Applied IPv4 Subnetting

1. Understanding the Purpose of the Subnet Mask

The following are the important key characteristics of the subnet mask and its responsibilities:

- An IPv4 subnet mask has the same length as an IPv4 address, which is 32 bits in length, while an IPv6 subnet mask is 128 bits in length.
- The subnet mask is used with an IPv4 or IPv6 address to help devices identify the network and host ports of the IP address.
- The subnet mask is used to help devices and network professionals determine the total number of IP addresses and usable (assignable) addresses within an IP network.
- Devices use the mask to determine whether a destination IP is in the same subnet or must be sent to a router.

Class	Default Subnet Mask
A	255.0.0.0
B	255.255.0.0
C	255.255.255.0

Figure 1: Default subnet masks

When working with classful addresses, an IPv4 Class A address such as 10.10.10.1 will be assigned a default subnet mask of 255.0.0.0. On the other hand, an IPv4 Class B address of 172.16.4.3 will be assigned a default subnet mask of 255.255.0.0 and an IPv4 Class C address of 192.168.1.20 will be assigned a default subnet mask of 255.255.255.0.

2. Delving into network prefixes and subnet masks

The “network prefix” is another way to represent the network portion of an IP address (for example /24 instead of 255.255.255.0).

- A subnet mask of 255.255.255.0 equals a /24 prefix.
- It is calculated based on the total number of bits, which are 1s within the subnet mask of the IPv4 or IPv6 address.
- Common masks & prefixes:
    - Class A: 255.0.0.0 - /8
    - Class B: 255.255.0.0 - /16
    - Class C: 255.255.255.0 - /24

Class A - 255.0.0.0	11111111	00000000	00000000	00000000
Class B - 255.255.0.0	11111111	11111111	00000000	00000000
Class C - 255.255.255.0	11111111	11111111	11111111	00000000

Figure 2: Subnet masks

- Using prefix notation simplifies planning and documentation.

The subnet mask helps network professionals and devices determine the network and host portions of an IP address. The network portion of the IP address is the same for all devices within the same IP network, while the host portion of the IP address is unique to the interface of the end device only.

10.0.0.0	00001010	00000000	00000000	00000000
255.0.0.0	11111111	00000000	00000000	00000000

Figure 3: network ID of Class A

Sometimes networks are using custom subnet masks such as 255.255.224.0. To calculate the network prefix, simply convert each octet from decimal into binary, as shown in the following steps:

- Converting the first octet, 255, into binary will be 11111111.
- Converting the second octet, 255, into binary will be 11111111.
- Converting the third octet, 224, into binary will be 1110000.
- Converting the fourth octet, 0, into binary will be 0000000.
- Lastly, calculating the sum of all bits that are 1s from each octet will provide a network prefix of /19.

192.168.1.54	11000000	10101000	00000001	0011 0110
255.255.255.240	11111111	11111111	11111111	1111 0000

Figure 4: Custom subnet mask

3. Determining the network ID

Let’s take a look at the following network topology, which contains a computer, a switch, and a router:

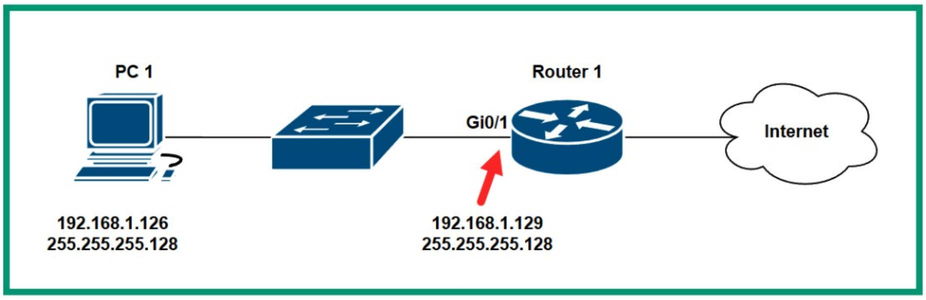

Figure 5: Network topology

As shown in the preceding diagram, there's a small network that contains a computer with a label of PC 1 that has an IPv4 address of 192.168.1.126 that uses a custom subnet mask of 255.255.255.128. On the same network, there's a router as the default gateway that provides access to the internet, which is configured using an IPv4 address of 192.168.1.129 with a custom subnet mask of 255.255.255.128.However, looking closely at the IPv4 addresses on both PC 1 and Router 1, it seems like both devices are on the same IPv4 network, right? What if I told you that these two devices are not on the same IP network and won't be able to communicate with each other?

To determine why PC 1 and Router 1 will not be able to communicate with each other, you need to calculate the network IDs of each device.

Step-by-Step Method:

1. Convert IP address to binary
2. Convert subnet mask to binary
3. Perform logical AND operation
4. Convert result back to decimal = Network ID

Logical AND Rules:

- 1 AND 1 = 1
- 1 AND 0 = 0
- 0 AND 1 = 0
- 0 AND 0 = 0

IP address	**11000000.10101000.00000001.01111110**
Subnet mask	**11111111.11111111.11111111.10000000**
Network ID	**11000000.10101000.00000001.00000000**

Figure 6: PC 1's Network ID

IP address	**11000000.10101000.00000001.10000001**
Subnet mask	**11111111.11111111.11111111.10000000**
Network ID	**11000000.10101000.00000001.10000000**

Figure 7: The router's network ID

- Converting the binary notation into decimal will provide the network ID of the PC as 192.168.1.0/25.
- Converting the binary notation into decimal will provide the network ID of the router as 192.168.1.128/25.

4. Understanding the importance of subnetting

- Imagine you're a network professional for an organization that has six branch offices within various cities of your country. Each branch office has no more than 50 end devices that need an IPv4 address.
  - Branch office 1: 192.168.0.0/24
  - Branch office 2: 192.168.1.0/24
  - Branch office 3: 192.168.2.0/24
  - Branch office 4: 192.168.3.0/24
  - Branch office 5: 192.168.4.0/24
  - Branch office 6: 192.168.5.0/24
- While this IPv4 addressing scheme will work, it's not the most efficient scheme as there will be a lot of wastage of IPv4 addresses within each of the six branch offices.
  1. Total IPv4 addresses = 2^H (The H value represents the number of host bits)
  2. Now, let's determine the number of host bits with any of the private Class C networks:

192.168.0.0	11000000	10101000	00000000	00000000
255.255.255.0	11111111	11111111	11111111	00000000

Figure 8: Determining host bits

  3. Next, substituting the value of H = 8 in our formula provides, there are a total of 256 IPv4 addresses within a Class C.
  4. Usable IPv4 address = $2^H - 2$
     $= 2^8 - 2$
     $= 256 - 2$
     $= 254$
- Therefore, using classful addressing with default subnet masks isn't the most suitable solution in some cases.
- Using a classless addressing scheme allows network professionals to create smaller networks with custom subnet masks with fewer usable IP addresses to avoid wastage by using a technique known as **subnetting**.
- Subnetting provides the following benefits to organizations and network professionals:
  - To efficiently distribute IP addresses with the least wastage
  - To create more networks with smaller broadcast domains

5. IPv4 subnetting and VLSM

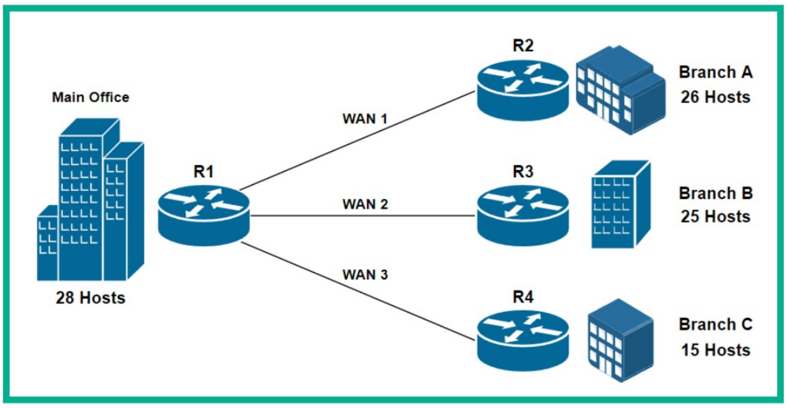

Figure 9: Network topology

Step 1: Determining the Appropriate IPv4 Block

- Analyze total host requirements across all network segments
- Select a network block that can accommodate all subnets
- Consider both current needs and future growth

	1st Octet	2nd Octet	3rd Octet	4th Octet
Class A - 255.0.0.0	11111111	00000000	00000000	00000000
Class B - 255.255.0.0	11111111	11111111	00000000	00000000
Class C - 255.255.255.0	11111111	11111111	11111111	00000000

Figure 10: Subnet masks

- Using the 2^H formula to calculate the total number of IPv4 addresses per class, the following results show the total size of each network per address class:
  - Class A = 2^{24} = 16,777,216 total IP addresses
  - Class B = 2^{16} = 65,536 total IP addresses
  - Class C = 2^{8} = 256 total IP addresses
- Therefore, using the $2^H – 2$ formula, to calculate the number of usable IPv4 addresses, the following results show the available IPv4 addresses per address class:
  - Class A = 2^{24} – 2 = 16,777,214 usable IP addresses
  - Class B = 2^{16} – 2 = 65,534 usable IP addresses
  - Class C = 2^{8} – 2 = 254 usable IP addresses
- Since we have already determined the number of networks within the organization, the following is a further breakdown listing the size of each network:
  - Main Office LAN: 28 hosts

   - Branch A LAN: 26 hosts
   - Branch B LAN: 25 hosts
   - Branch C LAN: 15 hosts
   - WAN 1 (R1-R2): 2 IPs are needed
   - WAN 2 (R2-R3): 2 IPs are needed
   - WAN 3 (R3-R4): 2 IPs are needed

Step 2: Creating New Subnets (Subnetworks)

- Calculate required subnet sizes based on host counts
- Determine appropriate subnet masks for each requirement
- Create logical subnet address ranges
- Let's get started by using the first available Class C address block of 192.168.0.0/24

Network block	11000000 . 10101000 . 00000000 . 00000000
Subnet mask	11111111 . 11111111 . 11111111 . 00000000

Figure 11: Network block and default subnet mask

- To create subnetworks from a network block, you will need to convert host bits into network bits.
- The following formula is used to determine the number of new networks:
  - Number of networks = 2^N
- Converting three host bits into network bits will provide eight new subnetworks(2^3=8).

Network block	11000000 . 10101000 . 00000000 . 00000000
Subnet mask	11111111 . 11111111 . 11111111 . 11100000

Figure 12: Remaining host bits

- Lets determine total number of IPv4 addresses per network using the following formula:
  - Total IPv4 addresses = 2^H

    $= 2^5 = 32$
  - Usable IPv4 address = $2^H - 2$

    $= 32 - 2 = 30$

- We have found a workable solution of using a Class C address block and using mathematical calculations.
- The new subnet mask is created for each of the new subnets, so they will be using 255.255.255.224 with a network prefix of /27.

Subnet 1	11000000 . 10101000 . 00000000 . 00000000	192.168.0.0/27
Subnet 2	11000000 . 10101000 . 00000000 . 00100000	192.168.0.32/27
Subnet 3	11000000 . 10101000 . 00000000 . 01000000	192.168.0.64/27
Subnet 4	11000000 . 10101000 . 00000000 . 01100000	192.168.0.96/27
Subnet 5	11000000 . 10101000 . 00000000 . 10000000	192.168.0.128/27
Subnet 6	11000000 . 10101000 . 00000000 . 10100000	192.168.0.160/27
Subnet 7	11000000 . 10101000 . 00000000 . 11000000	192.168.0.192/27
Subnet 8	11000000 . 10101000 . 00000000 . 11100000	192.168.0.224/27

Figure 13: New subnets

Step 3: Assigning Subnets to Each Network

- Allocate specific subnets to departments, locations, or functions
- Document all assignments clearly
- Reserve addresses for future expansion
    - To determine the first usable IP address within a subnet, use the network ID + 1 formula. In binary notation, the first bit from the left is set to 1.
    - To calculate the broadcast address within a subnet, use the Next network ID – 1 formula. In binary notation, it's when all the host bits are 1s within the address.
    - To calculate the last usable IP address within a subnet, use the Broadcast Address – 1 formula. In binary notation, it's where all the host bits are 1s except the bit to the farthest right.
- Using these guidelines, let's calculate the network range first four subnets and assign it to the main office and three brach offices.

Subnet 1	11000000 . 10101000 . 00000000 . 00000000	192.168.0.0/27
First usable IP	11000000 . 10101000 . 00000000 . 00000001	192.168.0.1/27
Last usable IP	11000000 . 10101000 . 00000000 . 00011110	192.168.0.30/27
Broadcast	11000000 . 10101000 . 00000000 . 00011111	192.168.0.31/27

Figure 14: Subnet 1 network range

Subnet 2	11000000 . 10101000 . 00000000 . 00100000	192.168.0.32/27
First usable IP	11000000 . 10101000 . 00000000 . 00100001	192.168.0.33/27
Last usable IP	11000000 . 10101000 . 00000000 . 00111110	192.168.0.62/27
Broadcast	11000000 . 10101000 . 00000000 . 00111111	192.168.0.63/27

Figure 15: Subnet 2 network range

Subnet 3	11000000 . 10101000 . 00000000 . 01000000	192.168.0.64/27
First usable IP	11000000 . 10101000 . 00000000 . 01000001	192.168.0.65/27
Last usable IP	11000000 . 10101000 . 00000000 . 01011110	192.168.0.94/27
Broadcast	11000000 . 10101000 . 00000000 . 01011111	192.168.0.95/27

Figure 16: Subnet 3 network range

Subnet 4	11000000 . 10101000 . 00000000 . 01100000	192.168.0.96/27
First usable IP	11000000 . 10101000 . 00000000 . 01100001	192.168.0.97/27
Last usable IP	11000000 . 10101000 . 00000000 . 01111110	192.168.0.126/27
Broadcast	11000000 . 10101000 . 00000000 . 01111111	192.168.0.127/27

Figure 17: Subnet 4 network range

- However, three WAN networks are used to interconnect each branch router to the main office router.
- These WAN links are point-to-point connections that require only two IP addresses per WAN connection.
- If we were to assign the remaining subnets to any of the WAN networks, there will be a lot of wastage of IPv4 addresses.
- To further avoid wastage of IPv4 addresses within our new subnets, we can use a technique known as Variable Length Subnet Masking (VLSM), which allows us to further break down a subnet into smaller subnetworks.

Subnet 5	11000000 . 10101000 . 00000000 . 10000000	192.168.0.128/27
Subnet 6	11000000 . 10101000 . 00000000 . 10100000	192.168.0.160/27
Subnet 7	11000000 . 10101000 . 00000000 . 11000000	192.168.0.192/27
Subnet 8	11000000 . 10101000 . 00000000 . 11100000	192.168.0.224/27

Figure 18: Unallocated networks

- Subnet 5, 6 and 7 will be documented and reserved for future office locations.
- Subnet 8 will be broken down using VLSM to create smaller subnetworks.

Step 4: Performing Variable-Length Subnet Masking (VLSM)

- Fine-tune subnet sizes to match exact requirements.
- Assign custom masks to each network segment.
- Ensure no address space overlap between subnets.
- To get started, let’s convert the 192.168.0.224/27 subnet into binary notation to visualize the network and host portions of the address.

Network ID	11000000 . 10101000 . 00000000 . 11100000	192.168.0.224
Subnet mask	11111111 . 11111111 . 11111111 . 11100000	255.255.255.224

Figure 19: Binary notation

- Number of usable IPv4 addresses = $2^H - 2$
    - for H=1, $2^1 - 2 = 0$
    - for H=2, $2^2 - 2 = 2$
- This leaves us with three remaining bits within the host portion of the 192.168.0.224/27 network block.
- Number of networks = $2^N = 2^3 = 8$
- Converting three host bits into network bits will provide us with a total of eight new subnets from the 192.168.0.224/27 network block.
- Each subnet will contain a total of four IPv4 addresses inclusive of two usable addresses.

VLSM Subnet 1	11000000 . 10101000 . 00000000 . 11100000	192.168.0.224/30
VLSM Subnet 2	11000000 . 10101000 . 00000000 . 11100100	192.168.0.228/30
VLSM Subnet 3	11000000 . 10101000 . 00000000 . 11101000	192.168.0.232/30
VLSM Subnet 4	11000000 . 10101000 . 00000000 . 11101100	192.168.0.236/30
VLSM Subnet 5	11000000 . 10101000 . 00000000 . 11110000	192.168.0.240/30
VLSM Subnet 6	11000000 . 10101000 . 00000000 . 11110100	192.168.0.244/30
VLSM Subnet 7	11000000 . 10101000 . 00000000 . 11111000	192.168.0.248/30
VLSM Subnet 8	11000000 . 10101000 . 00000000 . 11111100	192.168.0.252/30

Figure 20: VLSM networks

- The preceding table shows the eight new networks that were created from the 192.168.0.224 network block.

- The following are the calculations used to determine the network range of the first three subnet that will be assigned between the main office router and Branch (A,B,C)routers.

Subnet 1	11000000 . 10101000 . 00000000 . 11100000	192.168.0.224/30
First usable IP	11000000 . 10101000 . 00000000 . 11100001	192.168.0.225/30
Last usable IP	11000000 . 10101000 . 00000000 . 11100010	192.168.0.226/30
Broadcast	11000000 . 10101000 . 00000000 . 11100011	192.168.0.227/30

Figure 21: WAN 1 allocation(Main Office to Branch A)

Subnet 2	11000000 . 10101000 . 00000000 . 11100100	192.168.0.228/30
First usable IP	11000000 . 10101000 . 00000000 . 11100101	192.168.0.229/30
Last usable IP	11000000 . 10101000 . 00000000 . 11100110	192.168.0.230/30
Broadcast	11000000 . 10101000 . 00000000 . 11100111	192.168.0.231/30

Figure 22: WAN 2 allocation(Main Office to Branch B)

Subnet 3	11000000 . 10101000 . 00000000 . 11101000	192.168.0.232/30
First usable IP	11000000 . 10101000 . 00000000 . 11101001	192.168.0.233/30
Last usable IP	11000000 . 10101000 . 00000000 . 11101010	192.168.0.234/30
Broadcast	11000000 . 10101000 . 00000000 . 11101011	192.168.0.235/30

Figure 23: WAN 3 allocation(Main Office to Branch C)

- The following five subnets will be documented and reserved within the company to support future growth.

VLSM Subnet 4	11000000 . 10101000 . 00000000 . 11101100	192.168.0.236/30
VLSM Subnet 5	11000000 . 10101000 . 00000000 . 11110000	192.168.0.240/30
VLSM Subnet 6	11000000 . 10101000 . 00000000 . 11110100	192.168.0.244/30
VLSM Subnet 7	11000000 . 10101000 . 00000000 . 11111000	192.168.0.248/30
VLSM Subnet 8	11000000 . 10101000 . 00000000 . 11111100	192.168.0.252/30

Figure 24: Reserved WAN subnets

- Lastly, the following table shows the allocation for networks with a /27 network prefix:

Subnet 1	Main Office LAN	192.168.0.0/27
Subnet 2	Branch A LAN	192.168.0.32/27
Subnet 3	Branch B LAN	192.168.0.64/27
Subnet 4	Branch C LAN	192.168.0.96/27
Subnet 5	Reserved	192.168.0.128/27
Subnet 6	Reserved	192.168.0.160/27
Subnet 7	Reserved	192.168.0.192/27
Subnet 8	No longer available	192.168.0.224/27

Figure 25: Subnets for LANs

- The following table shows the allocation for networks that use the /30 network prefix:

VLSM Subnet 1	WAN 1	192.168.0.224/30
VLSM Subnet 2	WAN 2	192.168.0.228/30
VLSM Subnet 3	WAN 3	192.168.0.232/30
VLSM Subnet 4	Reserved	192.168.0.236/30
VLSM Subnet 5	Reserved	192.168.0.240/30
VLSM Subnet 6	Reserved	192.168.0.244/30
VLSM Subnet 7	Reserved	192.168.0.248/30
VLSM Subnet 8	Reserved	192.168.0.252/30

Figure 26: Subnets for WANs