Day:-9

Routing Fundamentals

What is routing?

- Routing is the process that routers use to determine the path that IP packet should take over a network to reach their destination.

→ Routers store routes of all of their known destinations in a routing table.

→ When routers receive packet, they look in the routing table to find the best route to forward that packet.

- There are two main routing methods (method that routers use to learn routes):

  Dynamic Routing: routers use dynamic routing protocols (i.e OSPF) to share routing information with each other automatically & build their routing tables.

  Static Routing: A network engineer/admin manually configures routes on the routers.

- A route tells the router: to send a packet to destination X, you should send the packet to next hop Y.

  next-hop = the next router in the path to the destination.

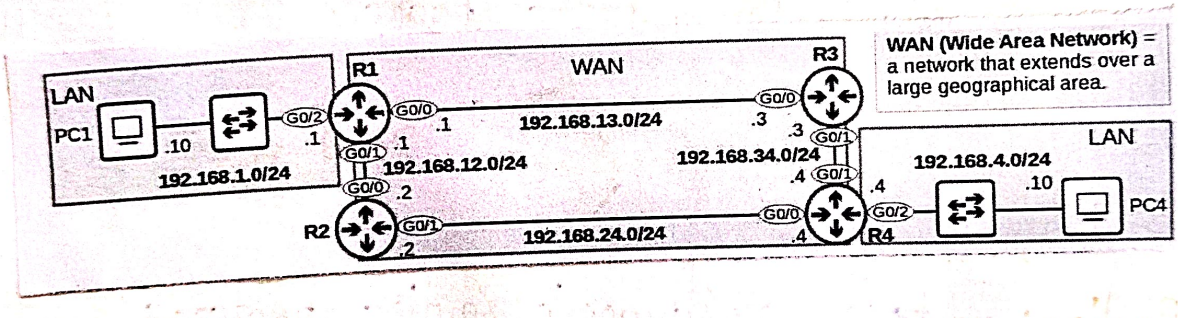
→ or, if the destination is directly connected to the routes, send the packet directly to the destination.

→ or, if destination is the router's own IP address, receive the packet for yourself (don't forward it)

To demonstrate routing in this video & the next one, we will use this example network.

In the next video, we will configure static routes on the routers to allow PC1 & PC4 to communicate with each other.

→ this video will focus on two type of routes automatically added to a router's routing table not dynamic routes or static routes



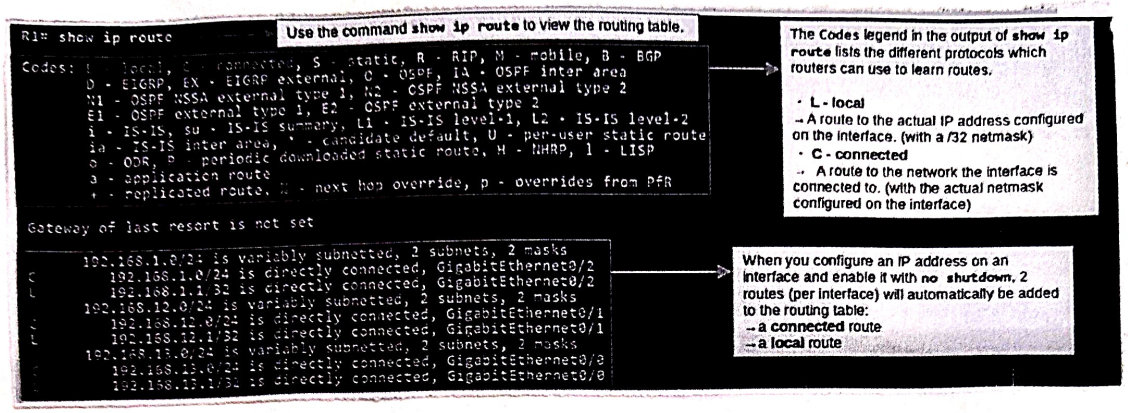
Let's configure the IP address before looking at routes.

```
R1# conf t
R1(config)# interface g0/0
R1(config-if)# ip address 192.168.13.1 255.255.255.0
R1(config-if)# no shutdown

R1(config-if)# interface g0/1
R1(config-if)# ip address 192.168.12.1 255.255.255.0
R1(config-if)# no shutdown

R1(config-if)# interface g0/2
R1(config-if)# ip address 192.168.1.1 255.255.255.0
R1(config-if)# no shutdown

R1# show ip int br
Interface              IP-Address      OK? Method Status                Protocol
GigabitEthernet0/0     192.168.13.1    YES manual up                    up
GigabitEthernet0/1     192.168.12.1    YES manual up                    up
GigabitEthernet0/2     192.168.1.1     YES manual up                    up
GigabitEthernet0/3     unassigned      YES NVRAM  administratively down down
```

There is no need to use **exit** to return to global config mode before entering **interface g0/1**. You can use the **interface g0/1** command directly from interface config mode.

Now let's Look at R1 routing table

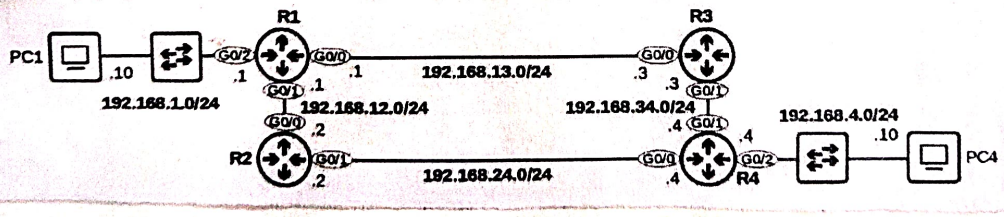
Routing Table (show ip route)



Connected and Local routes

- A connected route is a route to the network the interface is connected to.
- R1 G0/2 IP = 192.168.1.1/24
- Network Address = 192.168.1.0/24
- It provides a route to all hosts in that network (ie. 192.168.1.10, 192.168.1.100, 192.168.1.232, etc.)
- R1 knows: "If I need to send a packet to any host in the 192.168.1.0/24 network, I should send it out of G0/2".

- A local route is a route to the exact IP address configured on the interface.
- A /32 netmask is used to specify the exact IP address of the interface.
  → /32 means all 32 bits are 'fixed', they can't change.
- Even though R1's G0/2 is configured as 192.168.1.1/24, the connected route is to 192.168.1.1/32.
- R1 knows: "If I receive a packet destined for this IP address, the message is for me".



192.168.1.0/24

/24 means that the netmask is 255.255.255.0
The first 24 bits of the netmask are all 1,
so each octet is 255.

→ These bits are fixed, they can't change

→ However the last 8 bits, the last octet, are not fixed
They can be any no.

C 192.168.1.0/24 is directly connected, GigabitEthernet0/2

→ So the route for 192.168.1.0/24 matches 192.168.1.0
to 192.168.1.255

that's mean that if R1 receives a packet with
a destination in that range, it will send the
packet out of G0/2 interface

Some Example:-

192.168.1.2 = match
→ Send packet out of G0/2

192.168.1.7 = match
→ Send packet out of G0/2

192.168.2.1 = no match
→ Send the packet using a different route, or
drop the packet if there is no matching route.

A route matches a packet's destination if the packet's destination IP address is part of the network specified in the route.

Now, the local route.....

192.168.1.1/32

Because it's /32 all bits of the netmask are 1, so its 255.255.255.255

All these bits are fixed, they can't change

So,

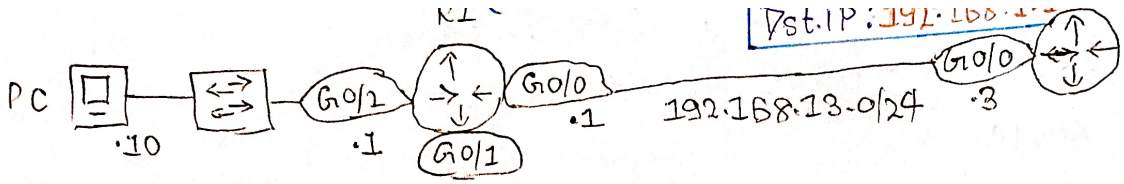
192.168.1.1/32 matches ONLY 192.168.1.1
no, other IP addresses

• Route Selection

We looked at those connected & local routes that were automatically added to R1's routing table when we configured IP addresses on its interfaces.

Now lets look another fundamental concept:
~~Routing~~ Route selection.

```
      192.168.1.0/24 is variable subnetted, 2 subnets, 2masks
C        192.168.1.0/24 is directly connected, GigabitEthernet0/2
L        192.168.1.1/32 is directly connected, GigabitEthernet0/2
```



- A packet destined for 192.168.1.1 is matched by both routes:

  192.168.1.0/24
  192.168.1.1/32

- Which route will R1 use for a packet destined for 192.168.1.1?
  → It will choose the most specific matching route

- The route to 192.168.1.0/24 includes 256 different IP addresses (192.168.1.0 - 192.168.1.255)
- The route to 192.168.1.1/32 includes only 1 IP addresses (192.168.1.1)
  → "This route is more specific"

When R1 receives a packet destined for 192.168.1.1, it will select the route to 192.168.1.1/32.
→ R1 will recive the packet to itself, rather than forward it out of G0/2.

LOCAL route = keep the packet, don't forward

- Most Specific matching route = the matching route will the longest prefix length.

Part : 2 "Static Routing

In the previous we looked at the basics of routing how routers decide where to forward packets and we looked two type of routes : Local routes
Connected routes

These routes are automatically added to a router's routing table when we configure an IP address on an interface

Local route provide a route to the router's own IP address and.
Connected route provide a route to the network the interface is connected to.

However, if you wanted routes to be able to send traffic to destination that aren't directly connected to the routes itself. Local & Connected routes aren't enough.

Static routes, enable routers to send packet to remote destinations, that aren't directly connected to the routes itself.

R2, R3, R4 Connected & Local Routes

Review Connected & Local routes by configuring IP addresses on the routers & checking their routing table

In last i do R1, so in this start from R2. then R3, R4.

```
R2# conf t
R2(config)# interface g0/0
R2(config-if)# ip address 192.168.12.2 255.255.255.0
R2(config-if)# no shutdown
R2(config-if)# interface g0/1
R2(config-if)# ip address 192.168.24.2 255.255.255.0
R2(config-if)# no shutdown

R2# show ip route
!codes output omitted

      192.168.12.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.12.0/24 is directly connected, GigabitEthernet0/0
L        192.168.12.2/32 is directly connected, GigabitEthernet0/0
      192.168.24.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.24.0/24 is directly connected, GigabitEthernet0/1
L        192.168.24.2/32 is directly connected, GigabitEthernet0/1
```

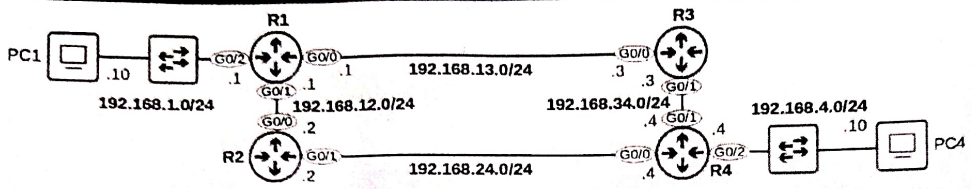
The following routes are automatically added to the routing table for each interface with an IP address configured:

- **C - Connected**
  - A route to the network the interface is connected to. (with the actual netmask configured on the interface)
- **L - Local**
  - A route to the actual IP address configured on the interface. (with a /32 netmask)

R2 knows how to reach its own IP addresses and destinations in its connected networks, but it doesn't know how to reach destinations in remote networks.

Knows:
192.168.12.0/24 (incl. 192.168.12.2/32)
192.168.24.0/24 (incl. 192.168.24.2/32)

Doesn't know:
192.168.1.0/24
192.168.4.0/24




```
R3# conf t
R3(config)# interface g0/0
R3(config-if)# ip address 192.168.13.3 255.255.255.0
R3(config-if)# no shutdown
R3(config-if)# interface g0/1
R3(config-if)# ip address 192.168.34.3 255.255.255.0
R3(config-if)# no shutdown

R3# show ip route
!codes output omitted

      192.168.13.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.13.0/24 is directly connected, GigabitEthernet0/0
L        192.168.13.3/32 is directly connected, GigabitEthernet0/0
      192.168.34.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.34.0/24 is directly connected, GigabitEthernet0/1
L        192.168.34.3/32 is directly connected, GigabitEthernet0/1
```

R3 knows how to reach its own IP addresses and destinations in its connected networks, but it doesn't know how to reach destinations in remote networks.

Knows:
192.168.13.0/24 (incl. 192.168.13.3/32)
192.168.34.0/24 (incl. 192.168.34.3/32)

Doesn't know:
192.168.1.0/24
192.168.4.0/24

```
R4(config)# interface g0/0
R4(config-if)# ip address 192.168.24.4 255.255.255.0
R4(config-if)# no shutdown
R4(config-if)# interface g0/1
R4(config-if)# ip address 192.168.34.4 255.255.255.0
R4(config-if)# no shutdown
R4(config-if)# interface g0/2
R4(config-if)# ip address 192.168.4.4 255.255.255.0
R4(config-if)# no shutdown

R4# show ip route
!codes output omitted
      192.168.4.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.4.0/24 is directly connected, GigabitEthernet0/2
L        192.168.4.4/32 is directly connected, GigabitEthernet0/2
      192.168.24.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.24.0/24 is directly connected, GigabitEthernet0/0
L        192.168.24.4/32 is directly connected, GigabitEthernet0/0
      192.168.34.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.34.0/24 is directly connected, GigabitEthernet0/1
L        192.168.34.4/32 is directly connected, GigabitEthernet0/1
```

R4 knows how to reach its own IP addresses and destinations in its connected networks, but it doesn't know how to reach destinations in remote networks.

Knows:
192.168.4.0/24 (incl. 192.168.4.4/32)
192.168.24.0/24 (incl. 192.168.24.4/32)
192.168.34.0/24 (incl. 192.168.34.4/32)

Doesn't know:
192.168.1.0/24
192.168.12.0/24
192.168.13.0/24

→ So, all these routers have connected & local routes

Now let's see how we can configure them to allow PC1 and PC4 to communicate.

Routing Packets : Default Gateway

First, we look the concept of 'Default Gateway'.

- End host like PC1 and PC4 can send packets directly to destination in their connected network
  - → PC1 is connected to 192.168.1.0/24, PC4 is connected to 192.168.4.0/24 so these can directly communicate in that network.

- However, to send packets to destinations outside of their local network, they must send the packets by to their 'defaut gateway'
  - → gateway is an old term for routers, so it mean 'default router'

So, these are the configs on PC1 & PC4.

PC1 (Linux) Config

```
iface eth0 inet static
        address 192.168.1.0/24
        gateway 192.168.1.1
```

PC4 (Linux Config)

```
iface eth0 inet static
        address 192.168.4.0/24
        gateway 192.168.4.4
```

In linux, the interface configuration are stored in a text file that you can edit.

On Pc1 So, to send packets to destination outside of its local network, Pc1 will send packet to R1

- The Default gateway configuration is also called a 'default route'. Basically, it's a route to 0.0.0.0/0 = all netmask bits set to 0. Includes all addresses from 0.0.0.0 to 255.255.255.255.

> The default route is the least specific route possible, because it includes all IP addresses 0.0.0.0/0 = 4294 967 296 IP add.
>
> A/32 route (i.e local route) is the most speific route possible - because it specifies only one IP address.
>
> 192.168.1.1/32 = 1 IP address.

- So, the deafault route say 'if there aren't any more specific matches for this packet don't drop it, send it via this route instead.

Later we see - How to configure a default route on a Cisco routes & what it can be used for but for Now just understand how it works for ends hosts like Pc1 & Pc4 ?

- End hosts usually have no need for any more specific routes.
  → They just need to know : to send packes outside of my local network. I will send them to my default gateway.

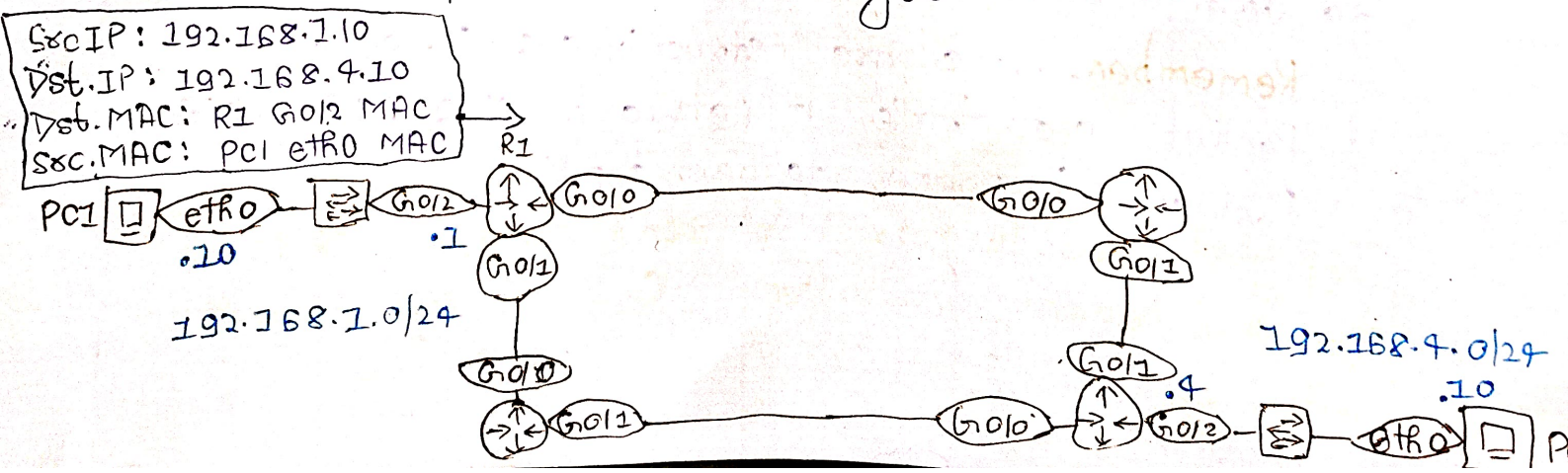
So, if PC1 wants to send packet to PC4, the source IP address in the IP header is 192.168.1.10 PC1's IP. And the destination IP is 192.168.4.10 PC4's IP.

What will the source & destination MAC Addresses be in the Ethernet header
This is where you can understand the role of layer 2 & layer 3.

At layer 3, PC1 wants to send the packet to PC4, so the destination is PC4's IP.
However it has to first forward this packet to its default gateway R1

→ So, it will encapsulate the packet in a frame & the destination MAC will be R1 G0/2's MAC addresses.
Now, how does it know R1 G0/2's MAC address?
To learn it, PC1 will first send an ARP request to 192.168.1.1, R1 G0/2's IP address.

"I will show this part of the process in more detail in the next part of the course, called 'Life of a Packet'. To keep things a bit simpler in this let's just assume each device already knows it's neighbors' MAC addresses. I won't show all of the ARP exchanges.



Routing Packets: Static Routes

→ So, PC1 sent that frame to its default gateway R1.

- When R1 receives the frame from PC1, it will de-encapsulate it (remove L2 header/trailer) and look at the inside packet.

- It will check the routing table for the most-specific matching route:

  Here is R1 routing table →

```
      192.168.1.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.1.0/24 is directly connected, GigabitEthernet0/2
L        192.168.1.1/32 is directly connected, GigabitEthernet0/2
      192.168.12.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.12.0/24 is directly connected, GigabitEthernet0/1
L        192.168.12.1/32 is directly connected, GigabitEthernet0/1
      192.168.13.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.13.0/24 is directly connected, GigabitEthernet0/0
L        192.168.13.1/32 is directly connected, GigabitEthernet0/0
```

Do any of these routes match the destination IP of the Packet?

→ R1 has no matching routes in its routing table. So what will do with the packet?

It has no choice but to drop it.
In its current state, R1 doesn't know how to properly forward the packet

- To properly forward the packet, R1 need a route to destination network (192.168.4.0/24).

  → Remember, routes are instructions: To send a Packet to destination in network 192.168.4.0/24, forward the packet to next hop Y.

→ Now we know the destination the 192.168.4.0/24 network, but what should be the the next hop?

- These are two possible path packets from PC1 to PC4 can take:
  1) PC1 → R1 → R3 → R4 → PC4
  2) PC1 → R1 → R2 → R4 → PC4

→ In this, we use the path via R3, not the path via R2.

Now, it is possible to configure the routers to use these multiple paths differently.
→ Instead of choosing 1 path, they can 'load-balance' between path 1) and path 2)
→ Use path 1) as the main path & path 2) as backup path.

Static Routing Configuration

→ Now to ensure PC1 & PC4 can communicate with each other, it's not just R1 that needs another route.

- Each routes in the path needs two routes:
  a route to 192.168.1.0/24 PC1's network
  and a route to 192.168.4.0/24 PC4's network.
  → This ensure two-way reachability (PC1 can send Packet to PC4, PC4 can send packet to PC1).

* routers don't need routes to all network in the path to the destination.
For Ex:- R1 doesn't need a route to 192.168.34.0/24 it just need to know: to send packets to 192.168.4.0/24 I should send the Packets to R3, it take care of that

- R1 has already a connected route to 192.168.1.0/24.
  R4 has already a conected route to 192.168.4.0/24.

→ The other routes must be manually configured (using static routes).

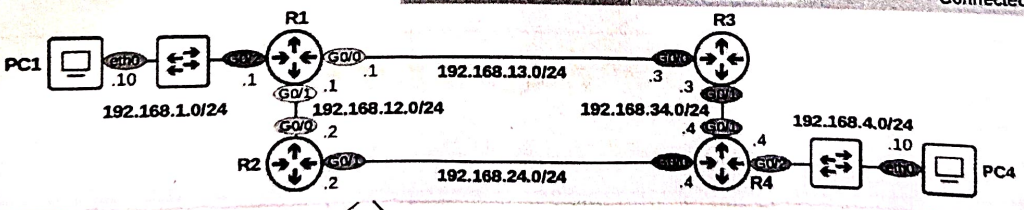
Before we get into actually configured static routes, let's plan out the routes we will configure

→ Here's a chart of the routes R1, R3, R4 need to allow PC1 and PC4 to communicate with each other. In Blue are R1 and R4 connected routes. note i listed the next-hop as 'connected'. Then in yellow are the static routes we have to configure.

*Note we only use via Path 3) not Path 2).

To allow PC1 and PC4 to communicate with each other over the network, let's configure these **Static routes** on R1, R3, and R4.

Router	Destination	Next-Hop
R1	192.168.1.0/24	Connected
	192.168.4.0/24	192.168.13.3
R3	192.168.1.0/24	192.168.13.1
	192.168.4.0/24	192.168.34.4
R4	192.168.1.0/24	192.168.34.3
	192.168.4.0/24	Connected



192.168.1.0/24

192.168.4.0/24

192.168.1.0/24

192.168.4.0/24

Image 17:25

Table

Topology.

Static Route Configuration (R1)

→ Let's configure R1's route to 192.168.4.0/24

Here is the format of command.

R1(config)# ip route ip-address netmast next-hop

" R1(config)# ip route 192.168.4.0 255.255.255.0 192.168.13
R1(config)# do show ip route.

→ Okay that's all we have configure on R1.
now it knows that to reach PC4's network
it should forward packet to 192.168.13.3 R3.

Static Route Configuration (R3)

→ It need two routes one 192.168.1.0/24 one to
192.168.4.0/24

```
R3(config)# ip route 192.168.1.0 255.255.255.0 192.168.13.1
R3(config)# ip route 192.168.4.0 255.255.255.0 192.168.34.4

R3(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
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
!some code output omitted

Gateway of last resort is not set

S     192.168.1.0/24 [1/0] via 192.168.13.1
S     192.168.4.0/24 [1/0] via 192.168.34.4
      192.168.13.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.13.0/24 is directly connected, GigabitEthernet0/0
L        192.168.13.3/32 is directly connected, GigabitEthernet0/0
      192.168.34.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.34.0/24 is directly connected, GigabitEthernet0/1
L        192.168.34.3/32 is directly connected, GigabitEthernet0/1
```

R3(config)#

Static Route Configuration (R4)

→ Let's configure R4's route to the 192.168.1.0/24 network.

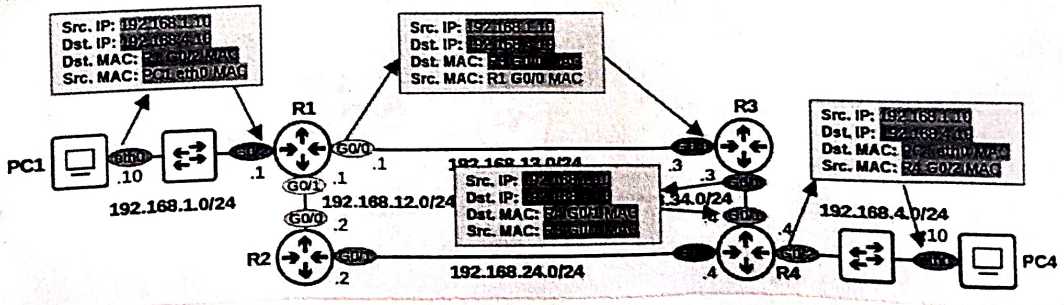
" R4(config)# ip route 192.168.1.0 255.255.255.0 192.168.34.3
R4(config)# do show ip route.

→ So we have now configured all of the static routes necessary for PC1 And PC4 to communicate. Let's test it out & see if they can actually communicate with each other

```
PC1:~$ ping 192.168.4.10
PING 192.168.4.10 (192.168.4.10): 56 data bytes
64 bytes from 192.168.4.10: seq=0 ttl=42 time=8.745 ms
64 bytes from 192.168.4.10: seq=1 ttl=42 time=4.423 ms
64 bytes from 192.168.4.10: seq=2 ttl=42 time=3.428 ms
64 bytes from 192.168.4.10: seq=3 ttl=42 time=3.544 ms
64 bytes from 192.168.4.10: seq=4 ttl=42 time=3.520 ms
^C
--- 192.168.4.10 ping statistics ---
5 packets transmitted, 5 packets received, 0% packet loss
round-trip min/avg/max = 3.428/4.732/8.745 ms
```

If the ping is successful, that means there is two-way reachability.
PC1 can reach PC4, and PC4 can reach PC1.

Packet traveling from PC1 to PC4:
*we will examine this step-by-step in the "Life of a Packet" video

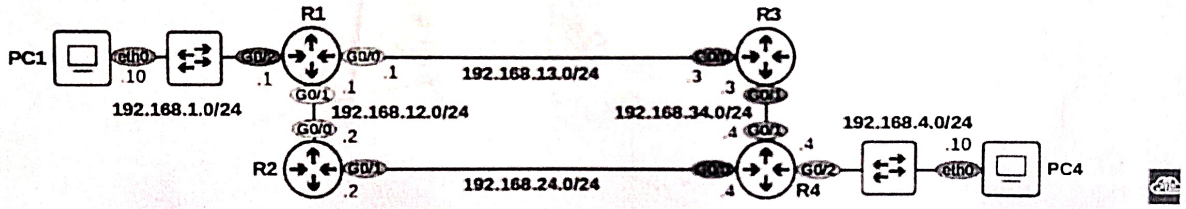


Static Routing Configuration with exit-interface

```
R2(config)# ip route 192.168.1.0 255.255.255.0 G0/0
R2(config)# ip route 192.168.4.0 255.255.255.0 G0/1 192.168.24.4

R2(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
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
!some code output omitted

Gateway of last resort is not set

S       192.168.1.0/24 is directly connected, GigabitEthernet0/0
S       192.168.4.0/24 [1/0] via 192.168.24.4, GigabitEthernet0/1
        192.168.12.0/24 is variably subnetted, 2 subnets, 2 masks
C          192.168.12.0/24 is directly connected, GigabitEthernet0/0
L          192.168.12.2/32 is directly connected, GigabitEthernet0/0
        192.168.24.0/24 is variably subnetted, 2 subnets, 2 masks
C          192.168.24.0/24 is directly connected, GigabitEthernet0/1
L          192.168.24.2/32 is directly connected, GigabitEthernet0/1
```

```
R2(config)# ip route ip-address netmask exit-interface
R2(config)# ip route ip-address netmask exit-interface next-hop
```

- Static routes in which you specify only the *exit-interface* rely on a feature called Proxy ARP to function.
- This is usually not a problem, but generally you can stick to *next-hop* or *exit-interface next-hop*.
- Neither is 'better' than the other: use which you prefer.

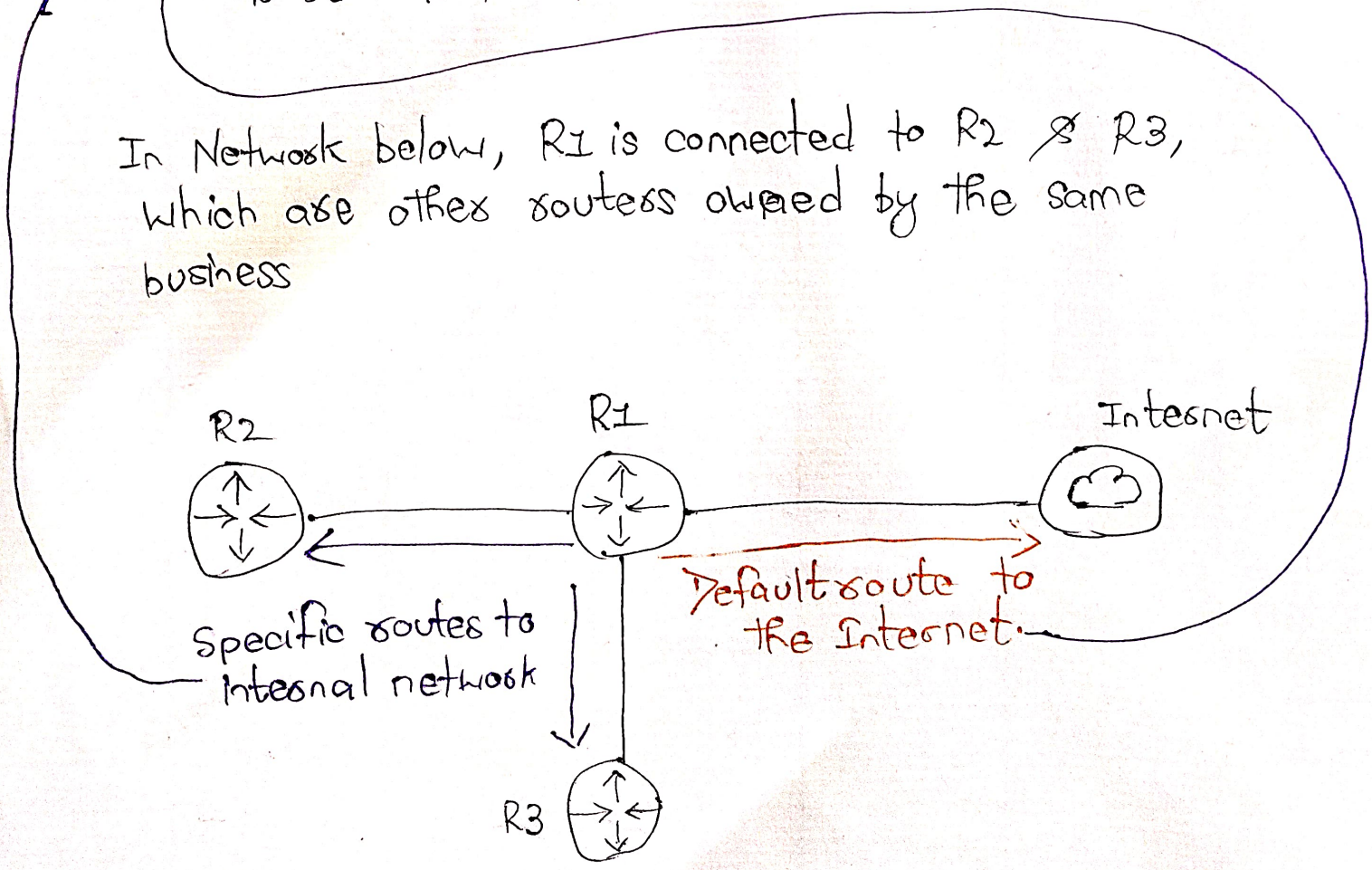


Default Route

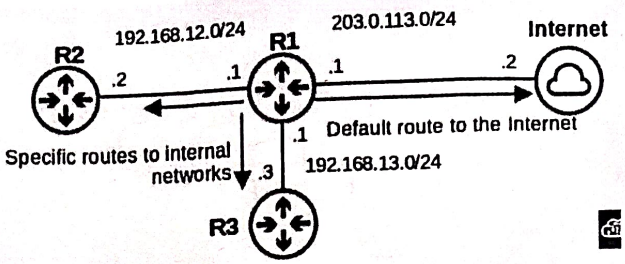
I introduce the concept of default routes when explaining how a pc's default gateway work but let's review.

- A default route is a route 0.0.0.0/0
  → 0.0.0.0/0 is the least specific route possible; it includes every possible destination IP address
- If the routes doesn't have any more specific routes that match a packet's destination IP address, the route will ~~often used to direct/forward~~ the packet using the default route.
- A default route is often used to direct traffic to the Internet
  → More specific routes are used for destinations in the internal corporate network.
  → Traffic to destinations outside of the internal network is sent to the Internet

In Network below, R1 is connected to R2 & R3, which are other routers owned by the same business



Okay I added some IP addresses to the diagram, & also configured a couple static routes which I'm not showing here



I then checked R1 routing table

NOTICE the part I higlighted

"Gateway of last resort is not set."
this mean that no default route has been configured yet.

Gateway of last resort another name of 'default gateway'

Now in R1's routing table there is a route to 10.0.0.0/8 with R2 as next hop & a route to 172.16.0.0/16 with R3 as the next hop. Perhaps these are networks used usually by the company.

Now lets tell R1 to send all over traffic to the Internet.

```
R1# show ip route
!codes omitted
Gateway of last resort is not set

S     10.0.0.0/8 [1/0] via 192.168.12.2
S     172.16.0.0/16 [1/0] via 192.168.13.3
      192.168.12.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.12.0/24 is directly connected, GigabitEthernet0/1
L        192.168.12.1/32 is directly connected, GigabitEthernet0/1
      192.168.13.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.13.0/24 is directly connected, GigabitEthernet0/0
L        192.168.13.1/32 is directly connected, GigabitEthernet0/0
      203.0.113.0/24 is variably subnetted, 2 subnets, 2 masks
C        203.0.113.0/24 is directly connected, GigabitEthernet0/2
L        203.0.113.1/32 is directly connected, GigabitEthernet0/2
```

No default route has been configured yet.

Here How to configure a default route.

The structure is same as any other static route but the network and netmask both be all 0s 0.0.0.0.

And that R1 Now has a default route.

I checked R1 Routing table

```
R1(config)# ip route 0.0.0.0 0.0.0.0 203.0.113.2
R1(config)# do show ip route
!most codes omitted
      ia - IS-IS inter area, * - candidate default, U - per-user static route
!most codes omitted
Gateway of last resort is 203.0.113.2 to network 0.0.0.0

S*    0.0.0.0/0 [1/0] via 203.0.113.2
S     10.0.0.0/8 [1/0] via 192.168.12.2
S     172.16.0.0/16 [1/0] via 192.168.13.3
      192.168.12.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.12.0/24 is directly connected, GigabitEthernet0/1
L        192.168.12.1/32 is directly connected, GigabitEthernet0/1
      192.168.13.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.13.0/24 is directly connected, GigabitEthernet0/0
L        192.168.13.1/32 is directly connected, GigabitEthernet0/0
      203.0.113.0/24 is variably subnetted, 2 subnets, 2 masks
C        203.0.113.0/24 is directly connected, GigabitEthernet0/2
L        203.0.113.1/32 is directly connected, GigabitEthernet0/2
```

Let me point out a few things.