# The Routing Table

Part 2 – The Routing Table Lookup Process

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This document is the second of two parts dealing with the routing table. Part I discussed the structure of the routing table, and how routes are created. Part II will discuss how the routing table lookup process finds the "best" route within the routing table.

What happens when a router receives an IP packet, examines the IP destination address and looks that address up in the routing table? How does the router decide which route in the routing table is the best match? What affect does the subnet mask have on the routing table? How does the router decide whether or not to use a supernet or default route if there is not a better match? We will answer these questions and more in this document.

The network we will be using is a simple three router network. RouterA and Router B share the common major network 172.16.0.0/24. RouterB and RouterC are connected by the 192.168.1.0/24 network. You will notice that RouterC also has a 172.16.4.0/24 subnet which is disconnected, or discontiguous, from the rest of the 172.16.0.0 network.
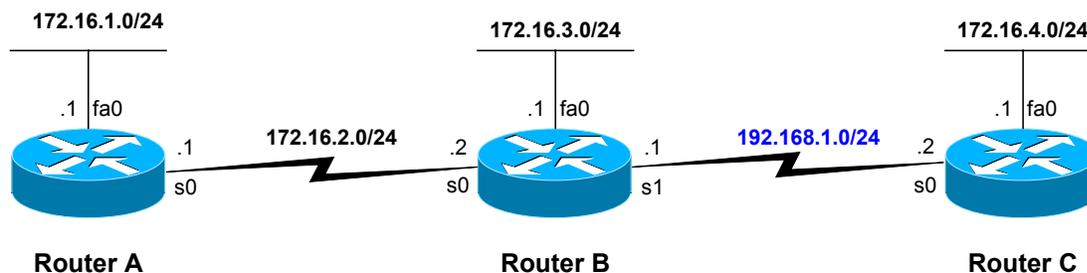
Most of this information is best explained by using examples. So, don't worry if you do not understand the information before you have seen an example, as there is an example for every topic.

One last note before we begin. As I mentioned previously in Part I, in order to keep this document simple and brief, I have left out some of the detail. For those of you who are interested in reading more about this subject and the inner-workings of the Cisco IOS as it pertains to routing, I highly recommend the book, *Cisco IP Routing, by Alex Zinin (ISBN 0-201-60473-6)*. However, this is not a book for beginners. It does contain some pseudocode, which can be skipped without missing any of the content.

The Setup

We will begin by assuming the following configurations have already been done to the three routers. If you are using the document as a lab, configure the routers with these configurations. You will notice that we are using RIPv1, a classful, distance-vector routing protocol.

The DCE cable is attached the serial interfaces of RouterA and RouterC. The command **exec-timeout 0 0** is an optional command that keeps the router from exiting privileged mode when the idle timer expires. The other optional command is **logging synchronous**. This command eliminates the debug and other output from becoming intermixed with the router prompt and input commands.

RouterA

```
hostname RouterA
!
interface FastEthernet0
 ip address 172.16.1.1 255.255.255.0
!
interface Serial0
 ip address 172.16.2.1 255.255.255.0
 clockrate 64000
!
router rip
 network 172.16.0.0
!
ip classless
!
line con 0
 exec-timeout 0 0
 logging synchronous
```

RouterB

```
hostname RouterB
!
interface Serial0
 ip address 172.16.2.2 255.255.255.0
!
interface Serial1
 ip address 192.168.1.1 255.255.255.0
!
interface FastEthernet0
 ip address 172.16.3.1 255.255.255.0
!
router rip
 network 172.16.0.0
 network 192.168.1.0!
!
line con 0
 exec-timeout 0 0
 logging synchronous
```

RouterC

```
hostname RouterC
!
interface FastEthernet0
 ip address 172.16.4.1 255.255.255.0
!
interface Serial0
 ip address 192.168.1.2 255.255.255.0
 clockrate 64000
!
router rip
 network 172.16.0.0
 network 192.168.1.0
!
ip classless
!
line con 0
 exec-timeout 0 0
 logging synchronous
```

The Routing Tables

```
RouterA#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
<text omitted>

Gateway of last resort is not set

     172.16.0.0/24 is subnetted, 3 subnets
C       172.16.1.0 is directly connected, FastEthernet0
C       172.16.2.0 is directly connected, Serial0
R       172.16.3.0 [120/1] via 172.16.2.2, 00:00:00, Serial0
R     192.168.1.0/24 [120/1] via 172.16.2.2, 00:00:00, Serial0
RouterA#
```

```
RouterB#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
<text omitted>

Gateway of last resort is not set

     172.16.0.0/24 is subnetted, 3 subnets
R       172.16.1.0 [120/1] via 172.16.2.1, 00:00:07, Serial0
C       172.16.2.0 is directly connected, Serial0
C       172.16.3.0 is directly connected, FastEthernet0
C     192.168.1.0/24 is directly connected, Serial1
RouterB#
```

```
RouterC#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
<text omitted>

Gateway of last resort is not set

     172.16.0.0/24 is subnetted, 1 subnets
C       172.16.4.0 is directly connected, FastEthernet0
C     192.168.1.0/24 is directly connected, Serial0
RouterC#
```

2.1 The Route Lookup Process

Let's begin by examining the overall route lookup process. (Don't worry if you do not understand these steps, they will be explained later.)

The route lookup process:

Step 1. The router begins by finding a network route, ultimate or parent that matches the IP packet's destination address.
Step 2. If the matching network is an ultimate route (not including subnet routes), and there are no more specific routes, this is the route used to forward the packet.
Step 3. If the matching network is a parent route, then the subnet routes are looked through to find the best-matching route.
Step 4. If there is no match of an ultimate or a subnet within a parent route, than what happens depends upon the whether or not the router is using in classful or classless routing behavior. (Discussed later.)

What do we mean a "match?"

The first step of the process, "1. The router begins by finding a network route, ultimate or parent that matches the IP packet's destination address." What do we mean when we say a route in the routing table *matches* IP packet's destination address? This is an often-overlooked concept that is important to understanding what happens during the routing table lookup process.

Reminder: As we saw in Part I The Routing Table Structure, routes are entered into the routing table with a network address and a subnet mask. If the route is an ultimate route or a child route with variable length subnet masks (VLSM), then the subnet mask is displayed with the individual route. If the subnets are all using the same subnet mask, then the subnet mask of the child routes will be displayed with the parent network. (See Part I if you need more information.)

What is a match? In order for there to be a "match" between a packet's destination IP address and a route in the routing table:
- The routing table process compares the left-most bits in the destination IP address with the left-most bits in the route in the routing table.
- The subnet mask of the route in the routing table specifies the minimum number of left-most bits that must match. (Remember, an IP packet only contains the IP address, and not the mask.)
    - Remember from Part 1, that for child route routes where VLSM is not in effect, the parent route contains the subnet mask.
- If there are multiple routes in the routing table that meet the previous conditions, then the route that has the most left-most bits that match the destination IP address is selected. This is known as the longest-bit-match.

Examples

The best way to understand what we mean by a match is to look at some examples.

Example 1: Packet with Destination IP Address 192.168.1.10

In this example, RouterA has received an IP packet with the destination IP address of **192.168.1.10**.

Figure 1
```
RouterA#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
<text omitted>

Gateway of last resort is not set

     172.16.0.0/24 is subnetted, 3 subnets
C       172.16.1.0 is directly connected, FastEthernet0
C       172.16.2.0 is directly connected, Serial0
R       172.16.3.0 [120/1] via 172.16.2.2, 00:00:00, Serial0
R    192.168.1.0/24 [120/1] via 172.16.2.2, 00:00:00, Serial0
RouterA#
```

Remember the first two steps of the Route Lookup Process?
Step 1. The router begins by finding a network route, ultimate or parent that matches the IP packet's destination address.
Step 2. If the matching network is an ultimate route (not including subnet routes), and there are no more specific routes, this is the route used to forward the packet.
<Steps 3 and 4 omitted>

In our example there is a match between the destination IP address 192.168.1.20 and the ultimate route of 192.168.1.0/24.
```
R    192.168.1.0/24 [120/1] via 172.16.2.2, 00:00:00, Serial0
```

Why is this route a match and not another route like one of the 172.16.0.0 subnets (child routes)? Lets begin by discussing why none of the 172.16.0.0 routes is a match. The 172.16.0.0/24 is a parent route of three subnets or child routes. *We will examine this much more closely in the next section.* For now, before a child route is examined for a match, there must be at least a match between the destination IP address of the packet and the **classful address** of the parent route.

The parent route is:
```
     172.16.0.0/24 is subnetted, 3 subnets
```

Although the subnet mask of **/24** is displayed, this is the subnet mask of the child routes, not the classful mask of this parent. The classful mask is not displayed (except for networks using VLSM), but since 172.16.0.0 is a Class B route, we know the classful or default mask is /16.

So, the question is, does at least 16 of the left-most bits (16 is the subnet mask of the parent route) match between the destination IP address of **192.168.1.10**, and the parent route of **172.16.0.0**? As we can see in Figure 2, the answer is no.

Figure 2
```
IP Packet
             192.168.1.10 |11000000     10101000     00000001     00001010

                          |16 bits must match, but only one bit matches.
Parent
Route        172.16.0.0   |10101100     00010000     00000000     00000000
```

As you can see in Figure 2, only the 1 of the left most bits match. Since there is no match with the parent route, the child routes are not examined. Again, we will see this in detail in the next section.

Now lets see if there is a match between the destination IP address of the packet, **192.168.1.10**, and the next route in the routing table, **192.168.1.0/24**, an ultimate route.

```
R    192.168.1.0/24 [120/1] via 172.16.2.2, 00:00:00, Serial0
```

The route, **192.168.1.0**, is an ultimate route, so it also contains the subnet mask, **/24**. For this route to be a match with our destination IP address, there must be a minimum match of at least 24 of the left most bits (the mask of the route). In Figure 3, we can see that this is a match!

Figure 3

IP Packet	192.168.1.10	11000000	10101000	00000001	00001010
			These 24 bits match!		
Ultimate Route	192.168.1.0	11000000	10101000	00000001	00000000

Not only does the minimum of 24 bits match, the subnet mask in the ultimate route, but actually, a total of 28 bits match as we can see in Figure 4. Is this important? As we will see later it can be when there are multiple matching routes in the routing table for the same destination IP address. Which one is the best route? The route with the most matching bits, i.e. the **longest-bit-match**. But as we said, we will discuss this later.

Figure 4

IP Packet	192.168.1.10	11000000	10101000	00000001	00001010
			These 28 bits match!		
Ultimate Route	192.168.1.0	11000000	10101000	00000001	00000000

Reviewing the steps for the Route Lookup Process:
Step 1. The router begins by finding a network route, ultimate or parent that matches the IP packet's destination address.
Step 2. If the matching network is an ultimate route (not including subnet routes), and there are no more specific routes, this is the route used to forward the packet.
<Steps 3 and 4 omitted>

We can see that in Step 1, there is a match with an ultimate or parent route. In Step 2, the match is with an ultimate route and there are no more specific matches (longer-bit-matches), so the end result is the routing table process will use this ultimate route of 192.168.1.0/24 with an exit interface of Serial0 to forward the packet with the destination IP address of 192.168.1.10. (Figure 5).

Figure 5

```
RouterA#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
<text omitted>

Gateway of last resort is not set

     172.16.0.0/24 is subnetted, 3 subnets
C       172.16.1.0 is directly connected, FastEthernet0
C       172.16.2.0 is directly connected, Serial0
R       172.16.3.0 [120/1] via 172.16.2.2, 00:00:00, Serial0
R    192.168.1.0/24 [120/1] via 172.16.2.2, 00:00:00, Serial0
RouterA#
```

Note: It is important to recognize that the subnet mask, of the route in the routing table, is used to determine the minimum number of left-most bits that must match between the route and the destination IP address of the packet.

2.2 The Route Lookup Process and Child Routes

Now lets take a closer look at what happens when there is a parent route, which of course means there are also child routes. As we saw in the previous section, in order for there to be a match there must be a minimum match of left-most bits between the destination IP address and the parent route. The minimum number of bits that must match is equal to that of the classful mask of the parent route. This classful mask is only displayed when there are VLSM child routes.

As we see in Figure 5, the subnet mask of **/24** is displayed in the parent network route of **172.16.0.0** for the three subnets of **172.16.1.0**, **172.16.2.0**, and **172.16.3.0**.

Before any child routes are examined for a match, there must be a match between the classful address of the parent route and the destination IP address of the packet. For these particular parent/child routes, before any of the **172.16.1.0**, **172.16.2.0**, and **172.16.3.0** child routes are examined, there must be a match of the 16 left-most bits (the classful subnet mask of the Class B route 172.16.0.0) and the destination IP address of the packet. If there is a match, then Step 3 states, "If the matching network is a parent route, then the subnet routes are looked through to find the best-matching route."

The route lookup process:

Step 1. The router begins by finding a network route, ultimate or parent that matches the IP packet's destination address.
Step 2. If the matching network is an ultimate route (not including subnet routes), and there are no more specific routes, this is the route used to forward the packet.
Step 3. If the matching network is a parent route, then the subnet routes are looked through to find the best-matching route.
Step 4. If there is no match of an ultimate or a subnet within a parent route, than what happens depends upon the whether or not the router is using in classful or classless routing behavior.

Note: If VLSM is being used, then the subnet mask is specified with the individual route.

Figure 5

```
RouterA#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
<text omitted>

Gateway of last resort is not set

     172.16.0.0/24 is subnetted, 3 subnets
C       172.16.1.0 is directly connected, FastEthernet0
C       172.16.2.0 is directly connected, Serial0
R       172.16.3.0 [120/1] via 172.16.2.2, 00:00:00, Serial0
R    192.168.1.0/24 [120/1] via 172.16.2.2, 00:00:00, Serial0
RouterA#
```

Lets see an example!

Example 2: Packet with Destination IP Address 172.16.3.10

In this example RouterA has received an IP packet with the destination IP address of **172.16.3.10**.

What does the destination IP address of 172.16.3.10 get matched to in the routing table? For there to be a match we said at a minimum the number of the left-most bits as specified by the subnet mask of the route in the routing table must match between the destination IP address of the packet and the IP address in the routing table. (*Okay, that is the last time I will mention what a match is!*)

First of all, does the packet's destination IP address, 172.16.3.10, match the parent route, 172.16.0.0?
```
     172.16.0.0/24 is subnetted, 3 subnets
```

The parent route's classful mask is /16 (not shown), and in Figure 6 we see that there is a match of at least 16 bits (/16, the classful mask of 172.16.0.0).

Figure 6

IP Packet	172.16.3.10	10101100	00010000	00000011	00001010
			These 16 bits match!		
Parent Route	172.16.0.0	10101100	00010000	00000000	00000000

Since there is a match with the parent route, the child routes can be examined for a match. However, this time we will use the subnet mask of **/24**, which is displayed with the parent route, for the minimum number of left-most bits that must match. (Remember, is the mask of the child routes!)
```
     172.16.0.0/24 is subnetted, 3 subnets
```

Now, the routing table process will see if it can find a match between the packet's destination IP address of **172.16.3.10** and one of the child routes, **172.16.1.0**, **172.16.2.0**, **172.16.3.0**. There must be a minimum of 24 bits that match! Figure 7 shows that the only route that has 24 left-most matching bits is the child route **172.16.3.0**.
```
C       172.16.1.0 is directly connected, FastEthernet0
C       172.16.2.0 is directly connected, Serial0
R       172.16.3.0 [120/1] via 172.16.2.2, 00:00:00, Serial0
```

Figure 6 (child routes shown in different order than with 'show ip route')

IP Packet	172.16.3.10	10101100	00010000	00000011	00001010
			These 24 bits match!		
Child Route	172.16.3.0	10101100	00010000	00000011	00000000
Child Route	172.16.1.0	10101100	00010000	00000001	00000000
Child Route	172.16.2.0	10101100	00010000	00000010	00000000

You will notice that more than the minimum 24 bits match, but actually 28 bits match between the IP packet's 172.16.3.10 address and the child route of 172.16.3.0.

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The routing table process will use this route, 172.16.3.0 to forward the packet with the destination IP address of 172.16.3.10 out the exit-interface of Serial0. (Figure 7)
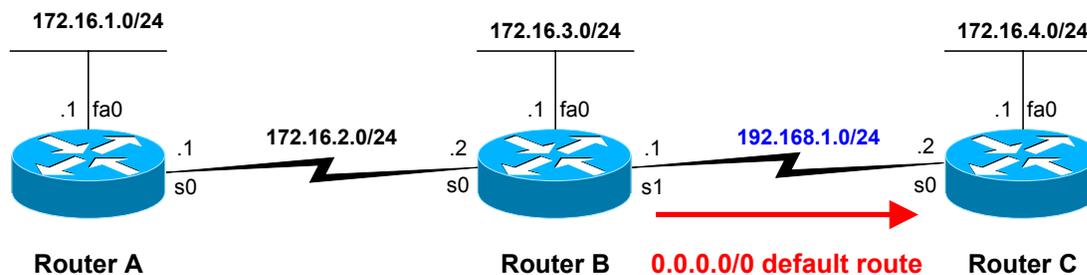
Figure 7

```
RouterA#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
<text omitted>

Gateway of last resort is not set

     172.16.0.0/24 is subnetted, 3 subnets
C       172.16.1.0 is directly connected, FastEthernet0
C       172.16.2.0 is directly connected, Serial0
R       172.16.3.0 [120/1] via 172.16.2.2, 00:00:00, Serial0
R    192.168.1.0/24 [120/1] via 172.16.2.2, 00:00:00, Serial0
RouterA#
```

2.3 Classful Routing Behavior and the no ip classless Command

We have made a couple of small changes to our configuration for RouterB and RouterC. On RouterB we added a static default route pointing to RouterC. In RouterC we added a route for the 172.16.0.0/16 network pointing to RouterB. The affect of these two static routes is to allow all of our routers to 'potentially' reach all of the networks in our diagram. (What do you mean 'potentially?' We'll see!)

Figure 8 shows the changes made to RouterB.

Figure 8

```
RouterB(config)#ip route 0.0.0.0 0.0.0.0 serial1
RouterB(config)#end

RouterB#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
<text omitted>

Gateway of last resort is 0.0.0.0 to network 0.0.0.0

     172.16.0.0/24 is subnetted, 3 subnets
R       172.16.1.0 [120/1] via 172.16.2.1, 00:00:13, Serial0
C       172.16.2.0 is directly connected, Serial0
C       172.16.3.0 is directly connected, FastEthernet0
C    192.168.1.0/24 is directly connected, Serial1
S*    0.0.0.0/0 is directly connected, Serial1
RouterB#
```

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Figure9 shows the changes made to RouterC.

Figure 9

```
RouterC(config)#ip route 172.16.0.0 255.255.0.0 serial0
RouterC(config)#end

RouterC#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
<text omitted>

Gateway of last resort is not set

     172.16.0.0/16 is variably subnetted, 2 subnets, 2 masks
C       172.16.4.0/24 is directly connected, FastEthernet0
S       172.16.0.0/16 is directly connected, Serial0
C    192.168.1.0/24 is directly connected, Serial0
RouterC#
```

The no ip classless Command

Special Note: We are now going to discuss the difference between classful routing behavior and classless routing behavior. ***It is very important to understand that this has nothing to do with classful routing protocols or classless routing protocols.*** Classful and classless routing protocols deal with how the routers exchange routing information, which is one of the ways routes get entered into the routing table. In our discussions of the routing table, including classful and classless routing behaviors, we are <u>not</u> concerned about how the routes got into the routing table. Instead we are only concerned with how the routing table finds the best route, *after* the routes get entered into the table. Classful and classless routing behavior (**no ip classless** and the **ip classless** commands) are completely independent of any dynamic routing protocol which might be used. It makes no difference whether or not we are using a classful routing protocol like RIPv1 or a classless routing protocol like OSPF.

Looking at the configuration and routing table in Figure 10 for RouterB we might assume that RouterB will use the default route to forward any packets that it does not match any of the other routes in the routing table. As we will see that may or may not be the case.

Looking at Step 4 of the Route Lookup Process, we see what happens next may depend on whether or not we are using classful or classless routing behavior.

The route lookup process:

Step 1. The router begins by finding a network route, ultimate or parent that matches the IP packet's destination address.
Step 2. If the matching network is an ultimate route (not including subnet routes), and there are no more specific routes, this is the route used to forward the packet.
Step 3. If the matching network is a parent route, then the subnet routes are looked through to find the best-matching route.
Step 4. If there is no match of an ultimate or a subnet within a parent route, than what happens depends upon the whether or not the router is using in classful or classless routing behavior.

Figure 10

```
RouterB#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
<text omitted>


Gateway of last resort is 0.0.0.0 to network 0.0.0.0


     172.16.0.0/24 is subnetted, 3 subnets
R       172.16.1.0 [120/1] via 172.16.2.1, 00:00:13, Serial0
C       172.16.2.0 is directly connected, Serial0
C       172.16.3.0 is directly connected, FastEthernet0
C    192.168.1.0/24 is directly connected, Serial1
S*   0.0.0.0/0 is directly connected, Serial1
RouterB#
```

Prior to IOS 11.3, **no ip classless** was the default behavior for Cisco routers. This means that the IP routing table would perform classful routing table lookups. The **no ip classless** (or **ip classless** command), is a global configuration command can be viewed by typing **show running config**. IOS 11.3 and later, the command ip classless became the default, creating a classless routing table lookups.

Let's see some examples to see what all of this means.

We will assume that we are running an IOS prior to 11.3 and the default is **no ip classless**. (Figure 11)

Figure 11

```
RouterB#show running-config
Building configuration...

Current configuration:
!
version 11.2
!
<text omitted>
!
no ip classless
!
<text omitted>
```

Example 3: Non-existent Child Route and no ip classless

In this example RouterB receives a packet with the destination IP address of **172.16.4.10**. The routing process searches the routing table and finds a 16 bit match (the classful subnet mask of the parent route) with the parent route 172.16.0.0.
```
parent        172.16.0.0/24 is subnetted, 3 subnets
```

Since there has been a match with the parent route, the child routes are searched next.
```
child   R       172.16.1.0 [120/1] via 172.16.2.1, 00:00:13, Serial0
child   C       172.16.2.0 is directly connected, Serial0
child   C       172.16.3.0 is directly connected, FastEthernet0
```

However, In Figure 12 we notice that none of the child routes have 24 left-most bits (/24 mask displayed in the parent route) that match the destination IP address of **172.16.4.10**. At most, only 21 bits match.

Figure 12

IP Packet	172.16.4.10	10101100	00010000	00000100	00001010
			No match!		
Child Route	172.16.3.0	10101100	00010000	00000011	00000000
Child Route	172.16.1.0	10101100	00010000	00000001	00000000
Child Route	172.16.2.0	10101100	00010000	00000010	00000000

So what happens next? *The router drops the packet!*

Because the router is running the default, **no ip classless**, classful routing behavior is in effect. What this means is that the router will **not** look beyond the child routes for a lesser match. The routing table process will **not** use the default route, 0.0.0.0/0, or any other route.
```
S*   0.0.0.0/0 is directly connected, Serial1
```

Why? The general idea of clasful routing behavior comes from the days when all networks were of a classful nature. This is when companies, colleges, etc., applied to InterNIC (or similar institution) for IP address space and received a Class A, Class B, or Class C major network address. Once a company has a classful IP major network address, it of course includes any and all of the subnets for that address. So the idea is that the routers in this network would know about all of the subnets for this major network. If the subnet isn't in the routing table, then it doesn't exist.

As you can see this doesn't work well for discontiguous subnets, like we have in our example. It also doesn't work for real world IP address allocation, where an ISP owns the address space and divides it up to its individual subscribers.

I have left out quite a bit of information and details on this subject. For more information I would suggest reading information regarding CIDR (Classless Inter-Domain Routing) and similar topics.

Let's summarize what happens with classful routing behavior, the **no ip classless** command. If there is a match with a parent route, and after examining the child routes there is **not** a match, then the routing process drops the packet. Default and supernet routes are **not** examined or used. (Figure 13)

Figure 13

```
Routing Behavior:  classful (no ip classless)
Packet's Destination IP Address:  172.16.4.10

            RouterB#show ip route
            Codes: C - connected, S - static, I - IGRP, R - RIP,
            <text omitted>

            Gateway of last resort is 0.0.0.0 to network 0.0.0.0

1. Match          172.16.0.0/24 is subnetted, 3 subnets
2. No Match   R      172.16.1.0 [120/1] via 172.16.2.1, 00:00:13, Serial0
3. No Match   C      172.16.2.0 is directly connected, Serial0
4. No Match   C      172.16.3.0 is directly connected, FastEthernet0
              C   192.168.1.0/24 is directly connected, Serial1
              S*  0.0.0.0/0 is directly connected, Serial1
5. Drop Packet   RouterB#
```

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2.4 Classless Routing Behavior and the ip classless Command

With IOS 11.3 and later, Cisco changed the default behavior of the routing table to classless. By looking at the running-config in Figure 14, we can see the **ip classless** command.

Figure 14

```
RouterB#show running-config
Building configuration...

Current configuration:
!
version 11.3
!
<text omitted>
!
ip classless
!
<text omitted>
```

This means that routing process no longer assumes that all subnets for a major network can only be reached within the child routes of the parent. Classless routing behavior works well for discontiguous networks and CIDR.

Let's use our previous example, but this time using classless routing behavior. Figure 15 shows the same routing table as before.

Figure 15

```
RouterB#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
<text omitted>

Gateway of last resort is 0.0.0.0 to network 0.0.0.0

     172.16.0.0/24 is subnetted, 3 subnets
R       172.16.1.0 [120/1] via 172.16.2.1, 00:00:13, Serial0
C       172.16.2.0 is directly connected, Serial0
C       172.16.3.0 is directly connected, FastEthernet0
C    192.168.1.0/24 is directly connected, Serial1
S*   0.0.0.0/0 is directly connected, Serial1
RouterB#
```

Example 4: Non-existent Child Route and ip classless

Figure 14 shows that the default is now, **ip classless**. Again, RouterB receives a packet with the destination IP address of **172.16.4.10**. Just like the previous example, the routing process searches the routing table and finds a match with the parent route 172.16.0.0/24.

```
parent        172.16.0.0/24 is subnetted, 3 subnets
```

Again, there has been a match with the parent route, so the child routes are searched next.

```
child   R       172.16.1.0 [120/1] via 172.16.2.1, 00:00:13, Serial0
child   C       172.16.2.0 is directly connected, Serial0
child   C       172.16.3.0 is directly connected, FastEthernet0
```

Once again, Figure 16 shows us that none of the child routes have 24 left-most bits (/24 mask displayed in the parent route) that match the destination IP address of **172.16.4.10**.

Figure 16

IP Packet	**172.16.4.10**	10101100	00010000	00000100	00001010
			***No** match!*		
Child Route	**172.16.3.0**	10101100	00010000	00000011	00000000
Child Route	**172.16.1.0**	10101100	00010000	00000001	00000000
Child Route	**172.16.2.0**	10101100	00010000	00000010	00000000

Now, what happens next?

Because the default is now, **ip classless**, the routing process continues searching the routing table, beyond this parent route and its child routes. The routing process will search the routing table for a route with a subnet mask fewer than the 16 bits of the previous parent route. In other words, the router will now continue to search the other routes in the routing table where there may be fewer bits that match, but still a match.

The 192.168.1.0/24 route does not match have **24** left-most bits that match with our destination IP address. How about the default route? How many bits need to match?
S*   0.0.0.0/0 is directly connected, Serial1

The mask is /0 so zero or no bits need to match. A default route, if used in the search, will be the lowest-bit-match. If no other route matches, the default route will! (Figure 17)

Figure 17

```
Routing Behavior:  classless (ip classless)
Packet's Destination IP Address:  172.16.4.10

            RouterB#show ip route
            Codes: C - connected, S - static, I - IGRP, R - RIP,
            <text omitted>

            Gateway of last resort is 0.0.0.0 to network 0.0.0.0

            172.16.0.0/24 is subnetted, 3 subnets
     R       172.16.1.0 [120/1] via 172.16.2.1, 00:00:13, Serial0
     C       172.16.2.0 is directly connected, Serial0
     C       172.16.3.0 is directly connected, FastEthernet0
     C     192.168.1.0/24 is directly connected, Serial1
     S*    0.0.0.0/0 is directly connected, Serial1
            RouterB#
```

1. Match
2. No Match
3. No Match
4. No Match
5. Match!

Changing between ip classless and no ip classless

Changing the default routing behavior, whether classful or classless, is simple. The command to enable classless routing behavior is:
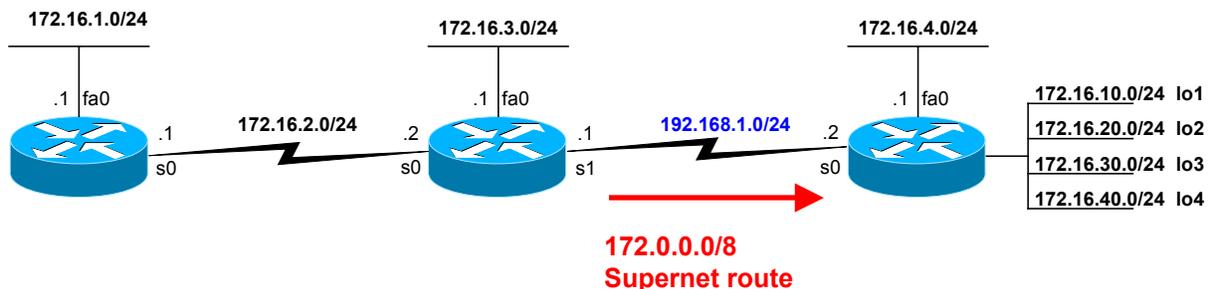
```
RouterB(config)#ip classless
RouterB(config)#
```

The command to disable classless routing behavior, in other words, enable classful routing behavior is:

```
RouterB(config)#no ip classless
RouterB(config)#
```

Use **show running-config** to verify which command is in affect.

2.5 Classless Routing Behavior and Supernet Routes

It is not the intention of this document to explain CIDR and supernets, and I would refer you to other sources such as:
- Cisco Networking Academy Curriculum, CCNP Advanced Routing
- CCNP Semester 5, Advanced Routing Companion Guide, by Mark McGregor
- Routing TCP/IP Volume II, by Jeff Doyle

One Cisco definition of a supernet is: "Aggregation of IP network addresses advertised as a single classless network address. For example, given four Class C IP networks—192.0.8.0, 192.0.9.0, 192.0.10.0, and 192.0.11.0—each having the intrinsic network mask of 255.255.255.0, one can advertise the address 192.0.8.0 with a subnet mask of 255.255.252.0."

Another definition of a supernet is as a route with a subnet mask which is less than the classful mask. For example, a route to the 172.16.0.0/16 network may be advertised as 172.0.0.0 with at /8 or 255.0.0.0 subnet mask.   Alex Zinin, in his book, Cisco IP Routing, defines a supernet as, "Routes installed in the routing table with route masks shorter than the default class mask."

How does a supernet route get created or propagated? A supernet route can be added by creating a static route, which we will do in our example. However, a supernet route can only be propagated, advertised, by a classless routing protocol. This is because classful routing protocols do not send the subnet mask like classless routing protocols, so the default classful mask would be assumed by the receiving router.

Supernet routes in the routing table are treated no differently than any other ultimate route during route lookups. They contain a network route and a subnet mask. The only difference is that the subnet mask is has few bits than the major network's classful mask. If both are present in the routing table, the major network route would be a longer-bit-match and be the preferred route.

Let's see an example.

Creating Supernet Routes

First, lets create some additional networks to RouterC by configuring loopback interfaces. A loopback interface is like any other interface. The networks can be routed and the interfaces can be pinged. They are virtual interfaces that never goes down.

We will add two more networks to RouterC, **172.20.0.0/16** and **172.30.0.0/16.** Figure 18 shows how to configure these loopback interfaces.

Figure 18
```
RouterC(config)#interface loopback1
RouterC(config-if)#ip add 172.20.0.1 255.255.0.0
RouterC(config-if)#exit
RouterC(config)#interface loopback2
RouterC(config-if)#ip add 172.30.0.1 255.255.0.0
RouterC(config-if)#exit

RouterC#show ip inter brief
Interface              IP-Address      OK? Method Status    Protocol
FastEthernet0          172.16.4.1      YES NVRAM  up        up
Loopback1              172.20.0.1      YES manual up        up
Loopback2              172.30.0.1      YES manual up        up
Serial0                192.168.1.2     YES NVRAM  up        up
RouterC#
```

Figure 19 shows these new networks in RouterC's routing table.

Figure 19
```
RouterC#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
<text omitted>

Gateway of last resort is not set

     172.16.0.0/16 is variably subnetted, 6 subnets, 2 masks
C       172.16.4.0/24 is directly connected, FastEthernet0
S       172.16.0.0/16 is directly connected, Serial0
C    172.20.0.0/16 is directly connected, Loopback1
C    172.30.0.0/16 is directly connected, Loopback2
C    192.168.1.0/24 is directly connected, Serial0
RouterC#
```

We will now add two supernet routes on RouterB. The actual order of the routes that you may see in your routing table may vary slightly from Figure 19's routing table.

Figure 19

```
RouterB(config)#ip route 172.0.0.0 255.0.0.0 serial1
RouterB(config)#ip route 160.0.0.0 240.0.0.0 serial1
RouterB(config)#end

RouterB#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
<text omitted>

Gateway of last resort is 0.0.0.0 to network 0.0.0.0

     172.16.0.0/24 is subnetted, 3 subnets
R       172.16.1.0 [120/1] via 172.16.2.1, 00:00:20, Serial0
C       172.16.2.0 is directly connected, Serial0
C       172.16.3.0 is directly connected, FastEthernet0
C    192.168.1.0/24 is directly connected, Serial1
S    172.0.0.0/8 is directly connected, Serial1
S    160.0.0.0/4 is directly connected, Serial1
S*   0.0.0.0/0 is directly connected, Serial1
RouterB#
```

RouterB will forward packets to RouterC using the 172.0.0.0/8 route if the first eight bits match the packet's destination IP address and use the 160.0.0.0/4 route if only the first four bits match. Because the routing process uses the longest-bit-match, the 172.0.0.0/8 route will always be preferred over the 160.0.0.0/4 route, as long as there are at least eight matching bits.

Carrying this one step further, the 160.0.0.0/4 route will be preferred over the default, 0.0.0.0/0 route, when there are at least four matching bits. If neither of the supernet routes match, then the default route 0.0.0.0/0 would be used, because only zero bits need to match. That's why the call it the *default*!

Let's see an example.

Example 5: Supernet Routes and the Destination IP Address 172.16.4.10

Once again we will use the example of RouterB receiving a packet with the destination IP address of **172.16.4.10**. The routing process searches the routing table and finds a match with the parent route 172.16.0.0/24, but does not find a match with a child route. We are using classless routing behavior, (**ip classless**), so the routing process will continue looking for a matching supernet or default route. If we were using classful routing behavior (**no ip classless**) that packet would be dropped at this point.

Figure 20

IP Packet	172.16.4.10	10101100	00010000	00000100	00001010
			No match!		
Child Route	172.16.3.0	10101100	00010000	00000011	00000000
Child Route	172.16.1.0	10101100	00010000	00000001	00000000
Child Route	172.16.2.0	10101100	00010000	00000010	00000000

In Figure 21, looking at the supernet routes we can see that 172.0.0.0/8 is a match. Even though the 160.0.0.0/4 and 0.0.0.0/0 routes are a match, the 172.0.0.0/8 is a longer-bit-match with the destination IP address, so becomes the preferred route. 172.0.0.0/8 requires a minimum of eight left-most bits matching, but we can see that it exceeds the minimum with eleven bits matching.

Figure 21

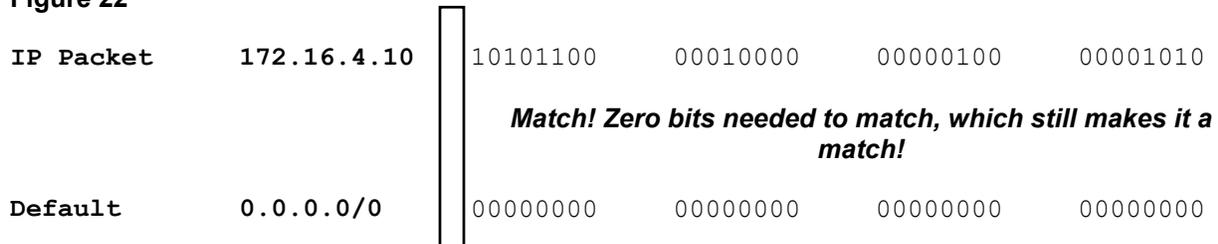|					
IP Packet	172.16.4.10	10101100	00010000	00000100	00001010
		Longest-bit-match! (11 bits match, 8 bits minimum)			
Supernet	172.0.0.0/8	10101100	00000000	00000000	00000000
Supernet	160.0.0.0/4	10100000	00000000	00000000	00000000
Default	0.0.0.0/0	00000000	00000000	00000000	00000000

If the 172.0.0.0/8 route went down and is no longer in the routing table, the next route with the longest-bit-match would be 160.0.0.0, with four left-most matching bits. (Figure 22)

Figure 21

IP Packet	172.16.4.10	10101100	00010000	00000100	00001010
		Longest-bit-match! (4 bits)			
Supernet	160.0.0.0/4	10100000	00000000	00000000	00000000
Default	0.0.0.0/0	00000000	00000000	00000000	00000000

Of course it is very possible, and very likely, that you will have some supernet routes that do not match the destination IP address of the packet. In the case when there is not a match with any ultimate route, including supernets) or subnet route within a parent, then the default route will be the match. The default route doesn't need to have any bits to match for this route to be used. Any other route that has one or more left-most matching bits will always be preferred over the default route.   This is why the default route is also known as the "gateway of last resort." (Figure 22)

Figure 22

```
IP Packet       172.16.4.10     10101100     00010000     00000100     00001010
```

Match! Zero bits needed to match, which still makes it a match!

```
Default         0.0.0.0/0       00000000     00000000     00000000     00000000
```

And of course, if there were <u>not</u> any supernet routes that matched, and there was <u>not</u> a default route, then the packet would be dropped.

Note: Remember that the child routes are only examined for a match if there is a classful match with the parent route. If the router receives the packet with the destination IP address of 160.10.10.10, there is not a match with any parent route, so the ultimate supernet route of 160.0.0.0/4 is used. Because parent routes were never examined, the supernet route would be used whether we were using classless (**ip classless**) or classful (**no ip classless**) routing behavior.

2.6 A Classful Route and a Child Route

RouterC was configured with a 172.16.4.0/24 subnet, a directly connected interface, but also included a 172.16.0.0/16 static route in order to reach all of the other 172.16.0.0 subnets on RouterA and RouterB. (Figure 23) This was to insure full connectivity for our sample network.

In case you were wondering what that looks like in the routing table, you will notice that it creates a "variably subnetted" entry in the routing table. Both the 172.16.4.0/24 and 172.16.0.0/16 routes are included as child routes, below the parent route 172.16.0.0.

Figure 23
```
RouterC(config)#ip route 172.16.0.0 255.255.0.0 serial0
RouterC(config)#end

RouterC#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
<text omitted>

Gateway of last resort is not set

     172.16.0.0/16 is variably subnetted, 2 subnets, 2 masks
C        172.16.4.0/24 is directly connected, FastEthernet0
S        172.16.0.0/16 is directly connected, Serial0
C    192.168.1.0/24 is directly connected, Serial0
RouterC#
```

2.7 Discard Routes and Avoiding Routing Loops

I have written another document, *Discard Routes and Avoiding Routing Loops*, which shows a practical example of a routing loop problem that can happen on a network, and how your understanding of the routing table can resolve this common problem. It is a much shorter document, and I think you will find it both interesting and useful.

2.8 Last Remarks

I hope you have found this useful document in understanding the routing table and the routing table lookup process. If you have any comments or questions regarding this document, you may email them to me at graziani@cabrillo.edu.

I would personally like to thank Alex Zinin, author of the book Cisco IP Routing, who's book opens up the inner-workings of the Cisco IOS to the rest of us.