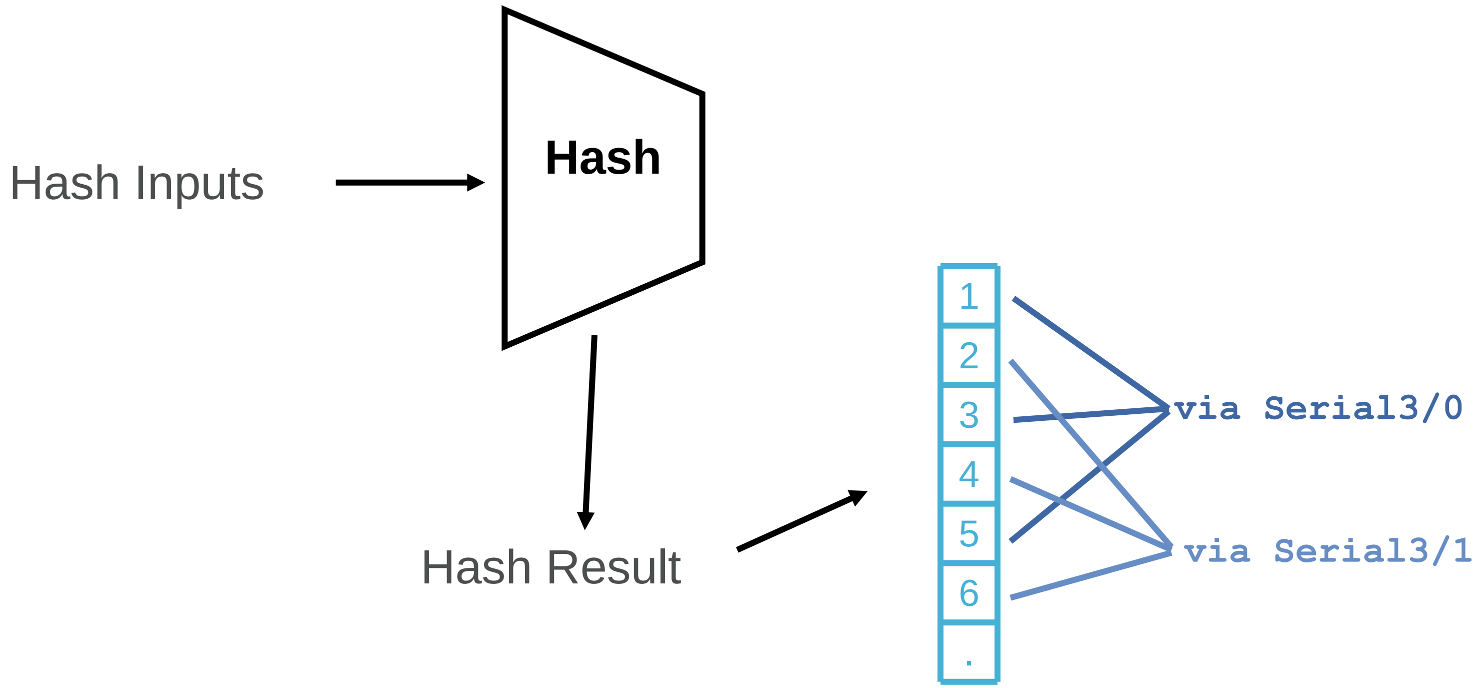
```
Router#sh ip cef 1.1.1.3 internal
[snip]
1.1.1.3/32, epoch 0, RIB[I], refcount 5, per-destination sharing
Ethernet1/0(7): 10.3.3.1, 10.3.3.2
  nexthop 10.3.3.1 Ethernet1/0, adjacency IP adj out of Ethernet1/0, addr 10.3.3.1
  nexthop 10.3.3.2 Ethernet1/0, adjacency IP adj out of Ethernet1/0, addr 10.3.3.2

flags: Per-session, for-rx-IPv4
    16 hash buckets
      < 0 > IP adj out of Ethernet1/0, addr 10.3.3.1 044C4608
      < 1 > IP adj out of Ethernet1/0, addr 10.3.3.2 044C44E8
      < 2 > IP adj out of Ethernet1/0, addr 10.3.3.1 044C4608
      < 3 > IP adj out of Ethernet1/0, addr 10.3.3.2 044C44E8
      < 4 > IP adj out of Ethernet1/0, addr 10.3.3.1 044C4608
      < 5 > IP adj out of Ethernet1/0, addr 10.3.3.2 044C44E8
      < 6 > IP adj out of Ethernet1/0, addr 10.3.3.1 044C4608
      < 7 > IP adj out of Ethernet1/0, addr 10.3.3.2 044C44E8
      < 8 > IP adj out of Ethernet1/0, addr 10.3.3.1 044C4608
      < 9 > IP adj out of Ethernet1/0, addr 10.3.3.2 044C44E8
      <10 > IP adj out of Ethernet1/0, addr 10.3.3.1 044C4608
      <11 > IP adj out of Ethernet1/0, addr 10.3.3.2 044C44E8
      <12 > IP adj out of Ethernet1/0, addr 10.3.3.1 044C4608
      <13 > IP adj out of Ethernet1/0, addr 10.3.3.2 044C44E8
      <14 > IP adj out of Ethernet1/0, addr 10.3.3.1 044C4608
      <15 > IP adj out of Ethernet1/0, addr 10.3.3.2 044C44E8
```

Each next-hop has 8 hash buckets

The result is a 50/50 chance of getting each next-hop

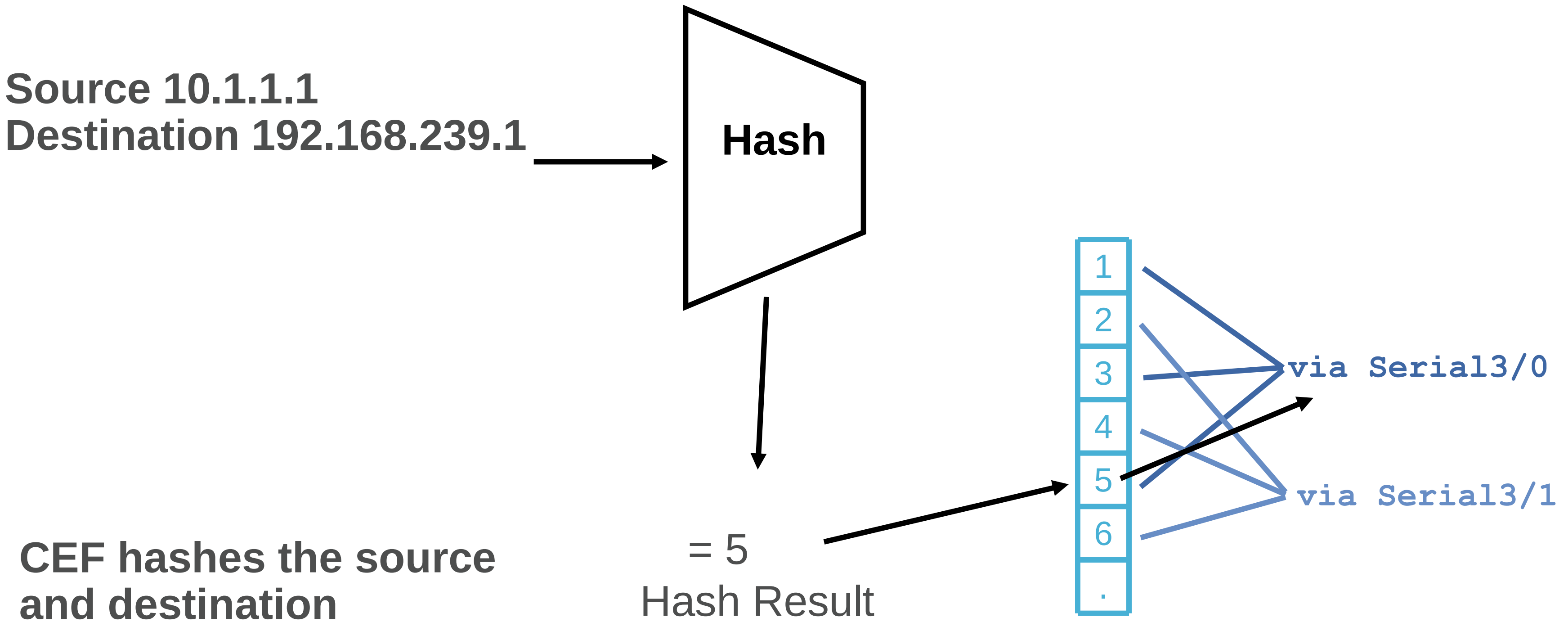
1:1 load-sharing

Load Sharing



- Per-destination Load-sharing takes a set of inputs, runs those inputs into the hash algorithm, and the result of the algorithm determines which load-sharing Hash bucket that packet will use
- Per-destination load-sharing algorithm used will determine which inputs are put into the hash

Load Sharing



CEF hashes the source and destination addresses, and chooses a bucket from the load share table

The load share table points to an adjacency corresponding to one of the next hops in the routing table

Load Sharing

- How do I tell which next-hop a particular packet will take?

```
router#show ip cef exact-route 10.1.1.1 192.168.239.1
10.1.1.1        -> 192.168.239.1    : Serial3/0 (next hop 192.168.246.10)
```

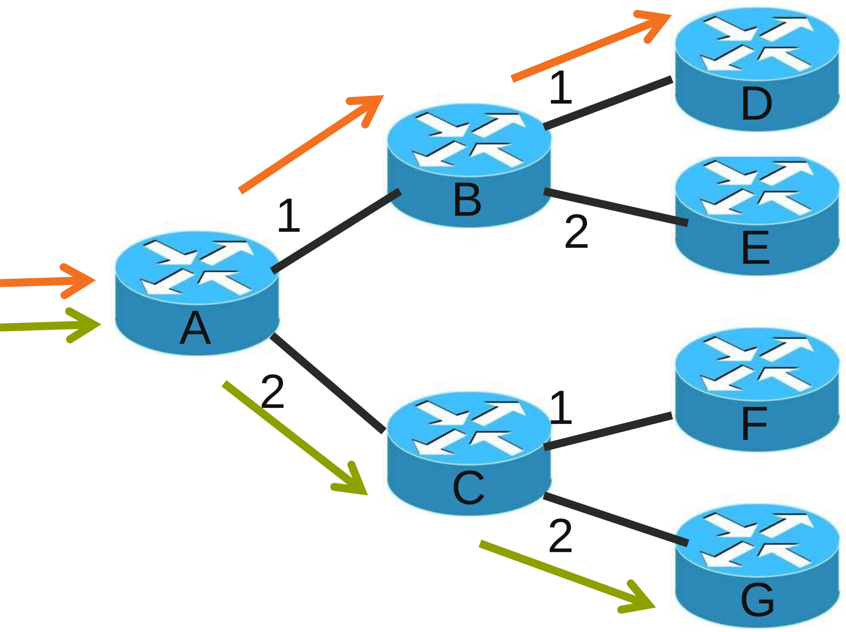
- ‘exact-route’ command in CEF takes hash inputs (source/destination IP) and puts them through the hash to result the egress interface
  - Useful in tracing path of packet during troubleshooting

Load Sharing

Polarization

- If the same input into the hash algorithm produces the same result, then what if there are many routers using the same algorithm?

Packet 1 = src 1.1.1.1 dst 2.2.2.2
Packet 2 = src 1.1.1.1 dst 3.3.3.3



If the hash for packet 1 always results in path 1

And if the hash for packet 2 always results in path 2

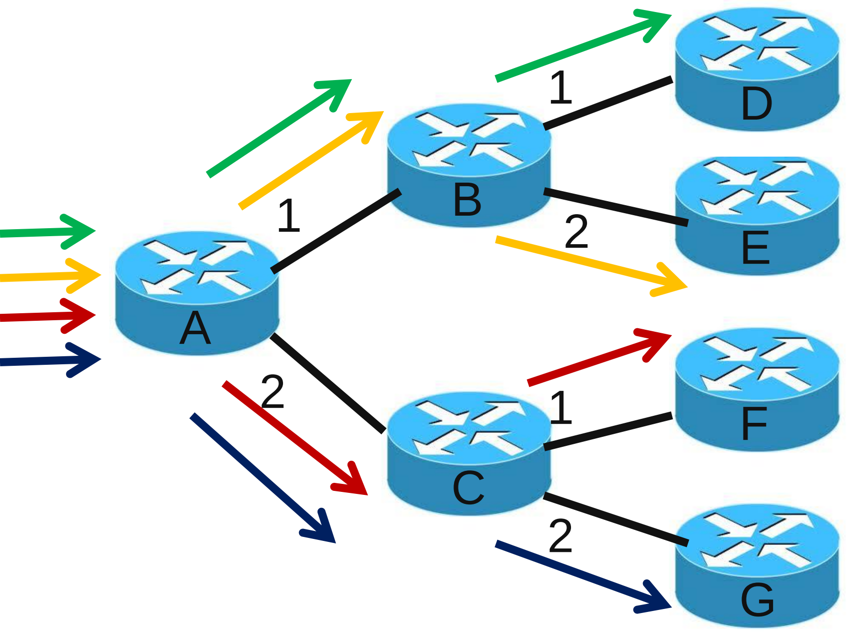
Then all routers will make the same path decision and as a result the links between B=>E and C=>F will never be used!

Load Sharing

Polarization

- We can fix this if we change the inputs on each router by looking at something else besides just the src/dst IP

  -But this extra input would need to be unique per router, otherwise every router will pick the same path again



Universal Algorithm

Each router adds a unique random number to the hash algorithm resulting in the possibility that the hash result on each hop may be different

Load Sharing

Algorithms

- Original algorithm—Src/Dst IP

  -could potentially produce distortions in load sharing across multiple routers because the same algorithm was used on every router (polarization)

- Universal algorithm—Src/Dst IP and Universal ID

  -allows each router on the network to make a different load sharing decision for each source-destination address pair (resolves polarization)

  -default algorithm in IOS.

- Tunnel algorithm—

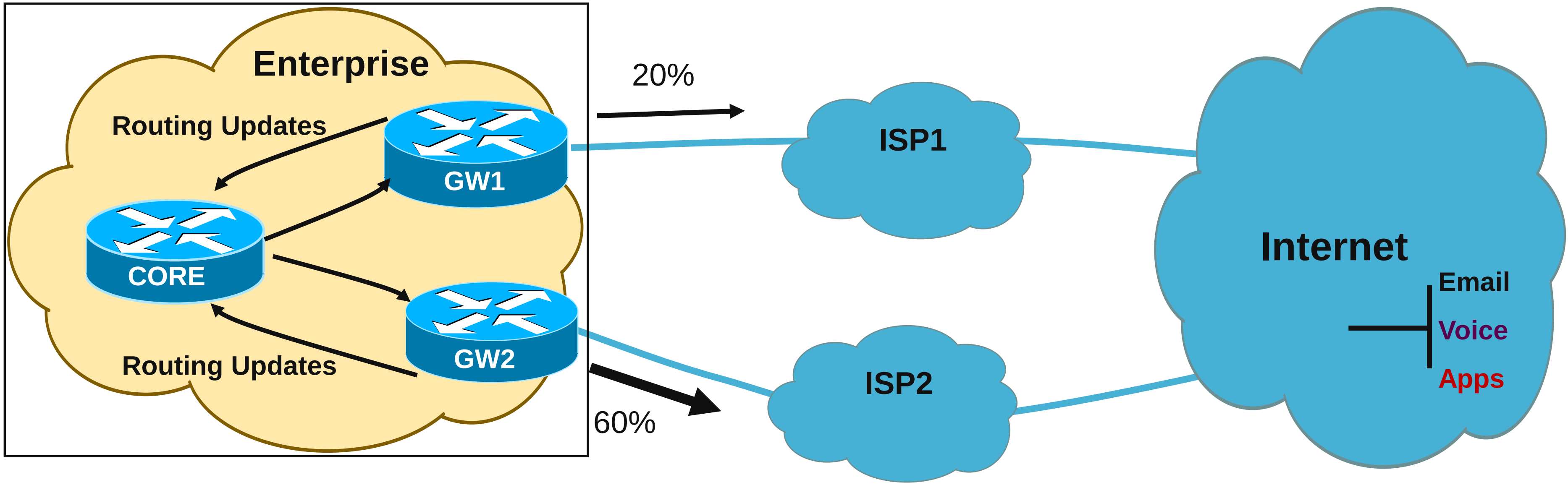
  -designed to balance the per-packet load when only a few source and destination pairs are involved.

- Include-ports algorithm— Src/Dst IP Src/Dst Port and Universal ID

  -allows you to use the Layer 4 source and destination ports as part of the load-balancing decision.

Load Sharing

Performance Routing



- In addition to load sharing traffic based on application policies, PfR can also load share or load balance traffic based on link utilization.

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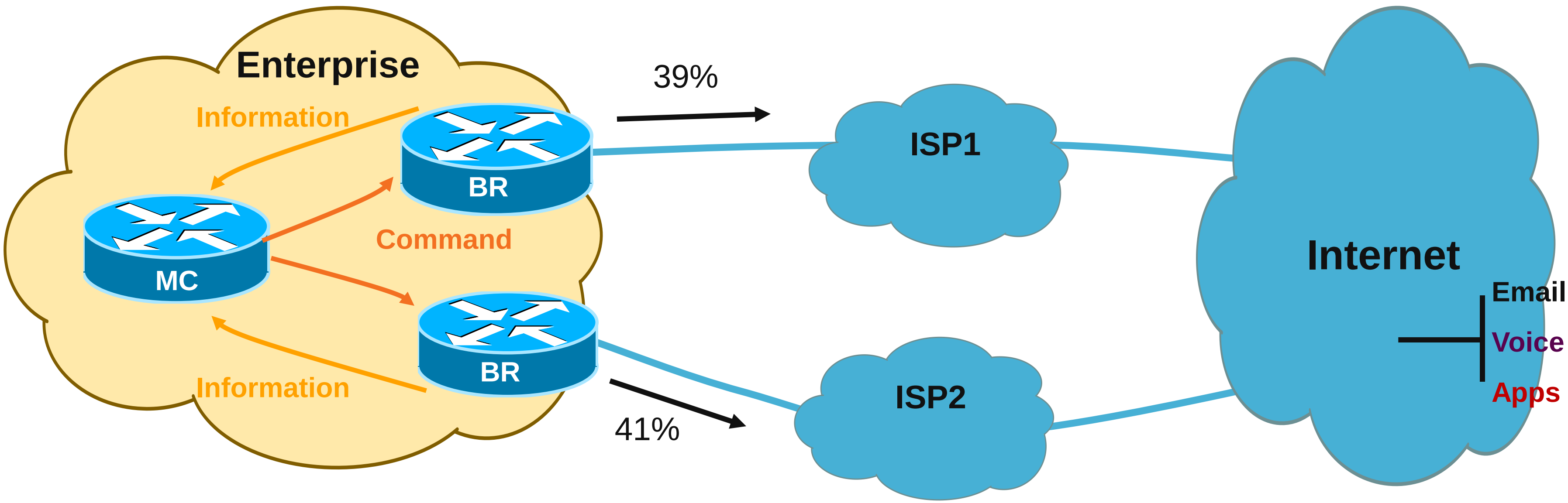
Load Sharing

Performance Routing



- CE2 link was 60% utilized and CE1 only 20%. PfR can identify this and move traffic to better balance out the egress link utilizations.
  - Done by configuring a policy to keep link utilization within a % of each other, so one link isn't utilized more than the other

www.cisco.com/go/pfr

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Routing Segmentation and Separation

Routing Segmentation and Separation

- When would you want to separate routing operations?
    - Prevent any potential exchange of data or routing information.
- Why not use ACLs or other security features?
    - Helpful but limited
- A VRF can help prevent the exchange of routes as well as data and does not have to be constantly updated.

Routing Segmentation and Separation

What is a VRF?

- A VPN Routing and Forwarding (VRF) is an IOS routing instance.
  - All tables (routing/cef) maintained in routing instance (vrf)
  - All protocols/features run independently in each VRF instance
  - Allows for logical separation at Layer-3
- Originally designed for MPLS VPN so multiple MPLS customers can use overlapping IP space and be logically separated from each other

This presentation will be referring to VRF outside of an MPLS VPN context. Also known as VRF-Lite.

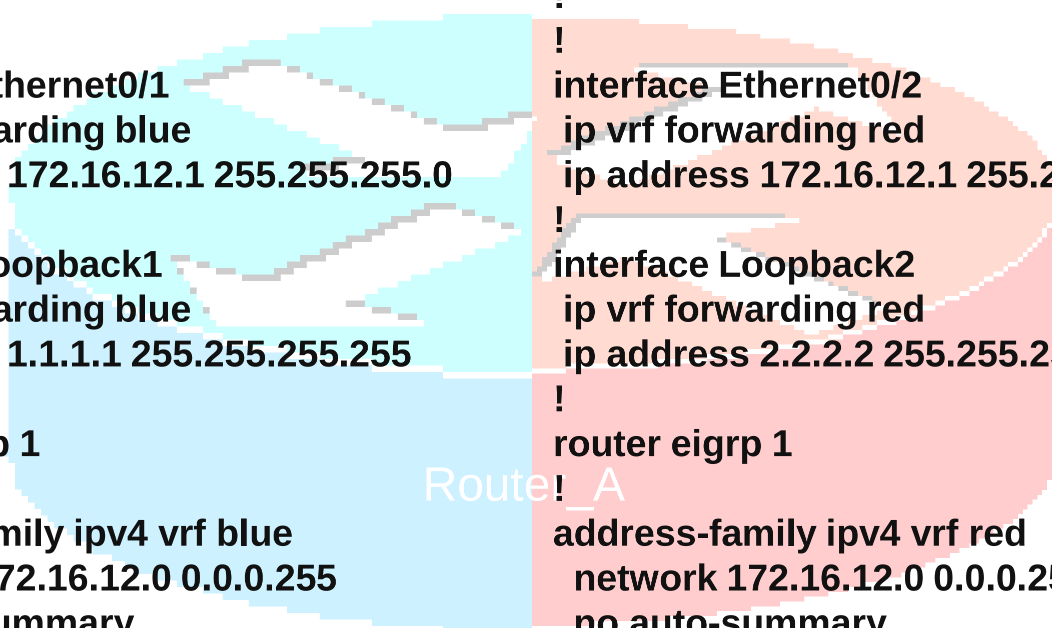
Routing Segmentation and Separation

```
Router_A#show run vrf blue

ip vrf blue
!
!
interface Ethernet0/1
 ip vrf forwarding blue
 ip address 172.16.12.1 255.255.255.0
!
interface Loopback1
 ip vrf forwarding blue
 ip address 1.1.1.1 255.255.255.255
!
router eigrp 1
!
address-family ipv4 vrf blue
  network 172.16.12.0 0.0.0.255
  no auto-summary
  autonomous-system 1
 exit-address-family
!
```

```
Router_A#show run vrf red

ip vrf red
!
!
interface Ethernet0/2
 ip vrf forwarding red
 ip address 172.16.12.1 255.255.255.0
!
interface Loopback2
 ip vrf forwarding red
 ip address 2.2.2.2 255.255.255.255
!
router eigrp 1
!
address-family ipv4 vrf red
  network 172.16.12.0 0.0.0.255
  no auto-summary
  autonomous-system 1
 exit-address-family
!
```



Routing Segmentation and Separation

How to configure and identify a VRF

```
Router#show ip vrf
  Name                          Default RD          Interfaces
  blue                          <not set>           Et0/1
                                                    Lo1
  red                           <not set>           Et0/2
                                                    Lo2

Router#show ip vrf int
Interface            IP-Address      VRF                     Protocol
Et0/1                172.16.12.1     blue                    up
Lo1                  1.1.1.1         blue                    up
Et0/2                172.16.12.1     red                     up
Lo2                  2.2.2.2         red                     up


Router#show ip route vrf blue

Routing Table: blue

     1.0.0.0/32 is subnetted, 1 subnets
C       1.1.1.1 is directly connected, Loopback1
     172.16.0.0/16 is variably subnetted, 2 subnets, 2 masks
C       172.16.12.0/24 is directly connected, Ethernet0/1
L       172.16.12.1/32 is directly connected, Ethernet0/1
```

Routing Segmentation and Separation

- Routing principles are the same within a VRF as in the global routing table.
- All routes and prefixes are unique to a given VRF unless route leaking is configured.
- Features that affect forwarding (like Routing Protocols/static routes/NAT/PBR) need to be configured on a per-VRF basis
- Interface-level features that affect traffic (like ACLs/QoS/uRPF) do not need to be configured to be VRF aware because they inherit the VRF of the interface on which they are configured

Routing and Router Resources:

CPU

CPU

- Central Processing Unit responsible for carrying out instructions.
- IOS uses a priority run-to-completion model for executing processes.
- The task scheduler is responsible for scheduling and executing kernel processes on the CPU
- Process Priorities:
  - Critical
  - High
  - Medium
  - Low
- There is no preemption but higher priority processes have more opportunity to access the CPU.

CPU

- What uses CPU resources?
  - Router processes
  - Packet switching
    - IP Input – Process switched packets
    - Interrupts – CEF switched packets

```
CPU utilization for five seconds: 5%/2%; one minute: 3%; five minutes: 2%
  PID  Runtime (ms)    Invoked   uSecs      5Sec   1Min    5Min  TTY  Process

[snip]
    2            68        585     116  1.00% 1.00%      0%      0   IP Input
   17            88       4232      20  0.20% 1.00%      0%      0   BGP Router
   18           152      14650      10     0%    0%      0%      0   BGP Scanner
```

CPU

How does routing information affect CPU resources?

- BGP scanner walks the BGP table and confirms reachability of the next hops as well as checks conditional-advertisement to determine whether or not BGP should advertise conditional prefixes.
- The larger the BGP table, the longer BGP scanner takes to run which in turn may force lower priority processes to wait.

CPU

How does routing information affect CPU resources?

- BGP router calculates the best BGP path and processes any route "churn". It also sends and receives routes, establishes peers, and interacts with the routing information base (RIB).
- Does a large amount of work during initial convergence where large amount of prefixes are exchanged.
- The larger the tables that are being exchanged, the more time BGP router will have to use the CPU.

CPU

Monitoring CPU usage

- Show commands:

    show process cpu sorted

    show process cpu history

- CPU threshold monitoring/logging

    process cpu threshold type {total | process | interrupt} rising *percentage interval seconds* **[falling** *percentage interval seconds***]**

18:41:20.934: %SYS-1-CPURISINGTHRESHOLD: Threshold: Total CPU Utilization(Total/Intr): 72%/0%, Top 3 processes(Pid/Util): 79/64%, 140/6%, 75/1%

CPU

- Reporting CPU events via EEM

```
event manager applet highcpu
  event snmp oid 1.3.6.1.4.1.9.9.109.1.1.1.1.3.1 get-type exact entry-op ge entry-val 90 poll-interval 10
  action 1.0 cli command "enable"
  action 2.0 cli command "show proc cpu sorted | redirect  flash:highcpu.txt“
  action 3.0 syslog msg “High CPU DETECTED "show process cpu sort" written to > flash:highcpu.txt “
  action 4.0 mail server "<mail_server_ip>" to "<email_address>" from "<sender>" subject “CPU
exceeded 90%."
```

- Event manager applet monitoring SNMP OID for CPU utilization percentage every 10 seconds
  - Actual OID will depend on platform/code
- If CPU OID value exceeds value 90 (90%), script will trigger the specified actions

www.cisco.com/web/go/eem

Routing and Router Resources:

Memory

Memory

- Managed in 2 pools: Processor and I/O
- The processor memory pool is the general memory pool common to all IOS systems including storage for routing information.
- The I/O pool or packet memory manages memory for interface packet buffers.

Memory

How does routing information affect memory resources?

- Most common example of where we see this is the storing of BGP prefixes.
- BGP generally carries the largest number of prefixes as well as the potential to store multiple tables.

Memory

- How much memory do I need to store my routing information?
  - Full BGP table
  - Multiple feeds
  - Route filtering
  - Soft reconfiguration inbound
  - Default route

Memory Usage Example

- BGP Profile 1

  Baseline memory usage with no BGP peers

- BGP Profile 2

  1 BGP peer sending 300,000 routes

- BGP Profile 3

  2 BGP peers both sending the exact same 300,000 prefixes

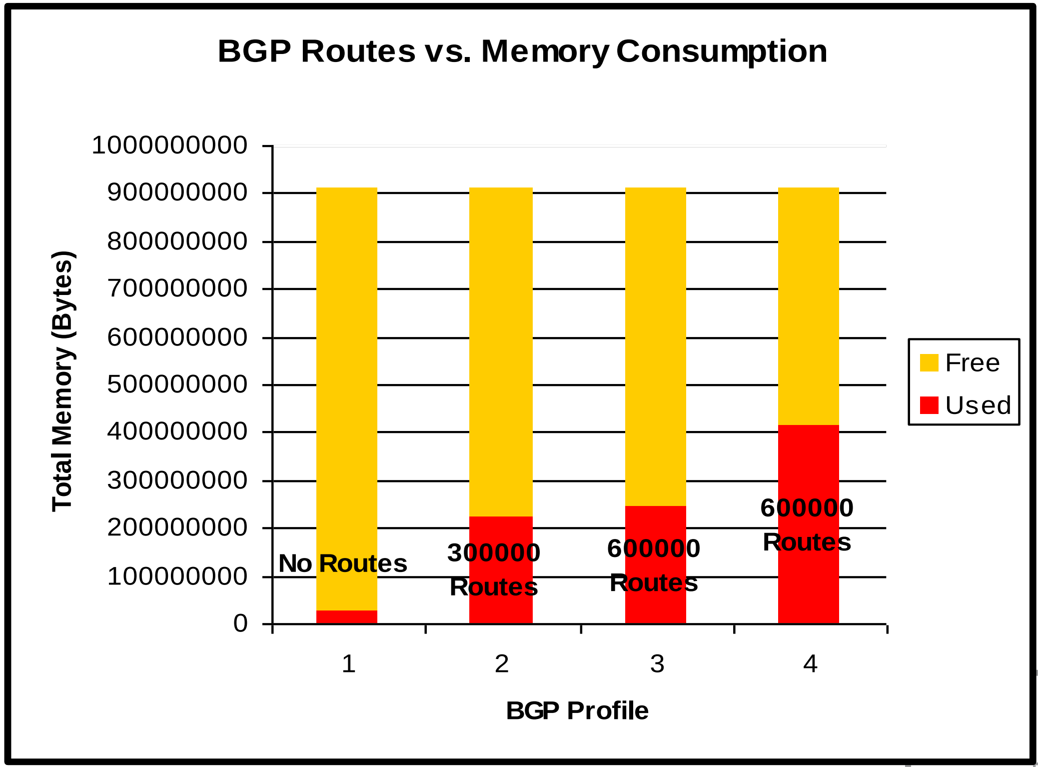
  Unique AS path and next-hop IP information from each peer

- BGP Profile 4

  2 BGP peers both sending 300,000 unique prefixes with zero overlap

  Unique AS path and next-hop IP information from each peer

Memory Usage Example



The amount of memory used to store prefixes also depends on the amount of overlap between peers.

BGP Profile	#Peers	#Routes	Memory
1	0	0	27.5MB
2	1	300,000	221.2MB
3	2	600,000	245.1MB
4	2	600,000	416.1MB

Memory

Monitoring memory availability

- Show commands

  show process memory sorted

  show memory statistics history

- Memory Threshold Notifications

  memory free low-watermark {processor *threshold* | **io** *threshold***}**

  memory reserve critical *kilobytes*

22:31:19.559: %SYS-4-FREEMEMLOW: Free Memory has dropped below 2000k
Pool: Processor Free: 66814056 freemem_lwm: 204800000

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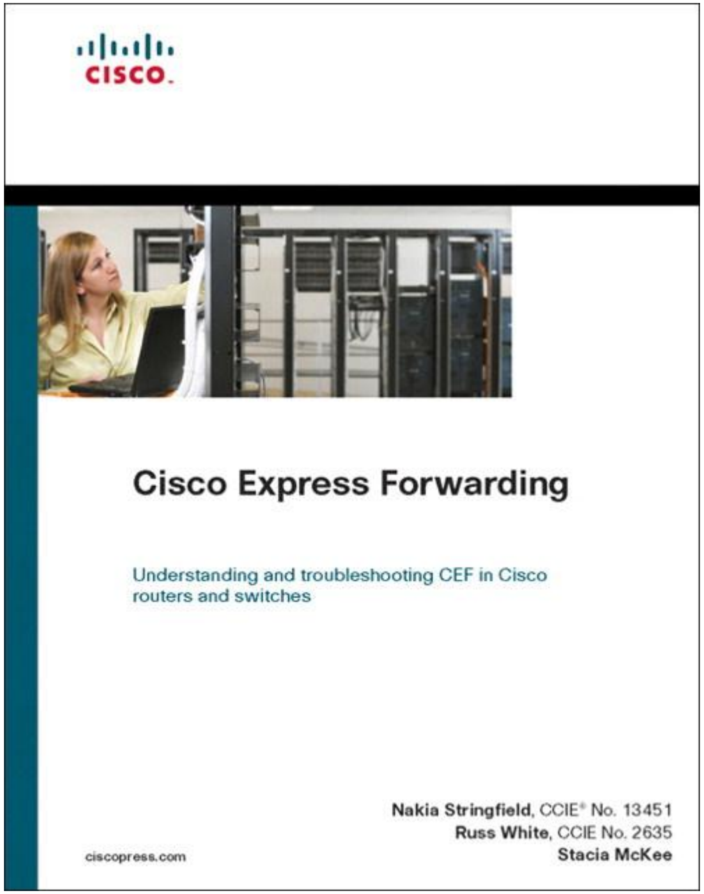
Q & A

Recommended Reading

- Continue your Cisco Live learning experience with further reading from Cisco Press
- Check the Recommended Reading flyer for suggested books



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Thank you.