The University of Jordan, Comp. Eng. Dept.
Networks lab: Handout: Experiment 2
IP Addressing: Version 4: (Theory and Practice)

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Parts Included: Classful IP addressing, Classless IP addressing, and Practical Demonstration of CIDR.

Part I. Classful IP Addressing

A. Internet Address and Classes of IP address

When **IP was first standardized in <u>September 1981</u>**, the specification required that each system attached to an IP-based Internet be assigned a unique, 32-bit Internet address value. Systems that have interfaces to more than one network require a unique IP address for each network interface. The first part of an Internet address identifies the network on which the host resides, while the second part identifies the particular host on the given network. This creates the two-level addressing hierarchy that is illustrated in Figure 1. On the other hand, Figure 2 shows the classes of IP address. Interestingly, the ranges of classes of IP address are shown in Figure 3.

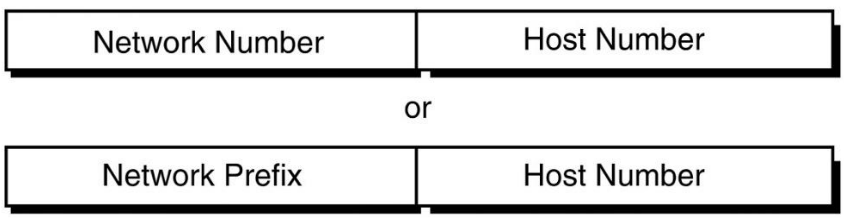


Figure 1. Two-Level Internet Address Structure

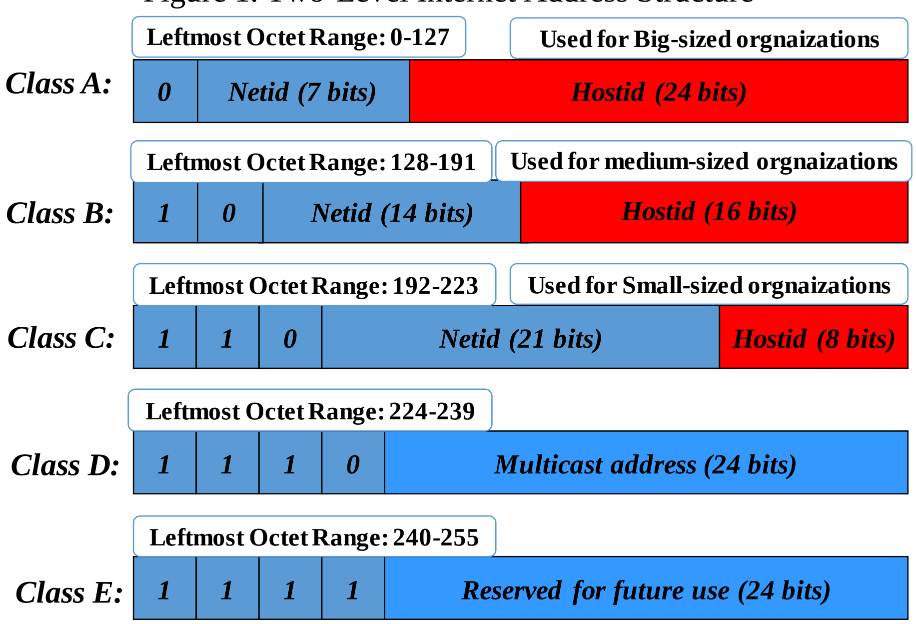
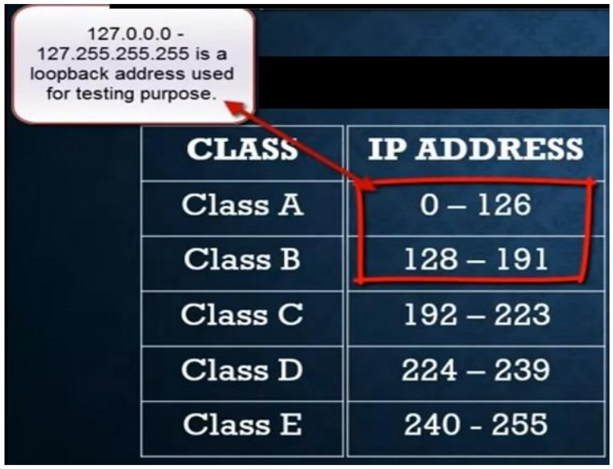


Figure 2. Classes of IP address



CLASS	IP ADDRESS
Class A	0 – 126
Class B	128 – 191
Class C	192 – 223
Class D	224 – 239
Class E	240 - 255

Figure 3. Ranges and default subnet masks of classes of IP address

A.1 Dotted-Decimal Notation:

To make Internet addresses easier for people to read and write, IP addresses are often expressed as four decimal numbers, each separated by a dot. This format is called "dotted-decimal notation."

Dotted-decimal notation divides the 32-bit Internet address into four 8- bit fields and specifies the value of each field independently as a decimal number with the fields separated by dots. Figure 4 shows how a typical /16 (Class B) Internet address can be expressed in dotted-decimal notation.

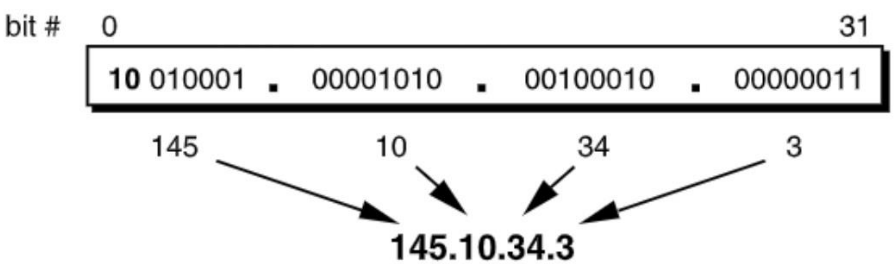


Figure 4. Dotted Decimal Notation

A.2 Unforeseen (Unexpected) Limitations to Classful Addressing:

The original Internet designers never envisioned that the Internet would grow into what it has become today.

- ✓ During the early days of the Internet, the seemingly unlimited address space allowed IP addresses to be allocated to an organization based on its request rather than its actual need. As a result, addresses were freely assigned to those who asked for them without concerns about the eventual depletion of the IP address space.
- ✓ The decision to standardize on a 32-bit address space meant that there were only 2^{32} (4,294,967,296) IPv4 addresses available. A decision to support a slightly larger address space would have exponentially increased the number of addresses thus eliminating the current address shortage problem.

B. Subnetting

In 1985, RFC 950 defined a standard procedure to support the subnetting, or division, of a single Class A, B, or C network number into smaller pieces. Subnetting was introduced to overcome some of the problems that parts of the Internet were beginning to experience with the classful two-level addressing hierarchy, such as:

- ✓ Internet routing tables were beginning to grow.
- ✓ Local administrators had to request another network number from the Internet before a new network could be installed at their site.

Both of these problems were attacked by adding another level of hierarchy to the IP addressing structure. Instead of the classful two-level hierarchy, subnetting supports a three-level hierarchy. Figure 5 illustrates the basic idea of subnetting, which is to divide the standard classful host number field into two parts-the subnet number and the host number on that subnet.

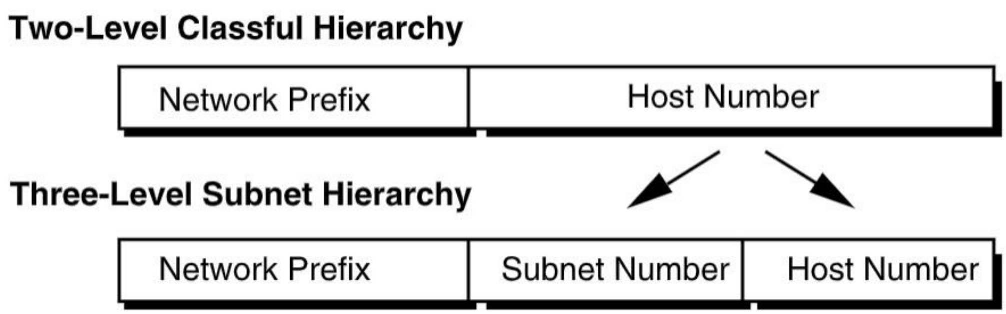


Figure 5. Subnet Address Hierarchy

Subnetting overcame the registered number issue by assigning each organization one (or at most a few) network numbers from the IPv4 address space. The organization was then free to assign a distinct subnetwork number for each of its internal networks. This allowed the organization to deploy additional subnets without obtaining a new network number from the Internet.

In Figure 6, a site with several logical networks uses subnet addressing with a single /16 (Class B) network address. The router accepts all traffic from the Internet addressed to network 130.5.0.0, and forwards traffic to the interior subnetworks based on the third octet of the classful address.

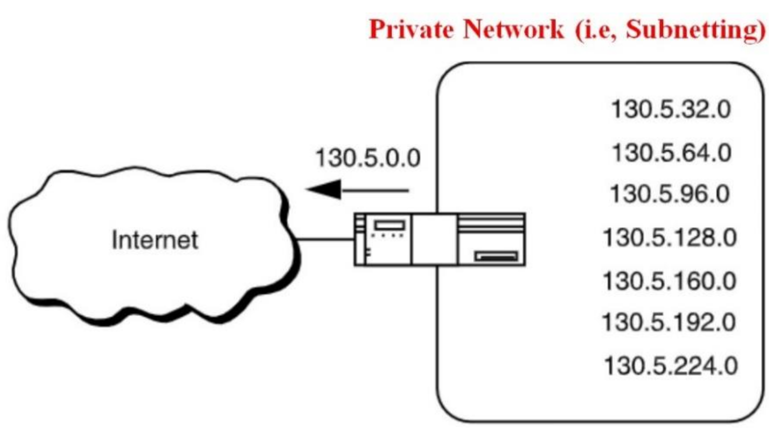


Figure 6. Subnetting – minimizing the routing entries

B.1 Subnetting Advantages:

The deployment of subnetting within the private network provides several benefits:

- ✓ The size of the global Internet routing table does not grow because the site administrator does not need to obtain additional address space and the routing advertisements for all of the subnets are combined into a single routing table entry.
- ✓ The local administrator has the flexibility to deploy additional subnets without obtaining a new network number from the Internet.
- ✓ Route flapping (that is, the rapid changing of routes) within the private network does not affect the Internet routing table since Internet routers do not know about the reachability of the individual subnets, they just know about the reachability of the parent network number.

B.2 Subnetting – Extended Network Prefix:

The extended network prefix is composed of the classful network prefix and the subnet number, as shown in Figure 7.

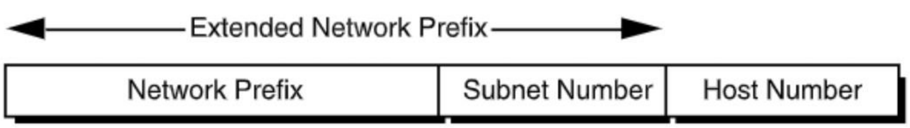


Figure 7. Extended Network Prefix

The extended network prefix has traditionally been identified by the subnet mask. For example, if an administrator has the /16 address of 130.5.0.0 and wants to use the entire third octet to represent the subnet number, the administrator must specify a subnet mask of 255.255.255.0.

The bits in the subnet mask and the Internet address have a one to one correspondence. The bits of the subnet mask are set to 1 (one) if the system examining the address should treat the corresponding bit in the IP address as part of the extended network prefix. The bits in the mask are set to 0 (zero) if the system should treat the bit as part of the host number. This numbering is illustrated in Figure 8 (A).

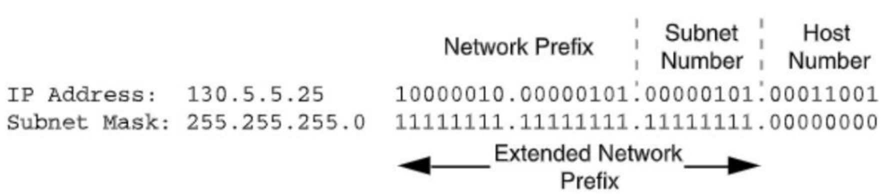


Figure 8 (A). Subnet Mask

It is worth mentioning that the subnet mask is quite necessary as the routing entries of a router have to be a few. The process of showing the need of subnet mask is shown in Figure 8 (B).

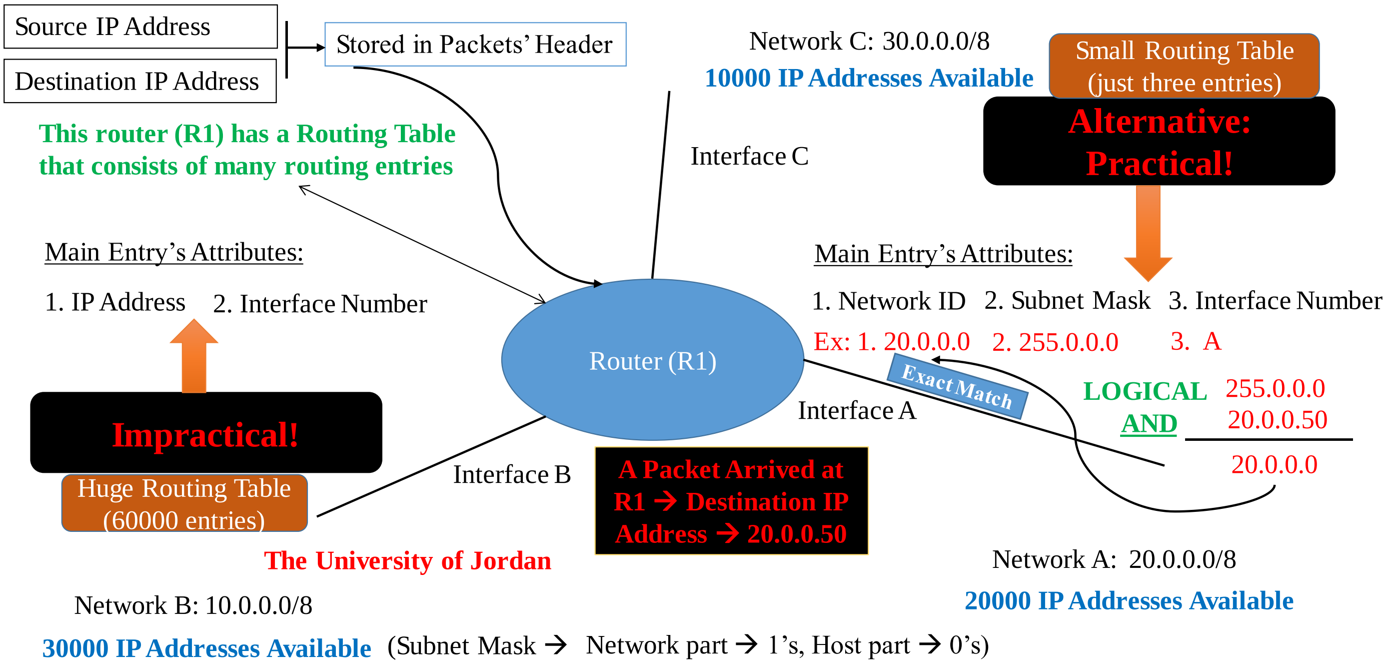
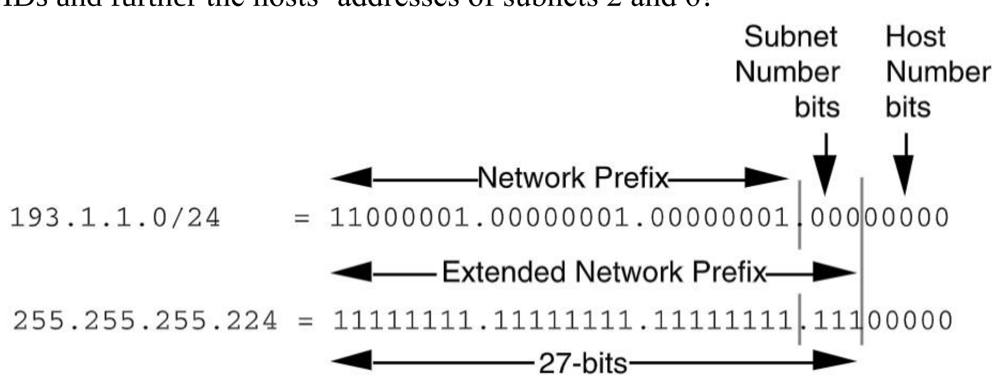


Figure 8 (B). The Need of Subnet Mask

B.3 Subnet Example:

An organization is assigned the network number 193.1.1.0/24 and it needs to define six subnets. The largest subnet is required to support 25 hosts. Show the subnet address hierarchy along with all subnets' IDs and further the hosts' addresses of subnets 2 and 6?



Base Net: <u>11000001.00000001.00000001 .00000000</u> = 193.1.1.0/24
Subnet #0: <u>11000001.00000001.00000001.**000**</u> 00000 = 193.1.1.0/27
Subnet #1: <u>11000001.00000001.00000001.**001**</u> 00000 = 193.1.1.32/27
Subnet #2: <u>11000001.00000001.00000001.**010**</u> 00000 = 193.1.1.64/27
Subnet #3: <u>11000001.00000001.00000001.**011**</u> 00000 = 193.1.1.96/27
Subnet #4: <u>11000001.00000001.00000001.**100**</u> 00000 = 193.1.1.128/27
Subnet #5: <u>11000001.00000001.00000001.**101**</u> 00000 = 193.1.1.160/27
Subnet #6: <u>11000001.00000001.00000001.**110**</u> 00000 = 193.1.1.192/27
Subnet #7: <u>11000001.00000001.00000001.**111**</u> 00000 = 193.1.1.224/27

Figure 9. Subnet Example -Defining the Subnet Mask/Extended Prefix Length

The valid host addresses for Subnet #2 in this example are listed in the following sample code. The underlined portion of each address identifies the extended network prefix, while the bold digits identify the 5- bit host number field:

Subnet #2: 11000001.00000001.00000001.010 **00000** = 193.1.1.64/27
Host #1: 11000001.00000001.00000001.010 **00001** = 193.1.1.65/27
Host #2: 11000001.00000001.00000001.010 **00010** = 193.1.1.66/27
Host #3: 11000001.00000001.00000001.010 **00011** = 193.1.1.67/27
Host #4: 11000001.00000001.00000001.010 **00100** = 193.1.1.68/27
Host #5: 11000001.00000001.00000001.010 **00101** = 193.1.1.69/27
.
.
Host #15: 11000001.00000001.00000001.010 **01111** = 193.1.1.79/27
Host #16: 11000001.00000001.00000001.010 **10000** = 193.1.1.80/27
.
.
Host #27: 11000001.00000001.00000001.010 **11011** = 193.1.1.91/27
Host #28: 11000001.00000001.00000001.010 **11100** = 193.1.1.92/27
Host #29: 11000001.00000001.00000001.010 **11101** = 193.1.1.93/27
Host #30: 11000001.00000001.00000001.010 **11110** = 193.1.1.94/27

The broadcast address for Subnet #2 is the all-1s host address or:
11000001.00000001.00000001.010 **11111** = 193.1.1.95

The valid host addresses for Subnet #6 are listed in the following sample code. The underlined portion of each address identifies the extended network prefix, while the bold digits identify the 5-bit host number field:

Subnet #6: 11000001.00000001.00000001.110 **00000** = 193.1.1.192/27
Host #1: 11000001.00000001.00000001.110 **00001** = 193.1.1.193/27
Host #2: 11000001.00000001.00000001.110 **00010** = 193.1.1.194/27
Host #3: 11000001.00000001.00000001.110 **00011** = 193.1.1.195/27
Host #4: 11000001.00000001.00000001.110 **00100** = 193.1.1.196/27
Host #5: 11000001.00000001.00000001.110 **00101** = 193.1.1.197/27
.
.
Host #15: 11000001.00000001.00000001.110 **01111** = 193.1.1.207/27
Host #16: 11000001.00000001.00000001.110 **10000** = 193.1.1.208/27
.
.
Host #27: 11000001.00000001.00000001.110 **11011** = 193.1.1.219/27
Host #28: 11000001.00000001.00000001.110 **11100** = 193.1.1.220/27
Host #29: 11000001.00000001.00000001.110 **11101** = 193.1.1.221/27
Host #30: 11000001.00000001.00000001.110 **11110** = 193.1.1.222/27

The broadcast address for Subnet #6 is the all-1s host address or:
11000001.00000001.00000001.110 **11111** = 193.1.1.223

C. Variable Length Subnet Masks (VLSM)

In 1987, RFC 1009 specified how a subnetted network could use more than one subnet mask. When an IP network is assigned more than one subnet mask, it is considered a network with (VLSM) since the extended network prefixes have different lengths.

C.1 VLSM Example

An organization has been assigned the network number 140.25.0.0/16 and it plans to deploy VLSM. Figure 10 provides a graphic display of the VLSM design for the organization.

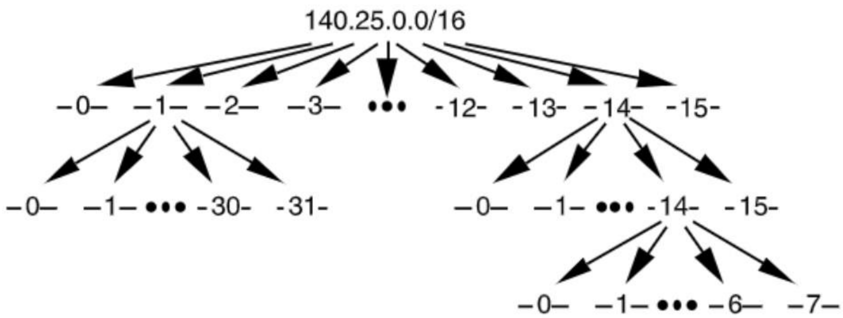


Figure 10. Graphic display of the VLSM design

The first step of the subnetting process divides the base network address into 16 equally sized address blocks, as shown in Figure 11.

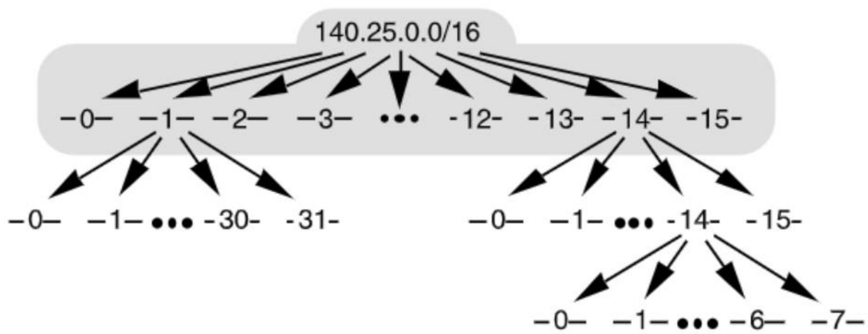


Figure 11. Sixteen Subnets for 140.25.0.0/16

The 16 subnets of the 140.25.0.0/16 address block are listed in the following code sample. The subnets are numbered 0 through 15. The underlined portion of each address identifies the extended network prefix, while the bold digits identify the 4 bits representing the subnet number field:

Base Network: 10001100.00011001 .00000000.00000000 = 140.25.0.0/16
Subnet #0: 10001100.00011001 .**0000** 0000.00000000 = 140.25.0.0/20
Subnet #1: 10001100.00011001 .**0001** 0000.00000000 = 140.25.16.0/20
Subnet #2: 10001100.00011001 .**0010** 0000.00000000 = 140.25.32.0/20

Subnet #3: 10001100.00011001 .**0011** 0000.00000000 = 140.25.48.0/20
Subnet #4: 10001100.00011001 .**0100** 0000.00000000 = 140.25.64.0/20
:
:
Subnet #13: 10001100.00011001 .**1101** 0000.00000000 = 140.25.208.0/20
Subnet #14: 10001100.00011001 .**1110** 0000.00000000 = 140.25.224.0/20
Subnet #15: 10001100.00011001 .**1111** 0000.00000000 = 140.25.240.0/20

Then Subnet #1 is divided into 32 equally sized address blocks, as shown in Figure 12. In what follows, the host Addresses of Subnet #3 (140.25.48.0/20) are defined:

Subnet #3: 10001100.00011001.0011 0000.00000000 = 140.25.48.0/20
Host #1: 10001100.00011001.0011 **0000.00000001** = 140.25.48.1/20
Host #2: 10001100.00011001.0011 **0000.00000010** = 140.25.48.2/20
Host #3: 10001100.00011001.0011 **0000.00000011** = 140.25.48.3/20
:
:
Host #4093: 10001100.00011001.0011 **1111.11111101** = 140.25.63.253/20
Host #4094: 10001100.00011001.0011 **1111.11111110** = 140.25.63.254/20
The broadcast address for Subnet #3 is the all-1s host address or: 10001100.00011001.0011 **1111.11111111** = 140.25.63.255

The Subnet #14 is divided into 16 equally sized address blocks, as shown in Figure 12. In what follows, the Sub-Subnets of Subnet #14 (140.25.224.0/20) are defined:

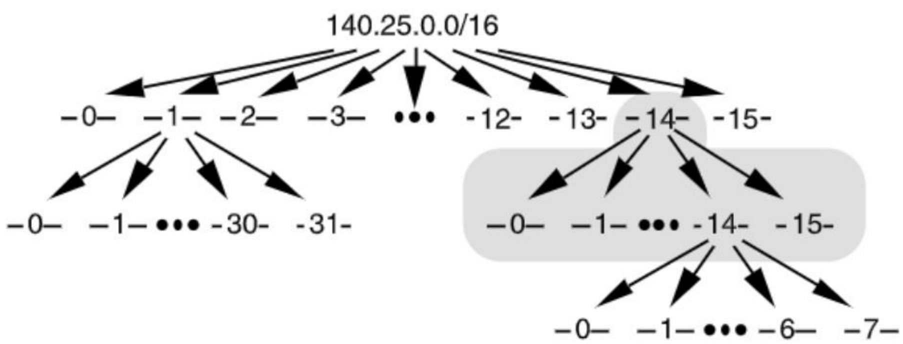


Figure 12. Sub-Subnets of Subnet #14 (140.25.224.0/20)

Subnet #14: 10001100.00011001.1110 0000.00000000 = 140.25.224.0/20
Subnet #14-0: 10001100.00011001.1110 **0000** .00000000 = 140.25.224.0/24
Subnet #14-1: 10001100.00011001.1110 **0001** .00000000 = 140.25.225.0/24
Subnet #14-2: 10001100.00011001.1110 **0010** .00000000 = 140.25.226.0/24
Subnet #14-3: 10001100.00011001.1110 **0011** .00000000 = 140.25.227.0/24
Subnet #14-4: 10001100.00011001.1110 **0100** .00000000 = 140.25.228.0/24
.
.

Subnet #14-14: 10001100.00011001.1110 **1110** .00000000 = 140.25.238.0/24
Subnet #14-15: 10001100.00011001.1110 **1111** .00000000 = 140.25.239.0/24

The host addresses of Subnet #14-3 (140.25.227.0/24) are defined as follows:

Subnet #14-3: 10001100.00011001.11100011 .00000000 = 140.25.227.0/24
Host #1 10001100.00011001.11100011 .**00000001** = 140.25.227.1/24
Host #2 10001100.00011001.11100011 .**00000010** = 140.25.227.2/24
Host #3 10001100.00011001.11100011 .**00000011** = 140.25.227.3/24
Host #4 10001100.00011001.11100011 .**00000100** = 140.25.227.4/24
Host #5 10001100.00011001.11100011 .**00000101** = 140.25.227.5/24
.
.
Host #253 10001100.00011001.11100011 .**11111101** = 140.25.227.253/24
Host #254 10001100.00011001.11100011 .**11111110** = 140.25.227.254/24
The broadcast address for Subnet #14-3 is the all-1s host address or:
10001100.00011001.11100011. **11111111** = 140.25.227.255

After Subnet #14 is divided into 16 subnets, Subnet #14-14 (140.25.238.0/24) is subdivided into eight equally sized address blocks, as shown in Figure 13.

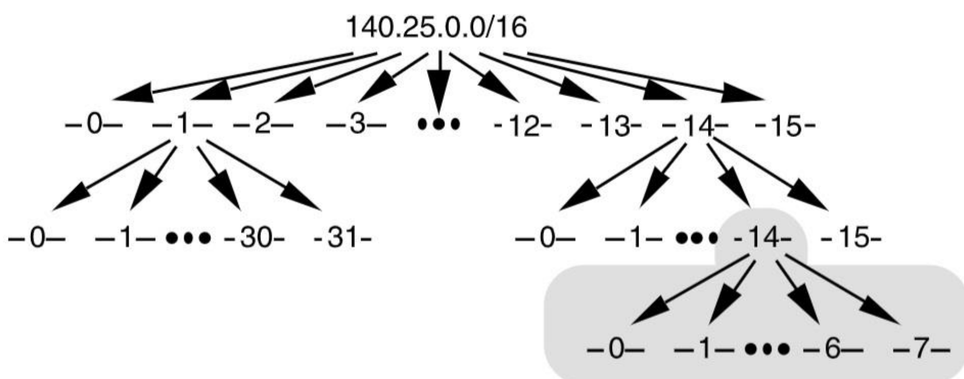


Figure 13. Sub-Subnets for Subnet #14-14 (140.25.238.0/24)

The eight subnets of the 140.25.238.0/24 address block are listed below. The subnets are numbered 0 through 7.

Subnet #14-14: 10001100.00011001.11101110 .00000000 = 140.25.238.0/24
Subnet#14-14-0: 10001100.00011001.11101110.**000** 00000 = 140.25.238.0/27
Subnet#14-14-1: 10001100.00011001.11101110.**001** 00000 = 140.25.238.32/27
Subnet#14-14-2: 10001100.00011001.11101110.**010** 00000 = 140.25.238.64/27
Subnet#14-14-3: 10001100.00011001.11101110.**011** 00000 = 140.25.238.96/27
Subnet#14-14-4: 10001100.00011001.11101110.**100** 00000 = 140.25.238.128/27
Subnet#14-14-5: 10001100.00011001.11101110.**101** 00000 = 140.25.238.160/27
Subnet#14-14-6: 10001100.00011001.11101110.**110** 00000 = 140.25.238.192/27

Subnet#14-14-7: 10001100.00011001.11101110.**111** 00000 = 140.25.238.224/27

The host addresses of Subnet #14-14-2 (140.25.238.64/27) are defined as follows:

Subnet#14-14-2: 10001100.00011001.11101110.010 00000 = 140.25.238.64/27
Host #1 10001100.00011001.11101110.010 **00001** = 140.25.238.65/27
Host #2 10001100.00011001.11101110.010 **00010** = 140.25.238.66/27
Host #3 10001100.00011001.11101110.010 **00011** = 140.25.238.67/27
Host #4 10001100.00011001.11101110.010 **00100** = 140.25.238.68/27
Host #5 10001100.00011001.11101110.010 **00101** = 140.25.238.69/27
.
.
Host #29 10001100.00011001.11101110.010 **11101** = 140.25.238.93/27
Host #30 10001100.00011001.11101110.010 **11110** = 140.25.238.94/27
The broadcast address for Subnet #14-14-2 is the all-1s host address or:
10001100.00011001.11011100.010 **11111** = 140.25.238.95

Part II. Classless IP Addressing - Classless Inter-Domain Routing (CIDR)

By 1992, the exponential growth of the Internet was raising serious concerns among members of the IETF (Internet Engineering Task Force) about the ability of the Internet's routing system to scale and support future growth. These problems were related to:

- ✓ The near-term exhaustion of the Class B network address space
- ✓ The rapid growth in the size of the global Internet's routing tables
- ✓ The eventual exhaustion of the 32-bit IPv4 address space

Throughout the Internet's growth, the first two problems listed became critical and the response to these immediate challenges was the development of Classless Inter-Domain Routing (CIDR). The third problem, which is of a more long-term nature, is resolved by IPv6, which will be discussed shortly.

CIDR was officially documented in September 1993 in RFC 1517, 1518, 1519, and 1520.
CIDR supports two important features that benefit the global Internet routing system:

- ✓ CIDR eliminates the traditional concept of Class A, Class B, and Class C network addresses.
- ✓ CIDR supports route aggregation where a single routing table entry can represent the address space of thousands of traditional classful routes.

A. CIDR Address Allocation Example 1: Noticing the differences with classful addressing

Assume that an ISP owns the address block 200.25.0.0/16. This block represents 65,536 (2^{16}) IP addresses (or 256 /24s). The ISP wants to allocate the smaller 200.25.16.0/20 address block, which represents 4,096 (2^{12}) IP addresses (or 16 /24s).

Address Block: 200.25.16.0/20: **11001000.00011001.00010000.00000000**

In a classful environment, the ISP is forced to use the /20 as 16 individual /24s, as shown in Figure 14.

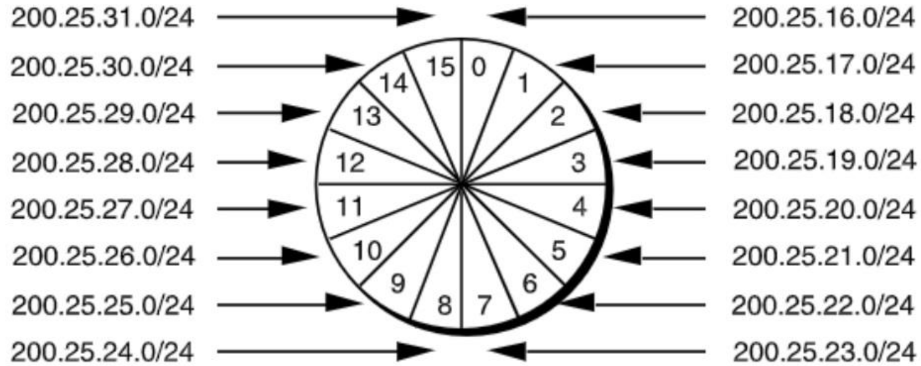


Figure 14. Slicing the Pie - Classful Environment

In a classless environment, the ISP is free to cut up the pie any way it wants. It could slice the original pie into pieces (each one-half of the address space) and assign one portion to Organization A, then cut the other half into two pieces (each one-fourth of the address space) and assign one piece to Organization B, and then slice the remaining fourth into two pieces (each one-eighth of the address space) and assign them to Organization C and Organization D, as shown in Figure 15.

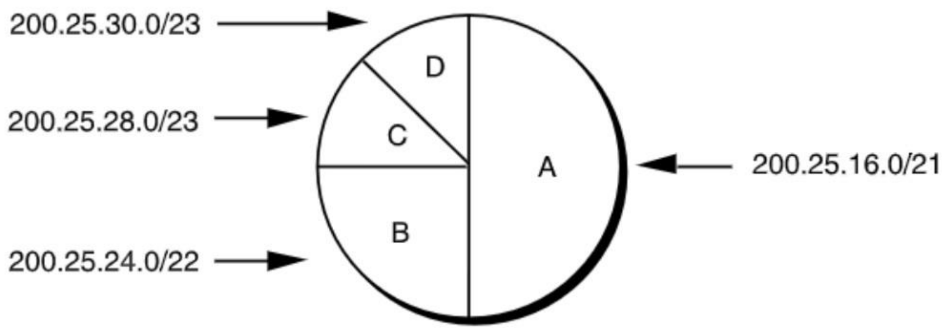


Figure 15. Slicing the Pie - Classless Environment

The following steps explain how to assign addresses with classless inter-domain routing.
Step #1: Divide the address block 200.25.16.0/20 into two equally sized slices. Each block represents one-half of the address space, or 2,048 (2^{11}) IP addresses.

ISP's Block:	**11001000.00011001.00010000.00000000:**	**200.25.16.0/20**
Org A:	**11001000.00011001.00010000.00000000:**	**200.25.16.0/21**
Reserved:	**11001000.00011001.00011000.00000000:**	**200.25.24.0/21**

Step #2: Divide the reserved block (200.25.24.0/21) into two equally sized slices. Each block represents one-fourth of the address space, or 1,024 (2^{10}) IP addresses.
Reserved: 11001000.00011001.00011000.00000000: 200.25.24.0/21
Org B: 11001000.00011001.00011000.00000000: 200.25.24.0/22
Reserved: 11001000.00011001.00011100.00000000: 200.25.28.0/22

Step #3: Divide the reserved address block (200.25.28.0/22) into two equally sized blocks. Each block represents one-eighth of the address space, or 512 (2^9) IP addresses.
Reserved: 11001000.00011001.00011100.00000000: 200.25.28.0/22
Org C: 11001000.00011001.00011100.00000000: 200.25.28.0/23
Org D: 11001000.00011001.00011110.00000000: 200.25.30.0/23

B. Comparing CIDR to VLSM:

The following details the key common features and main differences of CIDR and VLSM:

- ✓ CIDR and VLSM both allow a portion of the IP address space to be recursively divided into subsequently smaller pieces.
- ✓ The difference is that with VLSM, the recursion is performed on the address space previously assigned to an organization and is invisible to the global Internet.
- ✓ CIDR, on the other hand, permits the recursive allocation of an address block by an Internet Registry to a high-level ISP, a mid-level ISP, a low-level ISP, and a certain organization's network.

C. CIDR Address Allocation Example 2:

Before mentioning this example, it is good to have a clear picture about the network elements along with their known names. In fact, the whole picture is illustrated in Figure 16, shown below.

Now, you have been given the following network address: **100.5.0.0/20.** Considering the network topology, shown in Figure 17, perform **CIDR** to minimize the number of routing entries that each router will advertise. Consider that the default gateway IP addresses of the hosts (i.e., the routers' LAN interfaces) <u>are included in</u> the hosts' number, provided in each network, bearing in mind that it is going to be assigned the last addresses of the corresponding subnetworks. Particularly, it is necessary to just fill out Table 1, found below.

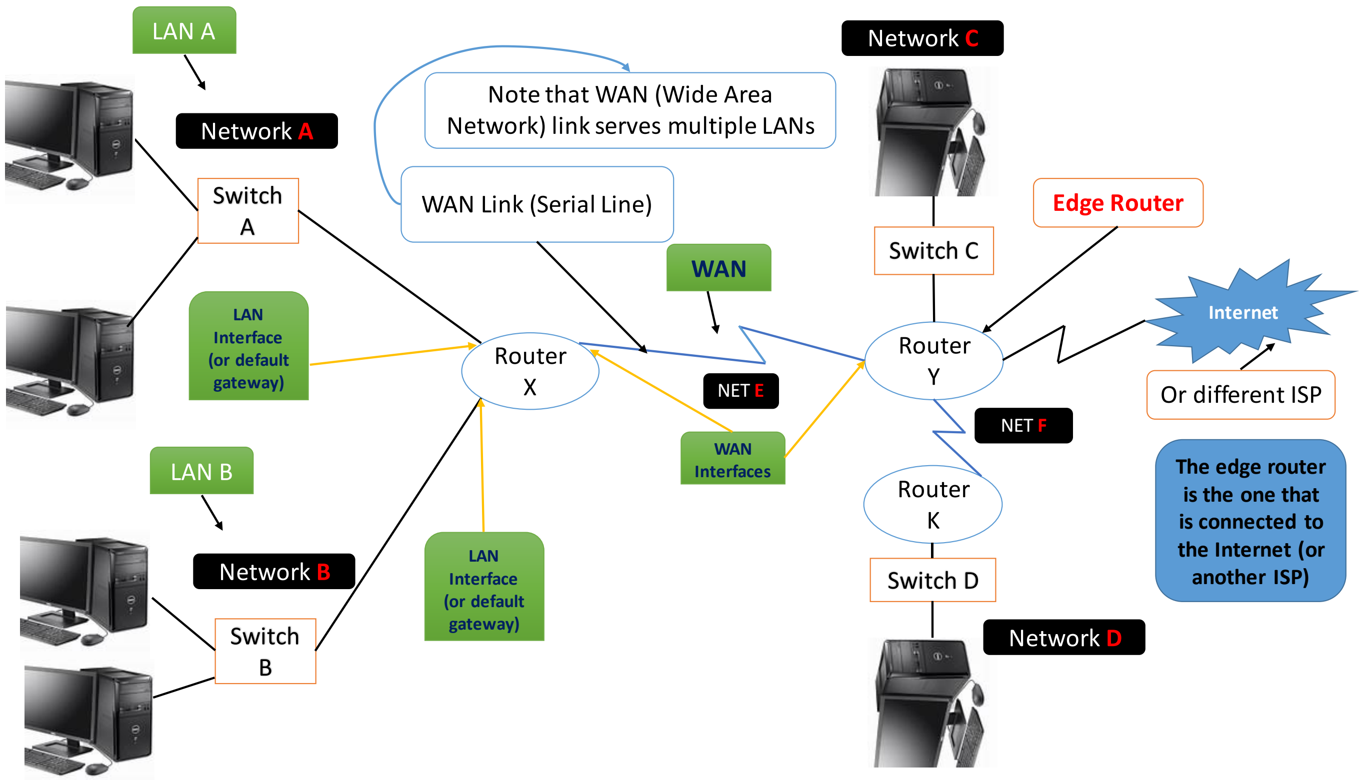


Figure 16. Network Elements – Details

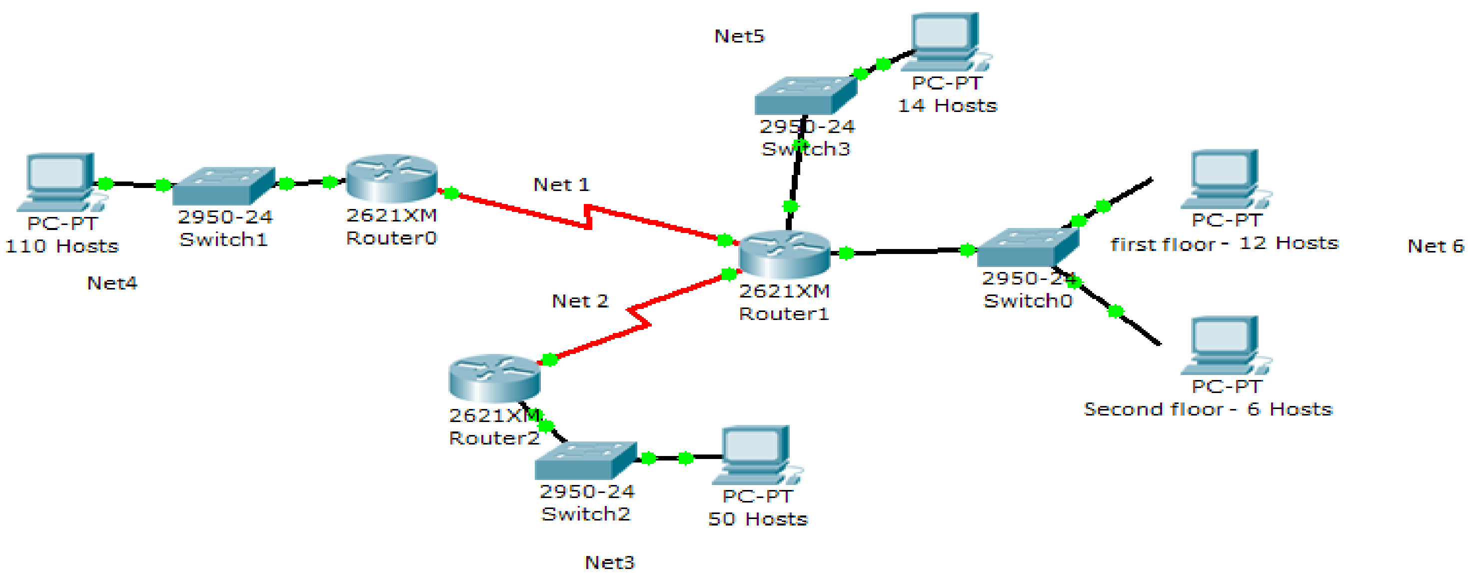


Figure 17. CIDR Address Allocation Example 2

Table 1. CIDR Address Allocation Example 2

Subnet #	Addresses Required	Number of required bits for hosts	2^(Number of required bits for hosts)	CIDR notation	Subnet mask	Network ID	Broadcast ID	Hosts range
Subnet 4	**110+2**	**7**	**128**	**32-7=/25**	**255.255.255.128**	**100.5.0.0**	**100.5.0.127**	**100.5.0.1 - 100.5.0.126**
Subnet 3	**50+2**	**6**	**64**	**32-6=/26**	**255.255.255.192**	**100.5.0.128**	**100.5.0.191**	**100.5.0.129 -100.5.0.190**
Subnet 6	**18+2**	**5**	**32**	**32-5=/27**	**255.255.255.224**	**100.5.0.192**	**100.5.0.223**	**100.5.0.193 -100.5.0.222**
Subnet 5	**14+2**	**4**	**16**	**32-4=/28**	**255.255.255.240**	**100.5.0.224**	**100.5.0.239**	**100.5.0.225 -100.5.0.238**
Subnet 1	**2+2**	**2**	**4**	**32-2=/30**	**255.255.255.252**	**100.5.0.240**	**100.5.0.243**	**100.5.0.241 -100.5.0.242**
Subnet 2	**2+2**	**2**	**4**	**32-2=/30**	**255.255.255.252**	**100.5.0.244**	**100.5.0.247**	**100.5.0.245 -100.5.0.246**

It is good to consider the following notes, which might be helpful while filling out Table 1:

- ✓ **Last assignable address = First assignable address + (2^number of host bits -3)**, whereas this equation would work only when dealing with just the last octet of network ID), which is colored in black in the host range, shown in Table 1.
- ✓ **Broadcast ID = Last assignable address + 1.**

Referring to Table 1, the following show the questions along with their proper answers:

- ✓ **What is the number of subnetworks needed to address this topology? 6**
- ✓ **What is the second valid address in subnet 5? 100.5.0.226**
- ✓ **What is the subnet mask of subnet 3 (decimal notation)? 255.255.255.192**
- ✓ **What is the broadcast address of subnet 6? 100.5.0.223**
- ✓ **What is the network ID of subnet 4? 100.5.0.0**
- ✓ **What is the CIDR notation of subnet 1? /30**
- ✓ **What is the number of loss host address in subnet 3? (64-52=12)**
- ✓ **What is the number of bit borrowed in subnet 4? 5 bits**
- ✓ **What is the number of host bits specified for hosts in subnet 5? 4 bits**
- ✓ **What is the last assignable address in subnet 6? 100.5.0.222**
- ✓ **What is the number of broadcast domains in this topology? 6**

D. CIDR Address Allocation Example 3:

You have been given the following network address: **200.50.100(01100100).0/22.** Considering the network topology above, shown in Figure 18, perform **CIDR** to minimize the number of routing entries that each router will advertise. Consider that the default gateway IP addresses of the hosts (i.e., the routers' LAN interfaces) are excluded from the hosts' number, bearing in mind that it is going to be assigned the last addresses of the corresponding subnetworks. Particularly, it is necessary to just fill out Table 2, found below.

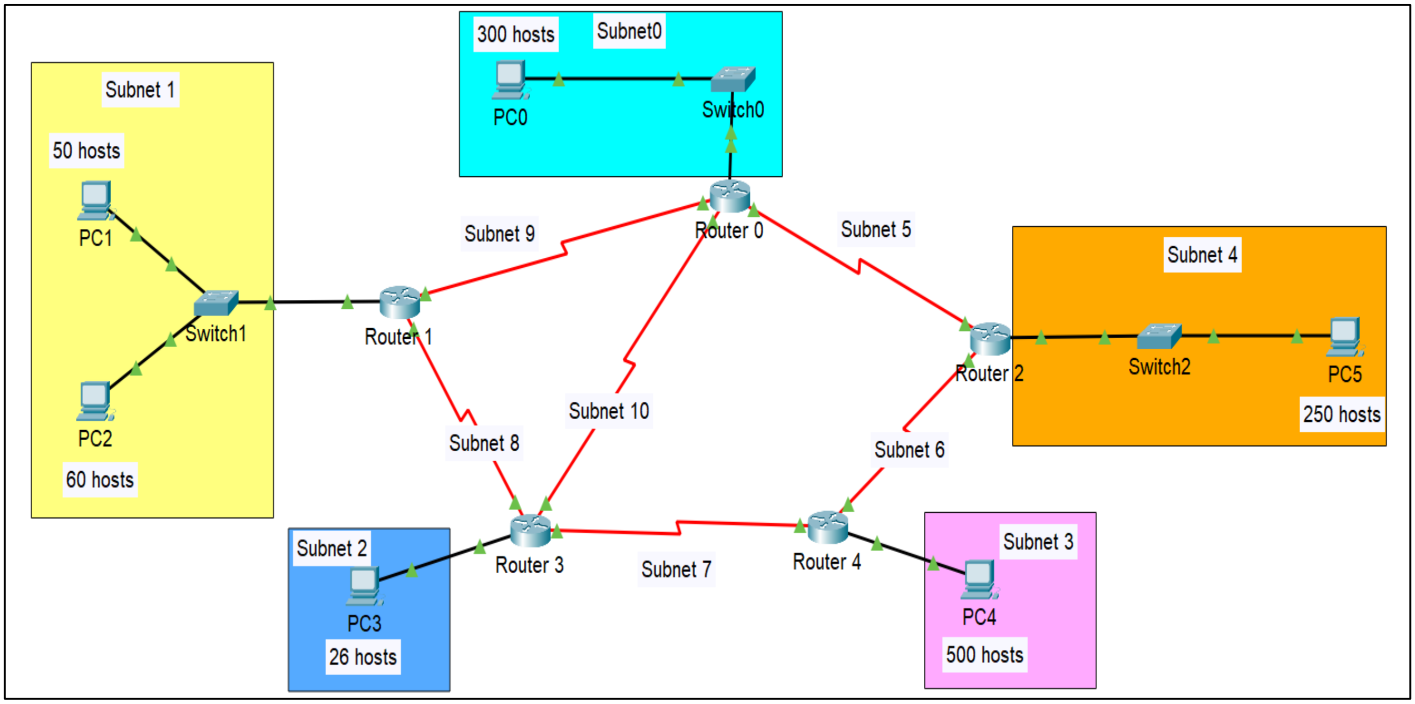


Figure 18. CIDR Address Allocation Example 3

Table 2. CIDR Address Allocation Example 3

Subnet #	Addresses Required	Number of required bits for hosts	2^(Number of required bits for hosts)	CIDR notation	Subnet mask	Network ID	Broadcast ID	Hosts range
Subnet 3	**500 +3**	**9**	**512**	**/23**	**255.255.254.0**	**200.50.100.0**	**200.50.101.255**	**200.50.100.1-200.50.101.254**
Subnet 0	**300+3**	**9**	**512**	**/23**	**255.255.254.0**	**200.50.102.0**	**200.50.103.255**	**200.50.102.1-200.50.103.254**
Subnet 4	**250+3**	**8**	**256**	**/24**	**255.255.255.0**	**200.50.104.0**	**200.50.104.255**	**200.50.104.1-200.50.104.254**

Subnet 1	**110+3**	**7**	**128**	**/25**	**255.255.255.128**	**200.50.105.0**	**200.50.105.127**	**200.50.105.1 – 200.50.105.126**
Subnet 2	**26+3**	**5**	**32**	**/27**	**255.255.255.224**	**200.50.105.128**	**200.50.105.159**	**200.50.105.129- 200.50.105.158**
Subnet 5	**2+2**	**2**	**4**	**/30**	**255.255.255.252**	**200.50.105.160**	**200.50.105.163**	**200.50.105.161- 200.50.105.162**
Subnet 6	**2+2**	**2**	**4**	**/30**	**255.255.255.252**	**200.50.105.164**	**200.50.105.167**	**200.50.105.165- 200.50.105.166**
Subnet 7	**2+2**	**2**	**4**	**/30**	**255.255.255.252**	**200.50.105.168**	**200.50.105.171**	**200.50.105.169- 200.50.105.170**
Subnet 8	**2+2**	**2**	**4**	**/30**	**255.255.255.252**	**200.50.105.172**	**200.50.105.175**	**200.50.105.173- 200.50.105.174**
Subnet 9	**2+2**	**2**	**4**	**/30**	**255.255.255.252**	**200.50.105.176**	**200.50.105.179**	**200.50.105.177- 200.50.105.178**
Subnet 10	**2+2**	**2**	**4**	**/30**	**255.255.255.252**	**200.50.105.180**	**200.50.105.183**	**200.50.105.181 200.50.105.182**

E. CIDR Address Allocation Example 4:

Do the following CIDR IPs, namely, 92.168.200.5/30 and 192.168.200.9/30 belong to the same network?

Referring to Figure 19, which illustrates the way of processing and solving such interesting question, we conclude that both addresses are therefore not in the same network.

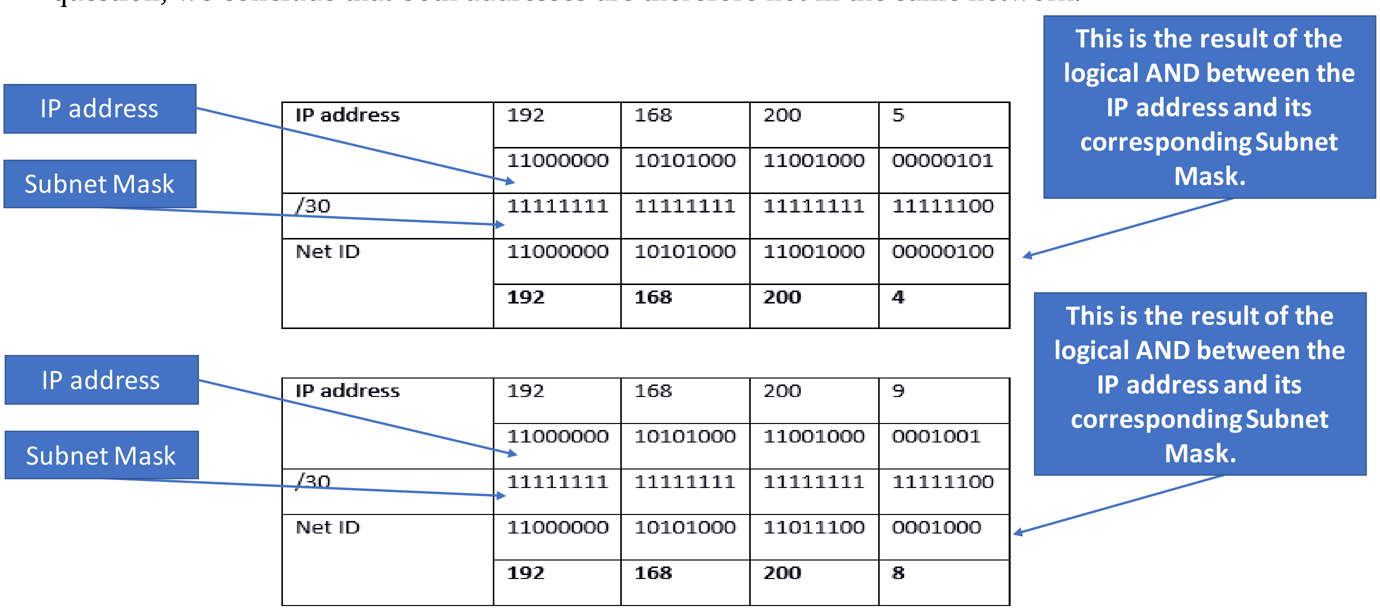


Figure 19. CIDR Address Allocation Example 4

Part III. Practical Demonstration of Subnetting and CIDR:

In this section, we will provide two comprehensive practical examples on how to do subnetting and CIDR for any given network, but before getting started, let's review the basic commands for this experiment. It is noteworthy to mention that we use the two methods to configure the router interface (i.e., Wizard configuration and CLI configuration).

A. Basic commands configurations:

Table 3 summarizes the basic CLI commands for this experiment.

Table 3. Basic CLI commands

Command	Usage
`Router>`	- User EXEC mode
`Router#`	- Privileged EXEC mode
`Router(config)#`	- Configuration mode
`Router(config-if)#`	- Interface level within configuration mode
`Router(config-if)#ip address [ip address] [subnet mask]`	- Configure the router interface with an IP address and subnet mask.
`Router(config-if)#clock rate [value]`	- Configure the interface with an appropriate clock rate value
`Router(config)#router rip`	- Activate the RIP routing protocol on the router
`Router(config-router)#`	- Routing engine level within configuration mode
`Router(config-router)#version 2`	- Use version 2 of RIP, it used in VLSM and CIDR.
`Router(config-router)#network [network address]`	-Configure the network address of directly connected interfaces.

B. Subnet Example Configuration:

Let's assume the example shown in the subnetting section, where an organization is assigned the network number **193.1.1.0/24 and it needs to define six subnets.** Figure 20 shows the topology that we need to configure. Moreover, Table 4 displays the addressing table of subnets.

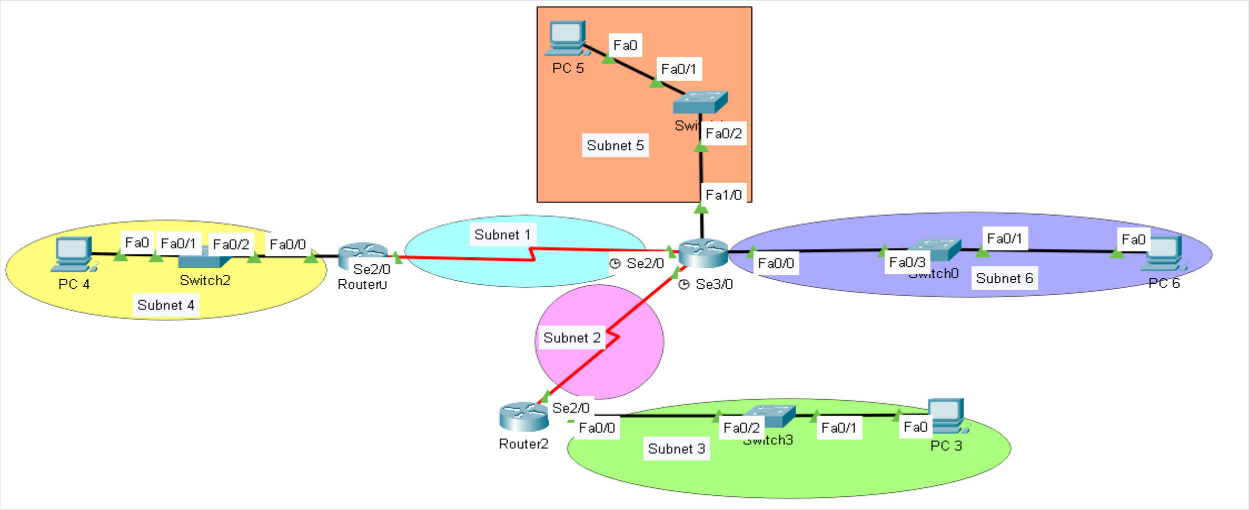


Figure 20. Network topology to be configured

Table 4. Addressing table for subnetting example

Subnet #	Network Address	Prefix length	Subnet mask	First assignable address	Last assignable address	Broadcast Address
Subnet 1	193.1.1.0	27	255.255.255.224	193.1.1.1	193.1.1.30	193.1.1.31
Subnet 2	193.1.1.32	27	255.255.255.224	193.1.1.33	193.1.1.62	193.1.1.63
Subnet 3	193.1.1.64	27	255.255.255.224	193.1.1.65	193.1.1.94	193.1.1.95
Subnet 4	193.1.1.96	27	255.255.255.224	193.1.1.97	193.1.1.126	193.1.1.127
Subnet 5	193.1.1.128	27	255.255.255.224	193.1.1.129	193.1.1.158	193.1.1.159
Subnet 6	193.1.1.160	27	255.255.255.224	193.1.1.161	193.1.1.190	193.1.1.191

You are required to adhere to the following steps:

- **For each LAN** (Subnet 3, Subnet 4, Subnet 6, and Subnet 6):
  1. Assign the first valid host address in each subnet to the LAN interface of each Router.
  2. Assign the last valid host address in each subnet to the PC in the corresponding subnet.
- **For each WAN** (Subnet 1 and Subnet 2):
  1. Assign the first valid host address in each subnet to the DCE WAN interface on Router.
  2. Assign the last valid host address in each subnet to the DTE WAN interface on Router.
- **Configure RIP v2 r**outing protocol on all routers in the topology.
- Test connectivity between all LANs to verify that the network is working properly by using ping command.

B.1 Configuration of PCs

To configure the PCs, you are required to adhere to the following steps:

1. Double click on PC, choose Desktop tab, and then double click on IP Configuration tab, as shown in Figure 21.

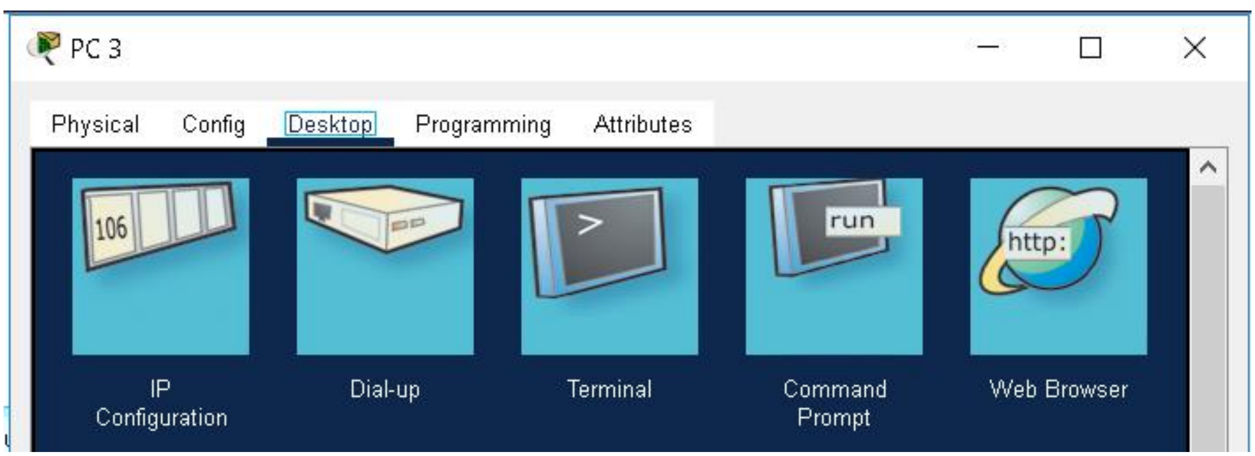


Figure 21. Entering the IP configuration tab for the PC on subnet 3

2. Enter the correct IPv4 address, subnet mask, and default gateway for Subnet 3, as shown in Figure 22.

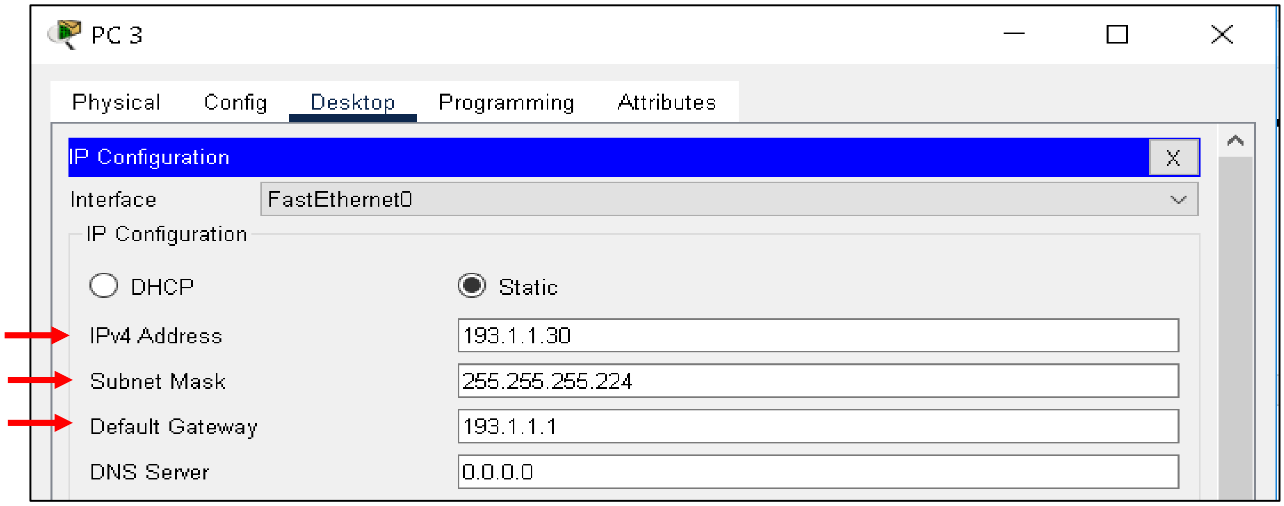


Figure 22. Configuring the IP address, subnet mask, and default gateway for the PC on subnet 3

3. Repeat the prior steps, to make the correct configuration to each PC (i.e., each subnet).

B.2 Configuration of router interfaces and RIP v2 routing protocol.

Router interfaces are divided into two parts: LAN interfaces and WAN interfaces. In these steps you are asked to configure these interfaces:

- ✓ Let's start to configure Router 0:
    1. Configure fast Ethernet 0/0.
    2. Configure Serial 2/0 (DTE).
    3. Enable RIP with the network addresses of subnets 1 and 4.
- ✓ Figure 23 shows the correct configuration.

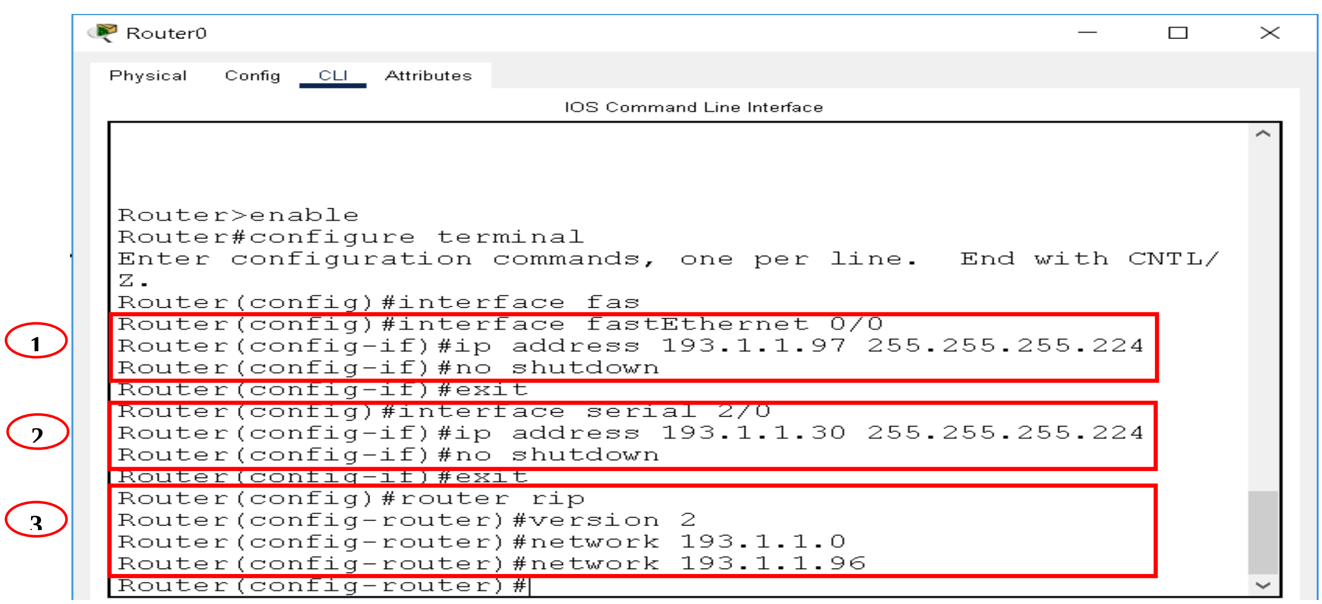


Figure 23. Configuring the router interfaces and RIP on router 0

Let’s start to configure Router 1 (f0/0, f1/0, s2/0, and s3/0):

1. Configure fast Ethernet 0/0 and fast Ethernet 1/0.
2. Configure Serial 2/0 and Serial 3/0 (DCE).
3. Enable RIP with the network addresses of subnets 1, 2, 4 and 5.

✓ Figure 24 shows the correct configuration.

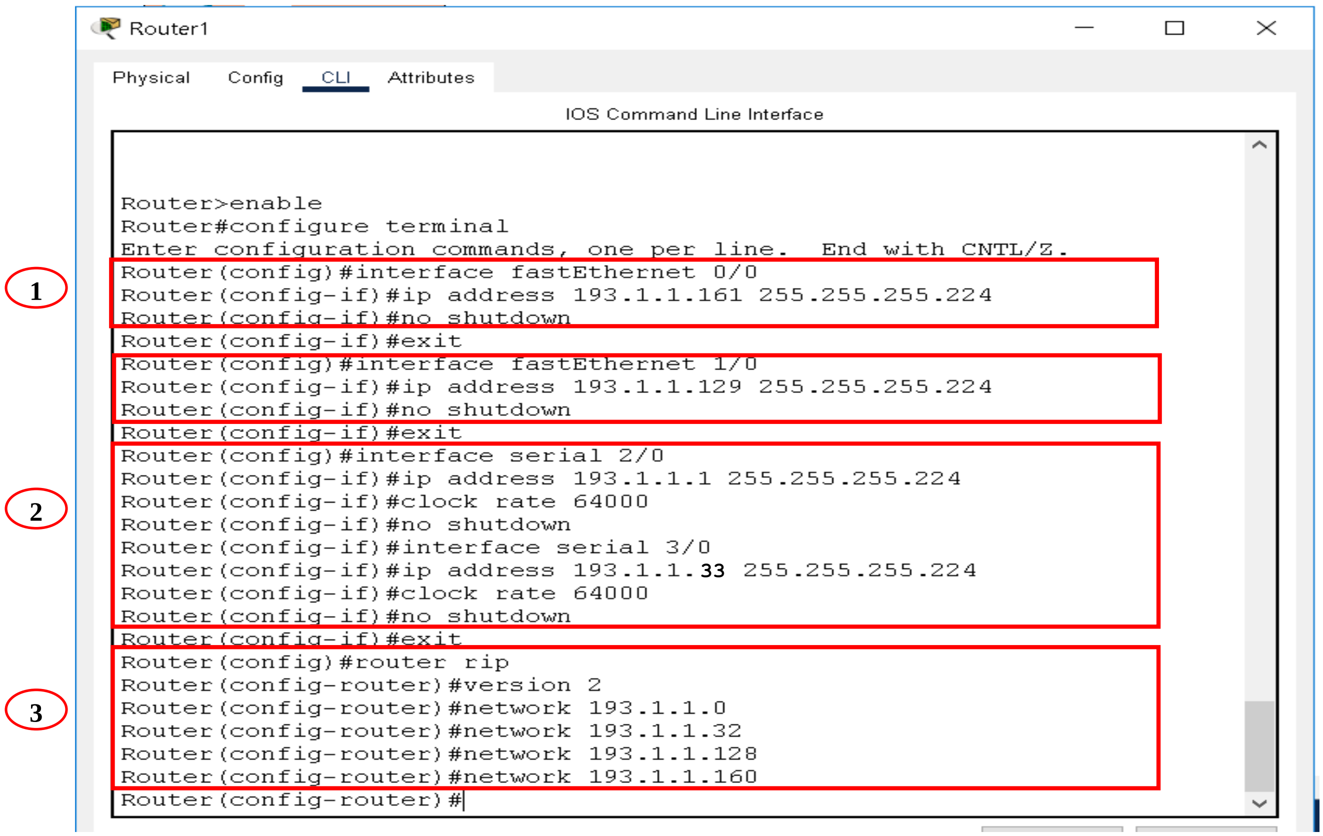


Figure 24. Configuring the router interfaces and RIP on router 1

Let’s start to configure Router 2 (f0/0, s2/0):

1. Configure fast Ethernet 0/0.
2. Configure Serial 2/0 (DTE).
3. Enable RIP with the network addresses of subnets 2 and 3.

Figure 25 shows the correct configuration.

Router2

Physical Config CLI Attributes

IOS Command Line Interface

```
Router>enable
Router#configure terminal
Enter configuration commands, one per line.  End with
CNTL/Z.
Router(config)#interface fa
Router(config)#interface fastEthernet 0/0
Router(config-if)#ip address 193.1.1.65 255.255.255.224
Router(config-if)#no shutdown
Router(config-if)#exit
Router(config)#interface serial 2/0
Router(config-if)#ip address 193.1.1.62 255.255.255.224
Router(config-if)#no shutdown
Router(config-if)#exit
Router(config)#router rip
Router(config-router)#version 2
Router(config-router)#network 193.1.1.32
Router(config-router)#network 193.1.1.64
Router(config-router)#
```

Figure 25. Configuring the router interfaces and RIP on router 2

B.3 Test the connectivity.

- ✓ Each PC must ping its default gateway, and each router must ping its neighbor router, and each PC must ping another PC in different networks, as shown in Figure 26.

PDU List Window

Fire	Last Status	Source	Destination	Type	Color	Time(sec)	Periodic	Num	Edit	Delete
	Successful	PC 4	Router0	ICMP		0.000	N	0	(edit)	
	Successful	PC 5	Router1	ICMP		0.000	N	1	(edit)	
	Successful	PC 6	Router1	ICMP		0.000	N	2	(edit)	
	Successful	PC 3	Router2	ICMP		0.000	N	3	(edit)	
	Successful	Router0	Router1	ICMP		0.000	N	4	(edit)	
	Successful	Router1	Router2	ICMP		0.000	N	5	(edit)	
	Successful	PC 3	PC 4	ICMP		0.000	N	6	(edit)	
	Successful	PC 3	PC 5	ICMP		0.000	N	7	(edit)	
	Successful	PC 3	PC 6	ICMP		0.000	N	8	(edit)	
	Successful	PC 4	PC 5	ICMP		0.000	N	9	(edit)	
	Successful	PC 4	PC 6	ICMP		0.000	N	10	(edit)	
	Successful	PC 5	PC 6	ICMP		0.000	N	11	(edit)	

Figure 26. The results of ping command after the configuration

C. CIDR Address Configuration Example:

Let's assume the example shown in the CIDR section, where an organization is assigned the network number 100.5.0.0/20. Figure 27 shows the topology that we need to configure. Moreover, Table 5 displays the addressing table of subnets.

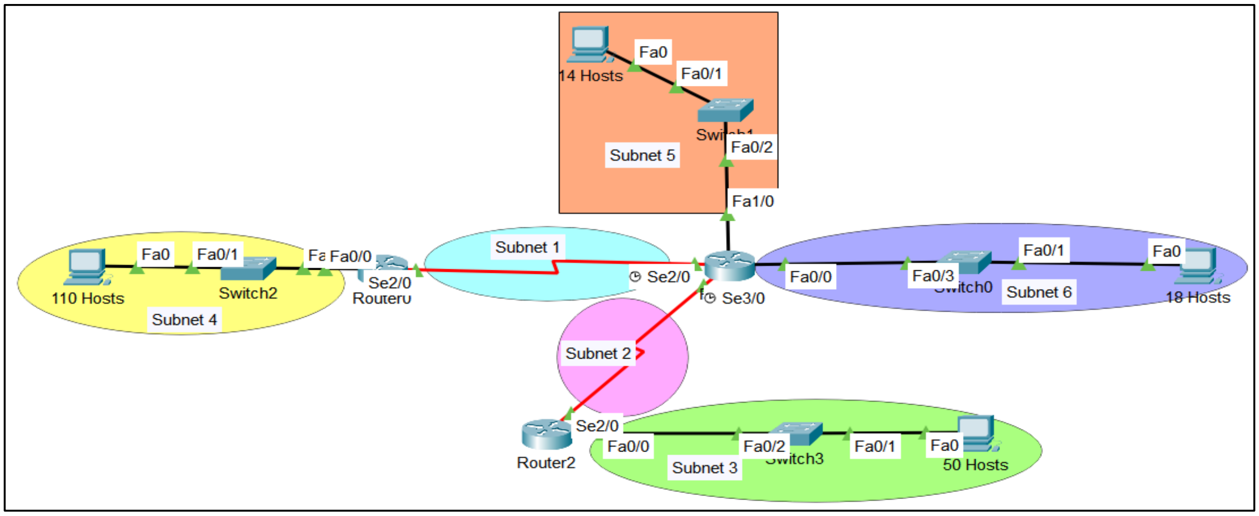


Figure 27. Network topology to be configured

Table 5. Addressing table for CIDR example

Subnet #	# of hosts	CIDR notation	Subnet mask	Network ID	Broadcast ID	Hosts range
Subnet 4	110	/25	255.255.255.128	100.5.0.0	100.5.0.127	100.5.0.1 -100.5.0.126
Subnet 3	50	/26	255.255.255.192	100.5.0.128	100.5.0.191	100.5.0.129 -100.5.0.190
Subnet 6	18	/27	255.255.255.224	100.5.0.192	100.5.0.223	100.5.0.193 -100.5.0.222
Subnet 5	14	/28	255.255.255.240	100.5.0.224	100.5.0.239	100.5.0.225 -100.5.0.238
Subnet 1	2	/30	255.255.255.252	100.5.0.240	100.5.0.243	100.5.0.241 -100.5.0.242
Subnet 2	2	/30	255.255.255.252	100.5.0.244	100.5.0.247	100.5.0.245 -100.5.0.246

You are required to adhere to the following steps:

- **For each LAN** (Subnet 3, Subnet 4, Subnet 5, and Subnet 6):
  3. Assign the first valid host address in each subnet to the LAN interface of each Router.
  4. Assign the last valid host address in each subnet to the PC in the corresponding subnet.
- **For each WAN** (Subnet 1 and Subnet 2):
  3. Assign the first valid host address in each subnet to the DCE WAN interface on the Router.
  4. Assign the last valid host address in each subnet to the DTE WAN interface on Router.
- **Configure RIP v2 r**outing protocol on all routers in the topology.
- Test connectivity between all LANs to verify that the network is working properly by using ping command.

C.1 Configuration of PCs:

To configure the PCs, you are required to adhere to the following steps:

1. Double click on PC, choose Desktop tab, and then double click on IP Configuration tab, as shown in Figure 28.

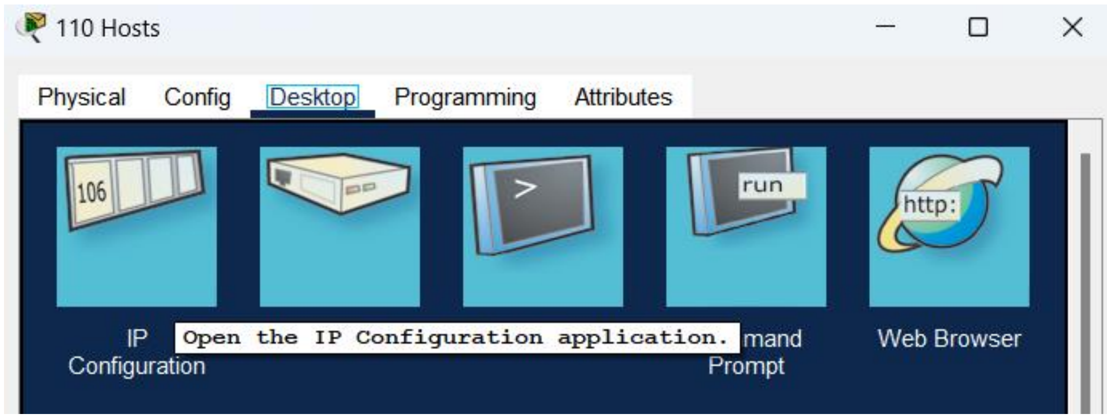


Figure 28. Entering the IP configuration tab for the PC.

2. Enter the correct IPv4 address, subnet mask, and default gateway for Subnet 4, as shown in Figure 29.

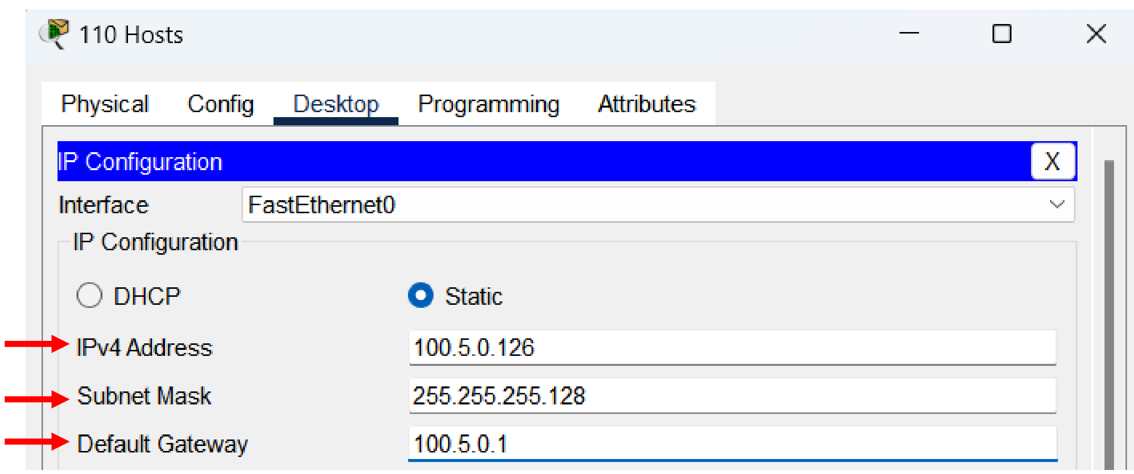


Figure 29. IPv4, Subnet mask, and default gateway configuration.

3. Repeat the prior steps, to make the correct configuration to each PC (i.e., each subnet).

C.2 Configuration of router interfaces and RIP v2 routing protocol.

Router interfaces are divided into two parts: LAN interfaces and WAN interfaces. In these steps you are asked to configure these interfaces:

- ✓ Let's start to configure Router 0:
  1. Configure fast Ethernet 0/0.
  2. Configure Serial 2/0 (DTE).
  3. Enable RIP with the network addresses of subnets 1 and 4.

Figure 30 shows the correct configuration.

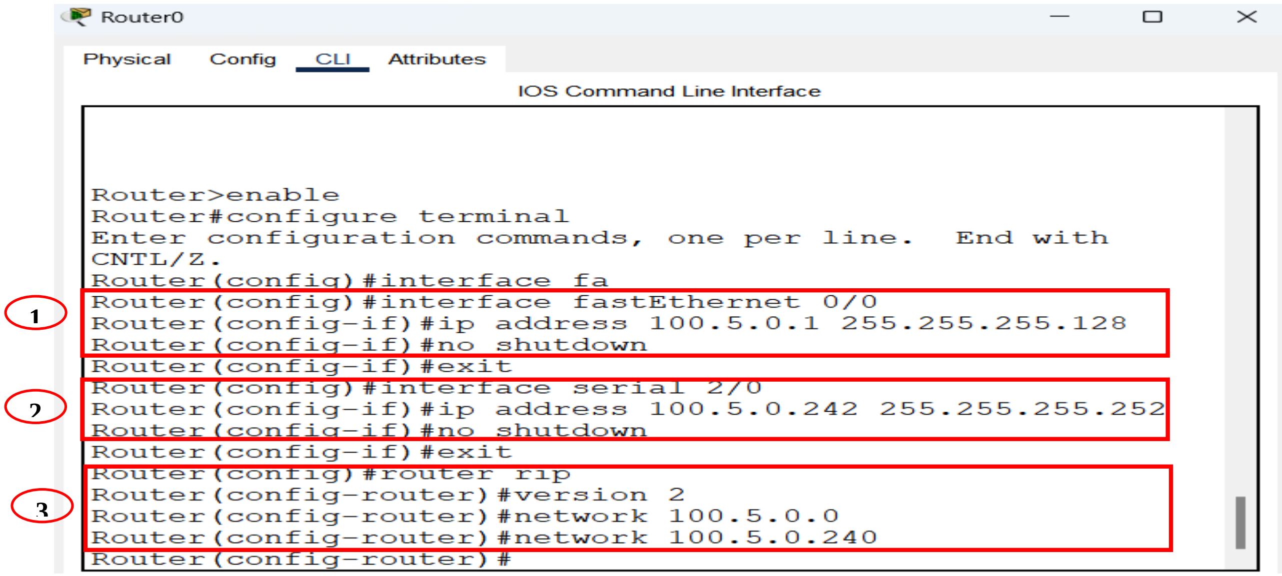


Figure 30. Configuring the router interfaces and RIP on router 0

Let's start to configure Router 1 (f0/0, f1/0, s2/0, and s3/0):

1. Configure fast Ethernet 0/0 and fast Ethernet 1/0.
2. Configure Serial 2/0 and Serial 3/0 (DCE).
3. Enable RIP with the network addresses of subnets 1, 2, 4 and 5.

Figure 31 shows the correct configuration.

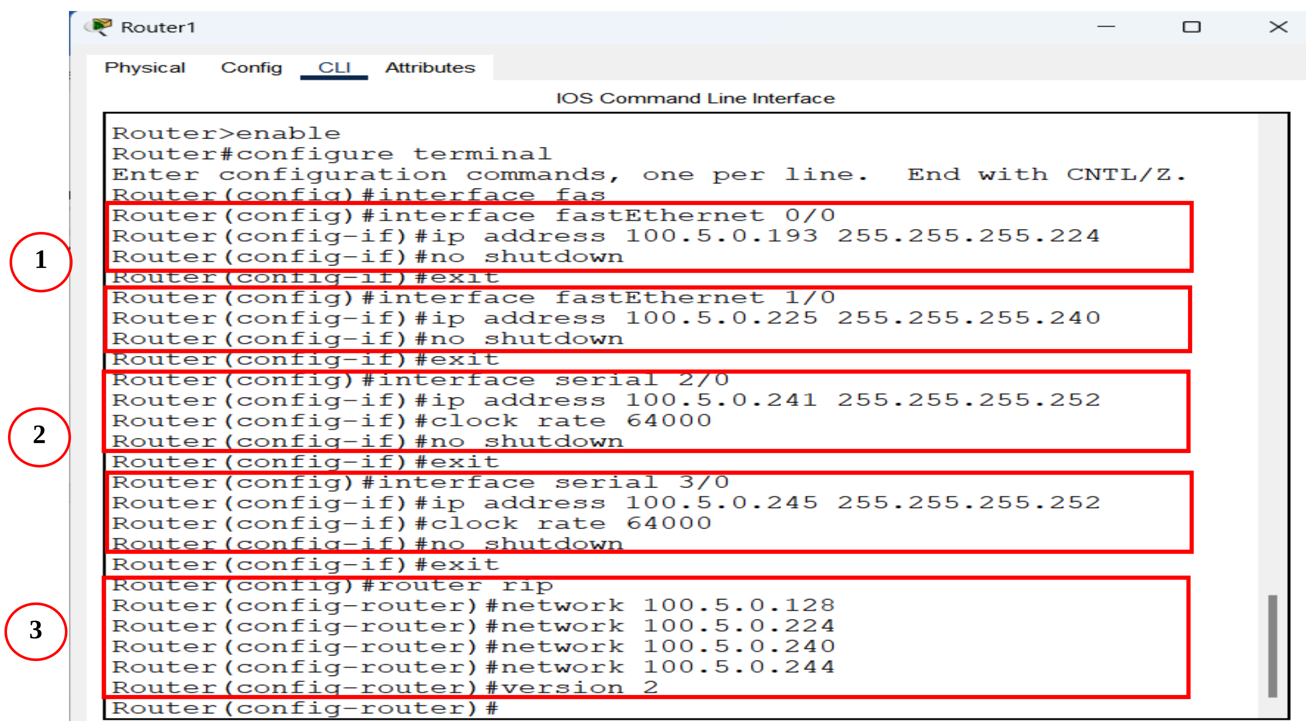


Figure 31. Configuring the router interfaces and RIP on router 1

Let’s start to configure Router 2 (f0/0, s2/0):

1. Configure fast Ethernet 0/0.
2. Configure Serial 2/0 (DTE).
3. Enable RIP with the network addresses of subnets 2 and 3.

Figure 32 shows the correct configuration.

Router2

Physical Config CLI Attributes

IOS Command Line Interface

```
Router>enable
Router#configure terminal
Enter configuration commands, one per line.  End with
CNTL/Z.
Router(config)#interface fa
Router(config)#interface fastEthernet 0/0
Router(config-if)#ip address 100.5.0.129 255.255.255.192
Router(config-if)#no shutdown
Router(config-if)#exit
Router(config)#interface serial 2/0
Router(config-if)#ip address 100.5.0.246 255.255.255.252
Router(config-if)#no shutdown
Router(config-if)#exit
Router(config)#router rip
Router(config-router)#version 2
Router(config-router)#network 100.5.0.128
Router(config-router)#network 100.5.0.244
Router(config-router)#
```

Figure 32. Configuring the router interfaces and RIP on router 2

C.3 Test the connectivity.

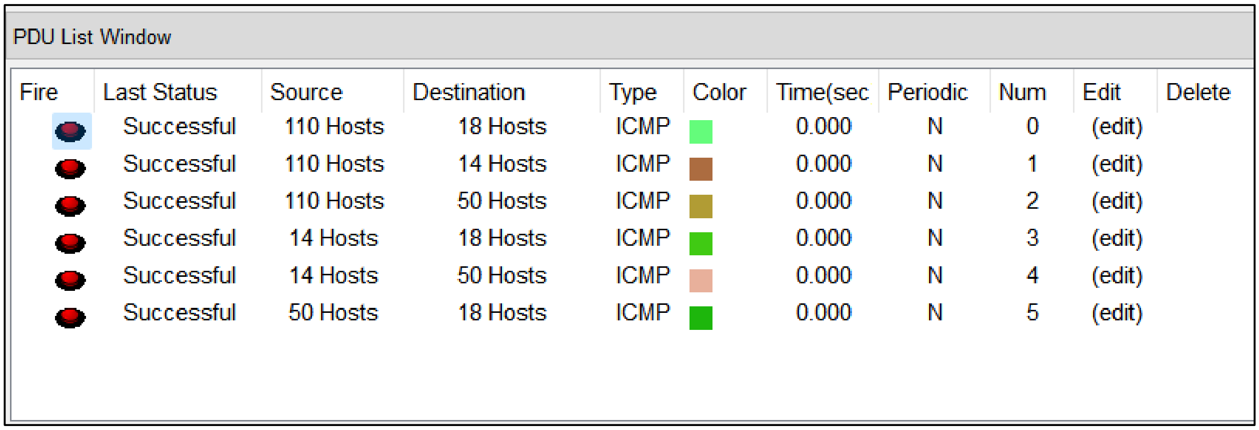
- ✓ Each PC must ping its default gateway, and each router must ping its neighbor router, as shown in Figure 33.

PDU List Window

Fire	Last Status	Source	Destination	Type	Color	Time(sec	Periodic	Num	Edit	Delete
	Successful	110 Hosts	Router0	ICMP		0.000	N	0	(edit)	
	Successful	14 Hosts	Router1	ICMP		0.000	N	1	(edit)	
	Successful	18 Hosts	Router1	ICMP		0.000	N	2	(edit)	
	Successful	50 Hosts	Router2	ICMP		0.000	N	3	(edit)	
	Successful	Router0	Router1	ICMP		0.000	N	4	(edit)	
	Successful	Router1	Router2	ICMP		0.000	N	5	(edit)	

Figure 33. The results of ping command after the configuration.

- ✓ Each PC can ping anther PC in different subnet, as shown in Figure 34.



PDU List Window

Fire	Last Status	Source	Destination	Type	Color	Time(sec	Periodic	Num	Edit	Delete
	Successful	110 Hosts	18 Hosts	ICMP		0.000	N	0	(edit)	
	Successful	110 Hosts	14 Hosts	ICMP		0.000	N	1	(edit)	
	Successful	110 Hosts	50 Hosts	ICMP		0.000	N	2	(edit)	
	Successful	14 Hosts	18 Hosts	ICMP		0.000	N	3	(edit)	
	Successful	14 Hosts	50 Hosts	ICMP		0.000	N	4	(edit)	
	Successful	50 Hosts	18 Hosts	ICMP		0.000	N	5	(edit)	

Figure 34. The results of ping command after the configuration.

- ✓ Ping the IP address of 18 Hosts PC from the command prompt of 118 Hosts PC, as shown in Figure 35.

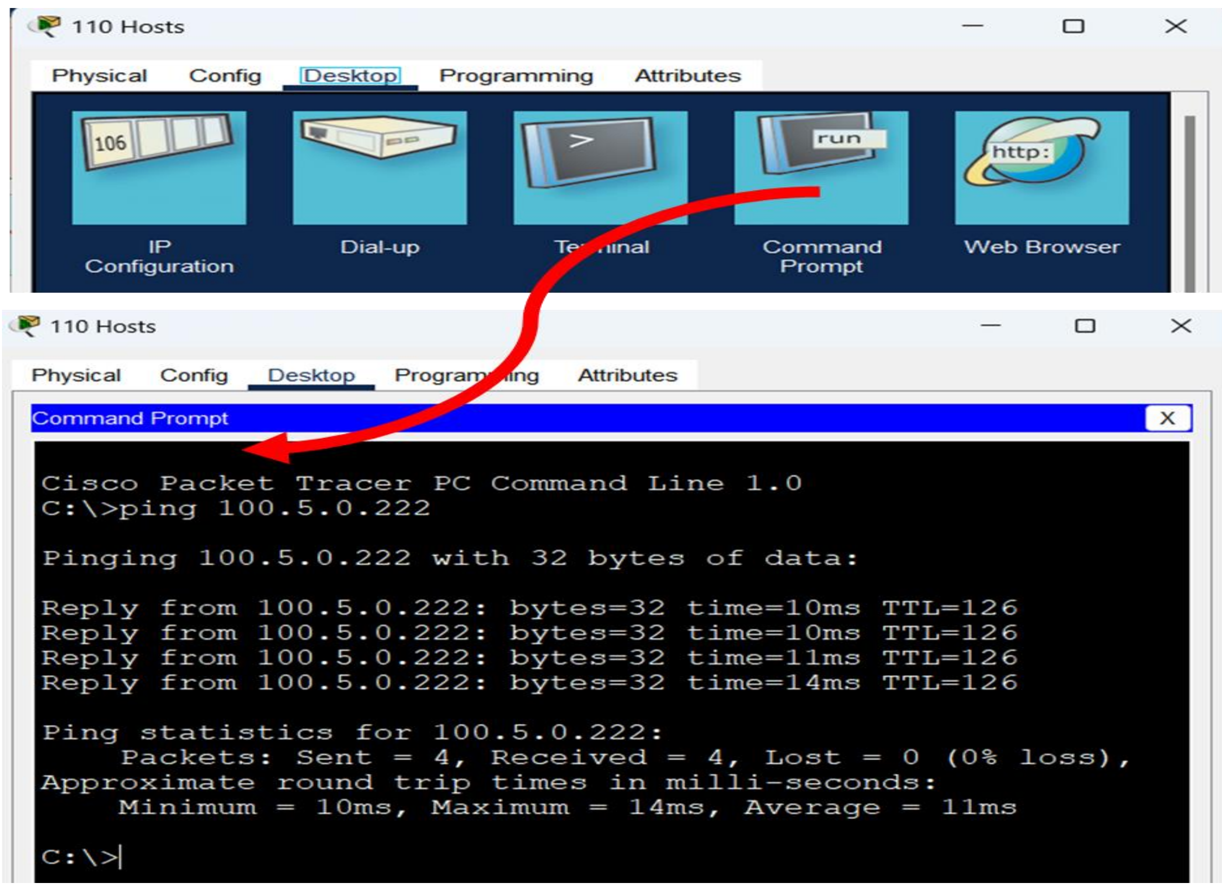


Figure 35. The results of ping command after the configuration.