Introduction to Networking

CTO43-3-1 Version VD1

Subnetting IP Networks

ASIA PACIFIC UNIVERSITY OF TECHNOLOGY & INNOVATION

Subnetting IP Networks

Topic & Structure of the Lesson

Topic Title	Topic Objective
Network Segmentation	Explain how subnetting segments a network to enable better communication.
Subnet an IPv4 Network	Calculate IPv4 subnets for /24 prefix.
IPv4 Issues	Explain the need for IPv6 addressing.
Subnet an IPv6	Implement a subnetted IPv6 addressing scheme.

Key Terms You Must Be Able To Use

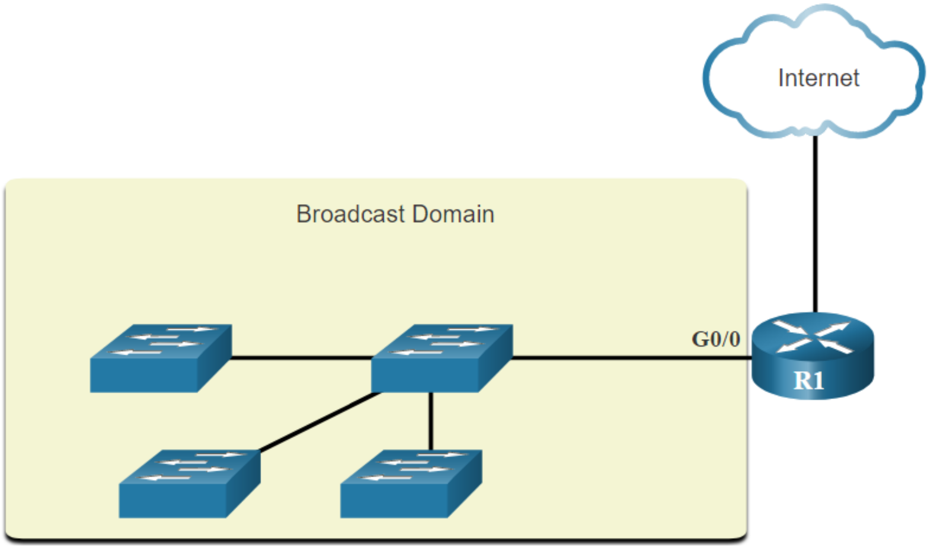
If you have mastered this topic, you should be able to use the following terms correctly in your exams:

- **Network Segmentation/ VLSM**
- **Subnet Mask and IPv4**
- **Subnet an IPv6 Network**

Network Segmentation

Broadcast Domains and Segmentation

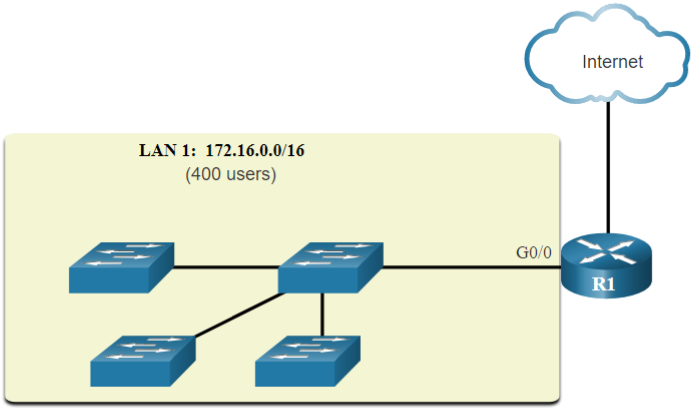
- Many protocols use broadcasts or multicasts (e.g., ARP use broadcasts to locate other devices, hosts send DHCP discover broadcasts to locate a DHCP server.)
- Switches propagate broadcasts out all interfaces except the interface on which it was received.

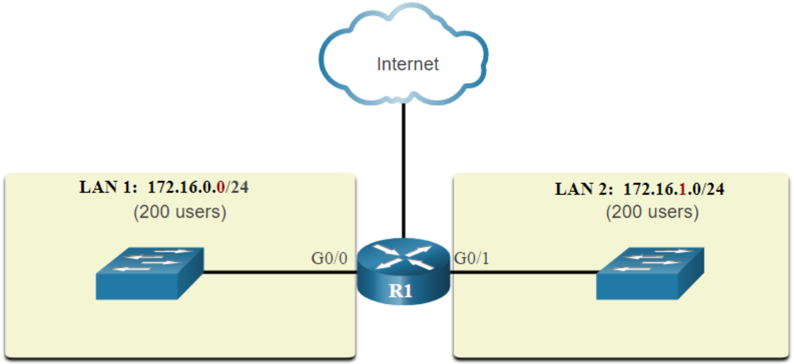


- The only device that stops broadcasts is a router.
- Routers do not propagate broadcasts.
- Each router interface connects to a broadcast domain and broadcasts are only propagated within that specific broadcast domain.

Problems with Large Broadcast Domains

- A problem with a large broadcast domain is that these hosts can generate excessive broadcasts and negatively affect the network.
- The solution is to reduce the size of the network to create smaller broadcast domains in a process called subnetting.
- Dividing the network address 172.16.0.0 /16 into two subnets of 200 users each: 172.16.0.0 /24 and 172.16.1.0 /24.
- Broadcasts are only propagated within the smaller broadcast domains.

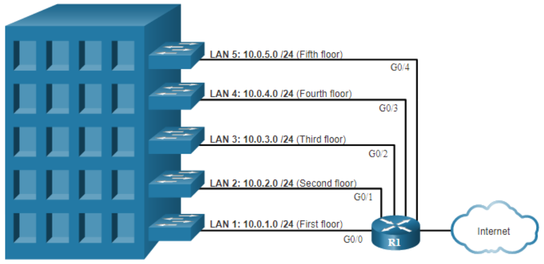




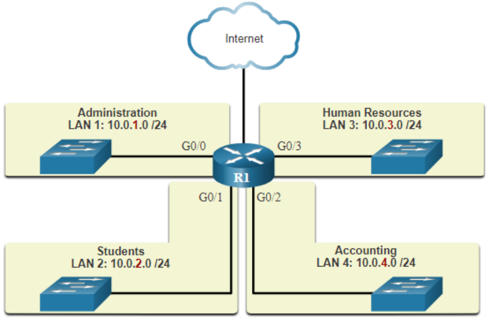
Reasons for Segmenting Networks

- Subnetting reduces overall network traffic and improves network performance.
- It can be used to implement security policies between subnets.
- Subnetting reduces the number of devices affected by abnormal broadcast traffic.
- Subnets are used for a variety of reasons including by:

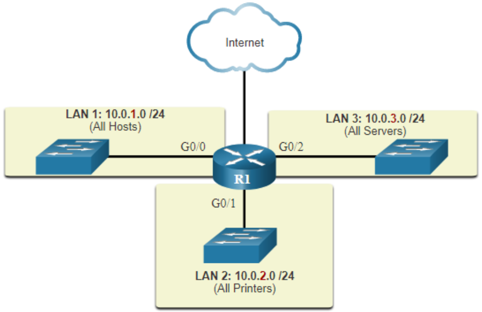
Location



Group or Function

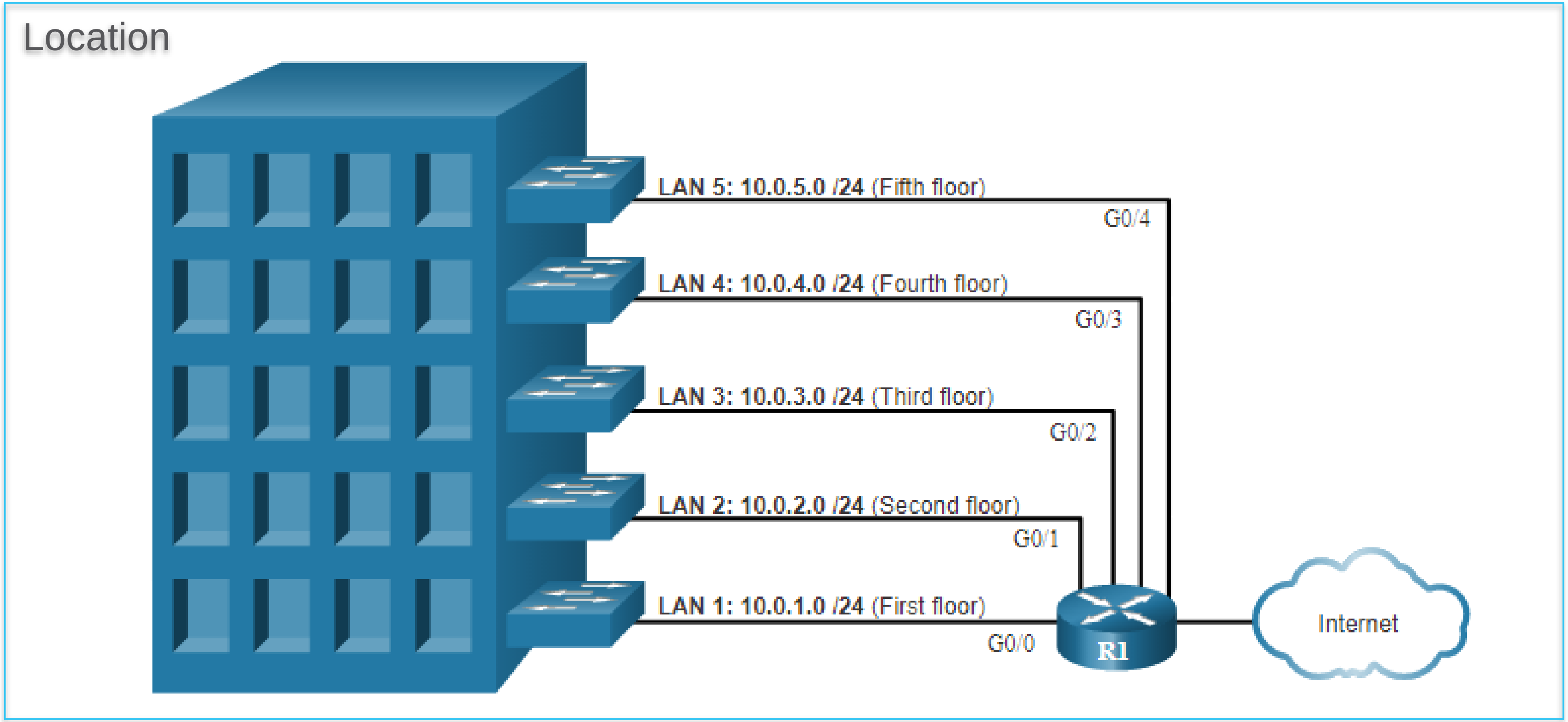


Device Type



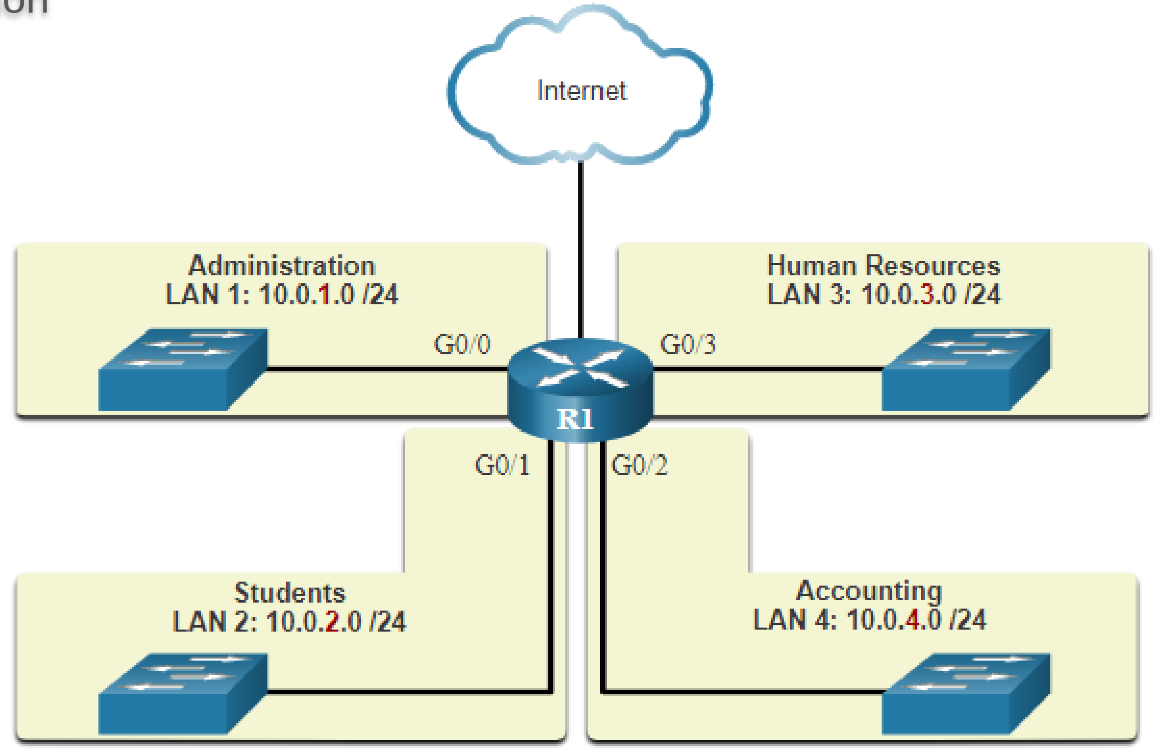
Network Segmentation

Reasons for Segmenting Networks



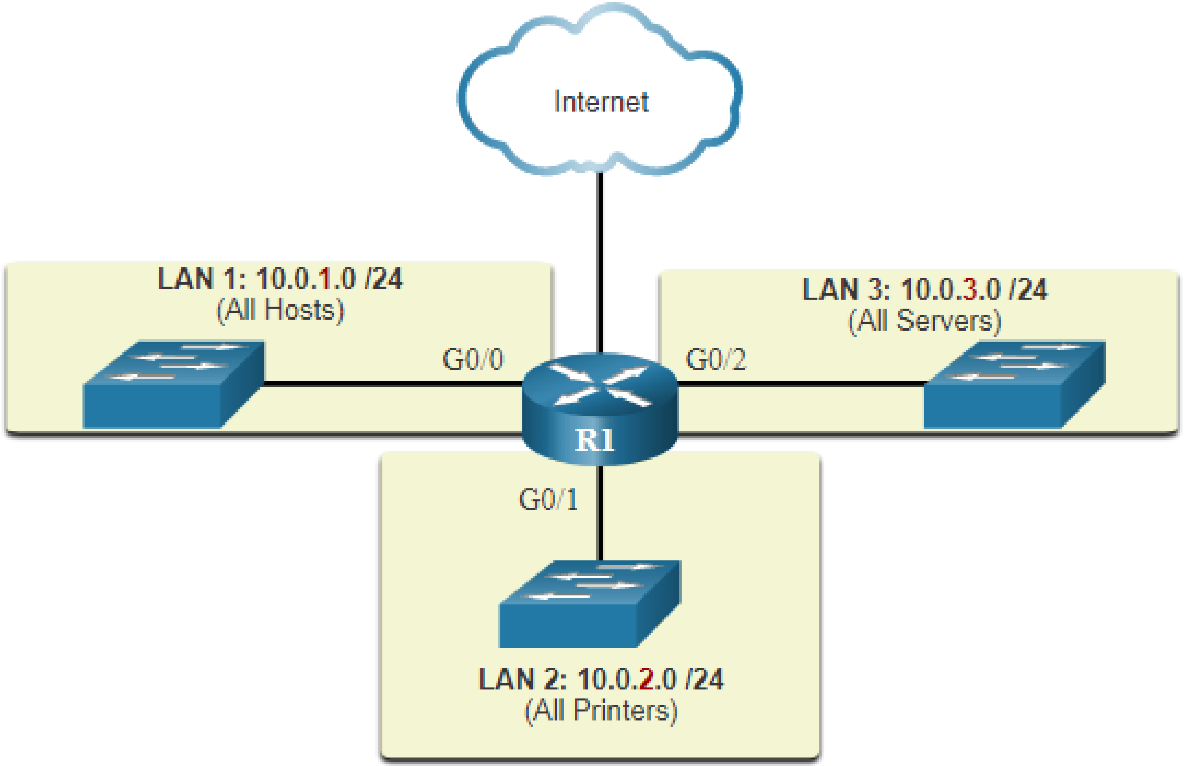
Reasons for Segmenting Networks

Group or Function



Reasons for Segmenting Networks

Device Type



Subnet an IPv4 Network

Subnet on an Octet Boundary

- Networks are most easily subnetted at the octet boundary of /8, /16, and /24.
- Notice that using longer prefix lengths decreases the number of hosts per subnet.

Prefix Length	Subnet Mask	Subnet Mask in Binary (n = network, h = host)	# of hosts
/8	**255**.0.0.0	**nnnnnnnn**.hhhhhhhh.hhhhhhhh.hhhhhhhh **11111111**.00000000.00000000.00000000	16,777,214
/16	**255.255**.0.0	**nnnnnnnn.nnnnnnnn**.hhhhhhhh.hhhhhhhh **11111111.11111111**.00000000.00000000	65,534
/24	**255.255.255**.0	**nnnnnnnn.nnnnnnnn.nnnnnnnn**.hhhhhhhh **11111111.11111111.11111111**.00000000	254

Subnet on an Octet Boundary (Cont.)

- In the first table 10.0.0.0/8 is subnetted using /16 and in the second table, a /24 mask.

Subnet Address (256 Possible Subnets)	**Host Range** (65,534 possible hosts per subnet)	**Broadcast**
10.0.0.0**/16**	**10.0**.0.1 - **10.0**.255.254	**10.0**.255.255
10.1.0.0**/16**	**10.1**.0.1 - **10.1**.255.254	**10.1**.255.255
10.2.0.0**/16**	**10.2**.0.1 - **10.2**.255.254	**10.2**.255.255
10.3.0.0**/16**	**10.3**.0.1 - **10.3**.255.254	**10.3**.255.255
10.4.0.0**/16**	**10.4**.0.1 - **10.4**.255.254	**10.4**.255.255
10.5.0.0**/16**	**10.5**.0.1 - **10.5**.255.254	**10.5**.255.255
10.6.0.0**/16**	**10.6**.0.1 - **10.6**.255.254	**10.6**.255.255
10.7.0.0**/16**	**10.7**.0.1 - **10.7**.255.254	**10.7**.255.255
...	...	...
10.255.0.0**/16**	**10.255**.0.1 - **10.255**.255.254	**10.255**.255.255

Subnet Address (65,536 Possible Subnets)	**Host Range** (254 possible hosts per subnet)	**Broadcast**
10.0.0.0**/24**	**10.0.0**.1 - **10.0.0**.254	**10.0.0**.255
10.0.1.0**/24**	**10.0.1**.1 - **10.0.1**.254	**10.0.1**.255
10.0.2.0**/24**	**10.0.2**.1 - **10.0.2**.254	**10.0.2**.255
…	…	…
10.0.255.0**/24**	**10.0.255**.1 - **10.0.255**.254	**10.0.255**.255
10.1.0.0**/24**	**10.1.0**.1 - **10.1.0**.254	**10.1.0**.255
10.1.1.0**/24**	**10.1.1**.1 - **10.1.1**.254	**10.1.1**.255
10.1.2.0**/24**	**10.1.2**.1 - **10.1.2**.254	**10.1.2**.255
…	…	…
10.100.0.0**/24**	**10.100.0**.1 - **10.100.0**.254	**10.100.0**.255
...	...	...
10.255.255.0**/24**	**10.255.255**.1 - **10.255.255**.254	**10.255.255**.255

Subnet within an Octet Boundary

- Refer to the table to see six ways to subnet a /24 network.

Prefix Length	Subnet Mask	Subnet Mask in Binary (n = network, h = host)	# of subnets	# of hosts
/25	255.255.255.128	nnnnnnnn.nnnnnnnn.nnnnnnnn.**n**hhhhhhh 11111111.11111111.11111111.**1**0000000	**2**	126
/26	255.255.255.192	nnnnnnnn.nnnnnnnn.nnnnnnnn.**nn**hhhhhh 11111111.11111111.11111111.**11**000000	**4**	62
/27	255.255.255.224	nnnnnnnn.nnnnnnnn.nnnnnnnn.**nnn**hhhhh 11111111.11111111.11111111.**111**00000	**8**	30
/28	255.255.255.240	nnnnnnnn.nnnnnnnn.nnnnnnnn.**nnnn**hhhh 11111111.11111111.11111111.**1111**0000	**16**	14
/29	255.255.255.248	nnnnnnnn.nnnnnnnn.nnnnnnnn.**nnnnn**hhh 11111111.11111111.11111111.**11111**000	**32**	6
/30	255.255.255.252	nnnnnnnn.nnnnnnnn.nnnnnnnn.**nnnnnn**hh 11111111.11111111.11111111.**111111**00	**64**	2

Create Subnets with a Slash /24 prefix

Example: You have sub-netted your class C network 192.168.1.0 with a subnet mask of 255.255.255.240. Please list the following: number of networks, number of hosts per network, the full range of the first three networks, and the usable address range from those first three networks.

Answers:

Number of networks = 16

Number of hosts = 14

Full Range for first three networks:

192.168.1.0-15

192.168.1.16-31

192.168.1.32-47

Usable Range for first three networks:

192.168.1.1-14

192.168.1.17-30

192.168.1.33-46

Class C Subnetting

# of Subnets	# of Hosts/Subnet	NetMask	4th Octet	CIDR Notation
2	126	255.255.255.128	10000000	/25
4	62	255.255.255.192	11000000	/26
8	30	255.255.255.224	11100000	/27
16	14	255.255.255.240	11110000	/28
32	6	255.255.255.248	11111000	/29
64	2	255.255.255.252	11111100	/30

Create Subnets with a Slash /24 prefix

Example: Assuming you are using a Class C IP address (195.16.1.0) and you need to create the following numbers of subnets for your network plan (as per stated in item a to below). For each of the numbers of required subnets below, provide how many bits would you borrow as subnet bits and what would be the subnet mask?

1) 5 subnets
2) 3 subnets
3) 8 subnets
4) 10 subnets
5) 25 subnets

Answers:

1) 5 subnets – Borrow 3 bits (2^3 = 8) and Subnet Mask is 255.255.255.224
2) 3 subnets - Borrow 2 bits (2^2 = 4) and Subnet Mask is 255.255.255.192
3) 8 subnets - Borrow 3 bits (2^3 = 8) and Subnet Mask is 255.255.255.224
4) 10 subnets - Borrow 4 bits (2^4 = 16) and Subnet Mask is 255.255.255.240
5) 25 subnets - Borrow 5 bits (2^5 = 32) and Subnet Mask is 255.255.255.248

Class C Subnetting

# of Subnets	# of Hosts/Subnet	NetMask	4th Octet	CIDR Notation
2	126	255.255.255.128	10000000	/25
4	62	255.255.255.192	11000000	/26
8	30	255.255.255.224	11100000	/27
16	14	255.255.255.240	11110000	/28
32	6	255.255.255.248	11111000	/29
64	2	255.255.255.252	11111100	/30

Subnet a Slash 16 and a Slash 8 Prefix

Create Subnets with a Slash 16 prefix

- The table highlights all the possible scenarios for subnetting a /16 prefix.

Prefix Length	Subnet Mask	Network Address (n = network, h = host)	# of subnets	# of hosts
/17	255.255.**128**.0	nnnnnnnn.nnnnnnnn.**n**hhhhhhh.hhhhhhhh 11111111.11111111.**1**0000000.00000000	**2**	32766
/18	255.255.**192**.0	nnnnnnnn.nnnnnnnn.**nn**hhhhhh.hhhhhhhh 11111111.11111111.**11**000000.00000000	**4**	16382
/19	255.255.**224**.0	nnnnnnnn.nnnnnnnn.**nnn**hhhhh.hhhhhhhh 11111111.11111111.**111**00000.00000000	**8**	8190
/20	255.255.**240**.0	nnnnnnnn.nnnnnnnn.**nnnn**hhhh.hhhhhhhh 11111111.11111111.**1111**0000.00000000	**16**	4094
/21	255.255.**248**.0	nnnnnnnn.nnnnnnnn.**nnnnn**hhh.hhhhhhhh 11111111.11111111.**11111**000.00000000	**32**	2046
/22	255.255.**252**.0	nnnnnnnn.nnnnnnnn.**nnnnnn**hh.hhhhhhhh 11111111.11111111.**111111**00.00000000	**64**	1022
/23	255.255.**254**.0	nnnnnnnn.nnnnnnnn.**nnnnnnn**h.hhhhhhhh 11111111.11111111.**1111111**0.00000000	**128**	510
/24	255.255.**255.0**	nnnnnnnn.nnnnnnnn.**nnnnnnnn**.hhhhhhhh 11111111.11111111.**11111111**.00000000	**256**	254
/25	255.255.**255.128**	nnnnnnnn.nnnnnnnn.**nnnnnnnn.n**hhhhhhh 11111111.11111111.**11111111.1**0000000	**512**	126
/26	255.255.**255.192**	nnnnnnnn.nnnnnnnn.**nnnnnnnn.nn**hhhhhh 11111111.11111111.**11111111.11**000000	**1024**	62
/27	255.255.**255.224**	nnnnnnnn.nnnnnnnn.**nnnnnnnn.nnn**hhhhh 11111111.11111111.**11111111.111**00000	**2048**	30
/28	255.255.**255.240**	nnnnnnnn.nnnnnnnn.**nnnnnnnn.nnnn**hhhh 11111111.11111111.**11111111.1111**0000	**4096**	14
/29	255.255.**255.248**	nnnnnnnn.nnnnnnnn.**nnnnnnnn.nnnnn**hhh 11111111.11111111.**11111111.11111**000	**8192**	6
/30	255.255.**255.252**	nnnnnnnn.nnnnnnnn.**nnnnnnnn.nnnnnn**hh 11111111.11111111.**11111111.111111**00	**16384**	2

Create 100 Subnets with a Slash 16 prefix

Consider a large enterprise that requires at least 100 subnets and has chosen the private address 172.16.0.0/16 as its internal network address.

- The figure displays the number of subnets that can be created when borrowing bits from the third octet and the fourth octet.
- Notice there are now up to 14 host bits that can be borrowed (i.e., last two bits cannot be borrowed).

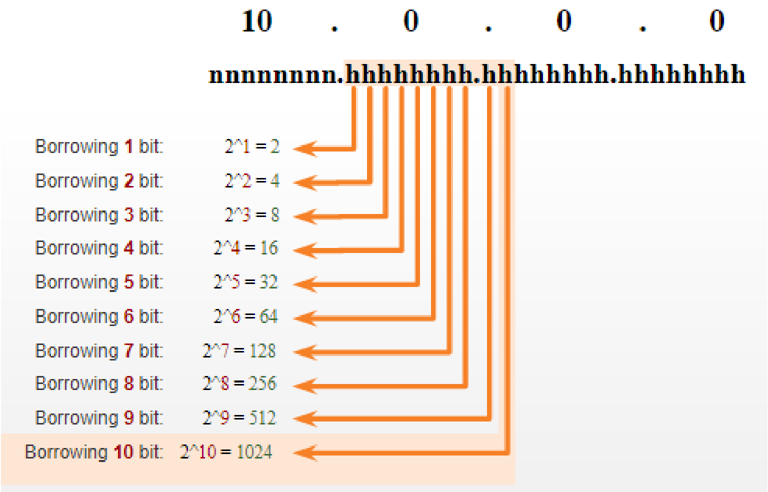
To satisfy the requirement of 100 subnets for the enterprise, 7 bits (i.e., $2^7 = 128$ subnets) would need to be borrowed (for a total of 128 subnets).

Create 1000 Subnets with a Slash 8 prefix

Consider a small ISP that requires 1000 subnets for its clients using network address 10.0.0.0/8 which means there are 8 bits in the network portion and 24 host bits available to borrow toward subnetting.

- The figure displays the number of subnets that can be created when borrowing bits from the second and third.
- Notice there are now up to 22 host bits that can be borrowed (i.e., last two bits cannot be borrowed).

To satisfy the requirement of 1000 subnets for the enterprise, 10 bits (i.e., 2^{10}=1024 subnets) would need to be borrowed (for a total of 128 subnets)

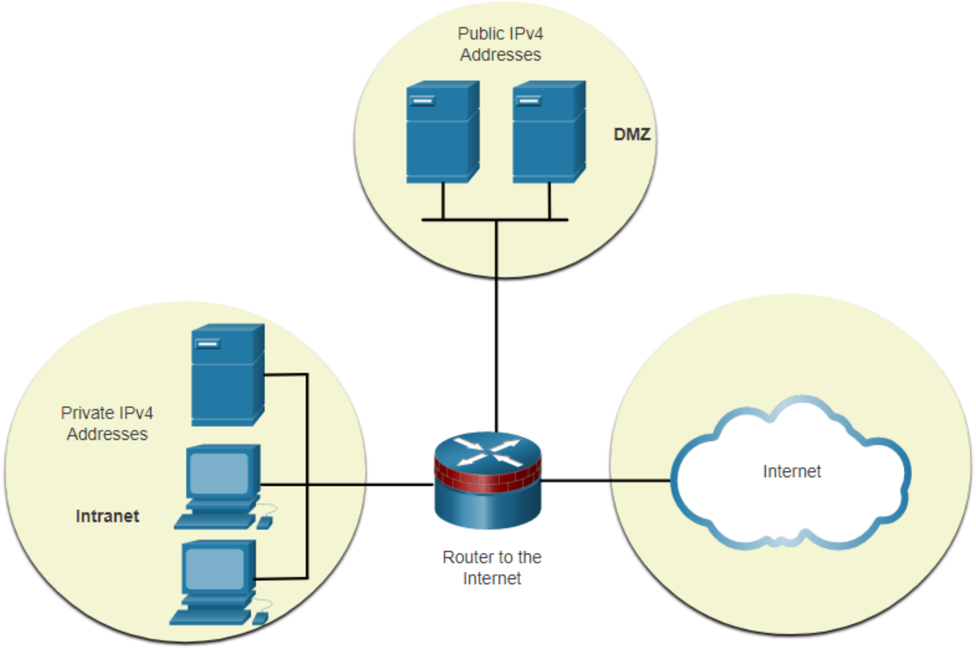


Subnet to Meet Requirements

Subnet Private versus Public IPv4 Address Space

Enterprise networks will have an:

- Intranet - A company's internal network typically using private IPv4 addresses.
- DMZ – A companies internet facing servers. Devices in the DMZ use public IPv4 addresses.
- A company could use the 10.0.0.0/8 and subnet on the /16 or /24 network boundary.
- The DMZ devices would have to be configured with public IP addresses.



Subnet to Meet Requirements

Minimize Unused Host IPv4 Addresses and Maximize Subnets

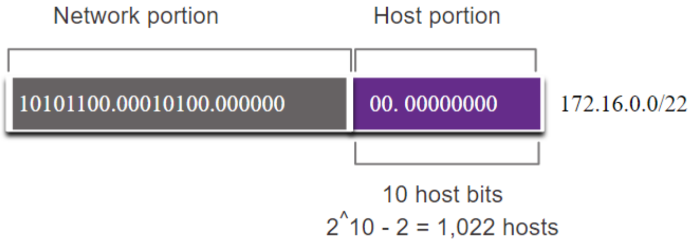
There are two considerations when planning subnets:

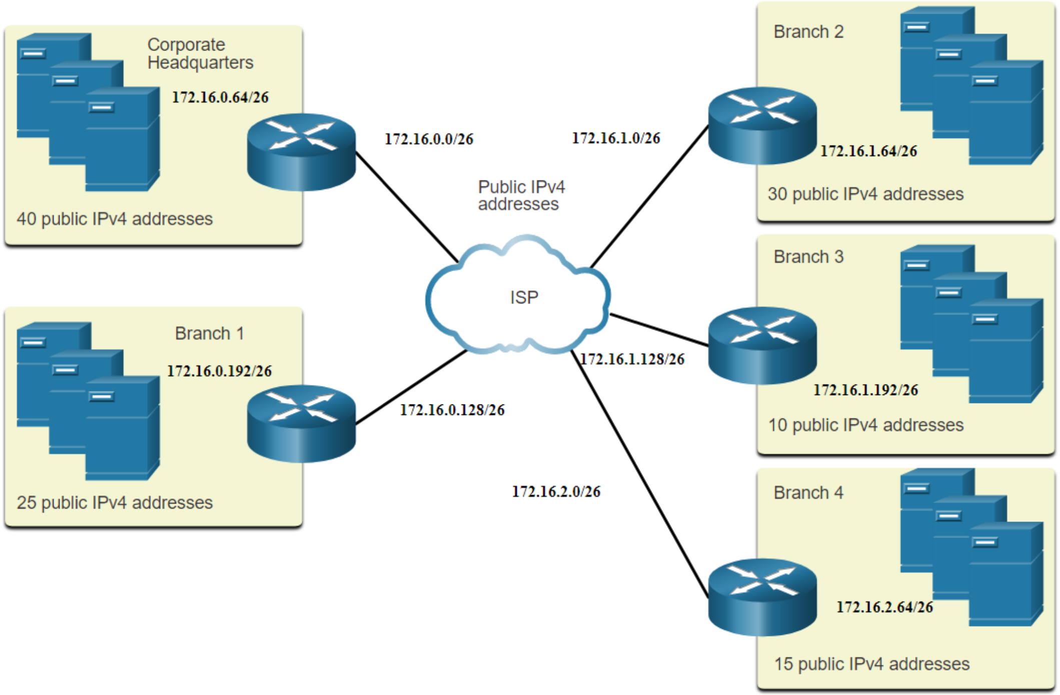
- The number of host addresses required for each network
- The number of individual subnets needed

Prefix Length	Subnet Mask	Subnet Mask in Binary (n = network, h = host)	# of subnets	# of hosts
/25	255.255.255.128	nnnnnnnn.nnnnnnnn.nnnnnnnn.**n**hhhhhhh 11111111.11111111.11111111.**1**0000000	**2**	126
/26	255.255.255.192	nnnnnnnn.nnnnnnnn.nnnnnnnn.**nn**hhhhhh 11111111.11111111.11111111.**11**000000	**4**	62
/27	255.255.255.224	nnnnnnnn.nnnnnnnn.nnnnnnnn.**nnn**hhhhh 11111111.11111111.11111111.**111**00000	**8**	30
/28	255.255.255.240	nnnnnnnn.nnnnnnnn.nnnnnnnn.**nnnn**hhhh 11111111.11111111.11111111.**1111**0000	**16**	14
/29	255.255.255.248	nnnnnnnn.nnnnnnnn.nnnnnnnn.**nnnnn**hhh 11111111.11111111.11111111.**11111**000	**32**	6
/30	255.255.255.252	nnnnnnnn.nnnnnnnn.nnnnnnnn.**nnnnnn**hh 11111111.11111111.11111111.**111111**00	**64**	2

Example: Efficient IPv4 Subnetting

- In this example, corporate headquarters has been allocated a public network address of 172.16.0.0/22 (10 host bits) by its ISP providing 1,022 host addresses.
- There are five sites and therefore five internet connections which means the organization requires 10 subnets with the largest subnet requires 40 addresses.
- It allocated 10 subnets with a /26 (i.e., 255.255.255.192) subnet mask.



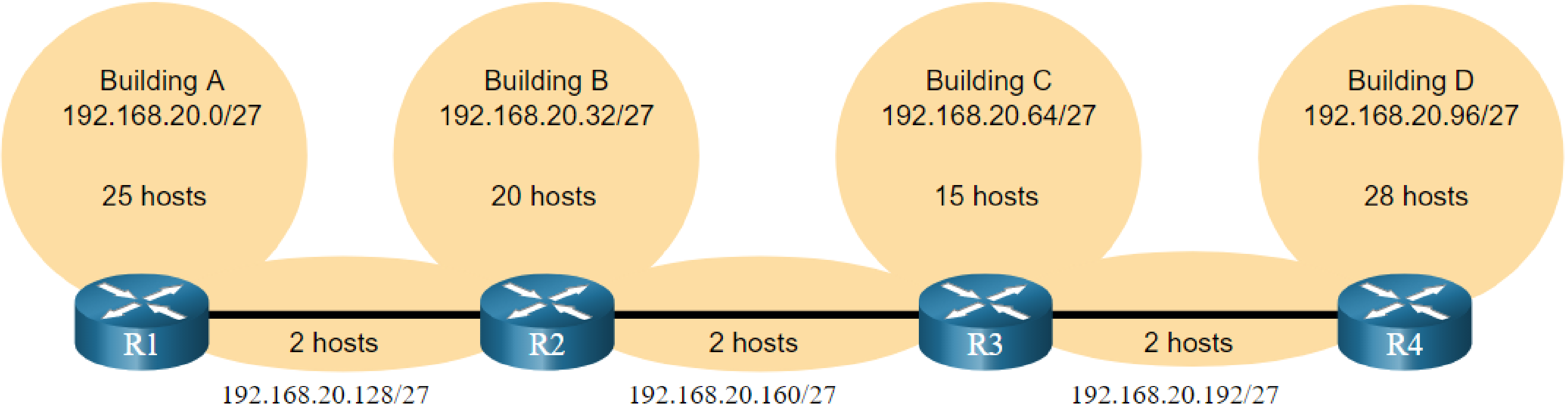


VLSM

IPv4 Address Conservation

Given the topology, 7 subnets are required (i.e, four LANs and three WAN links) and the largest number of host is in Building D with 28 hosts.

- A /27 mask would provide 8 subnets of 30 host IP addresses and therefore support this topology.



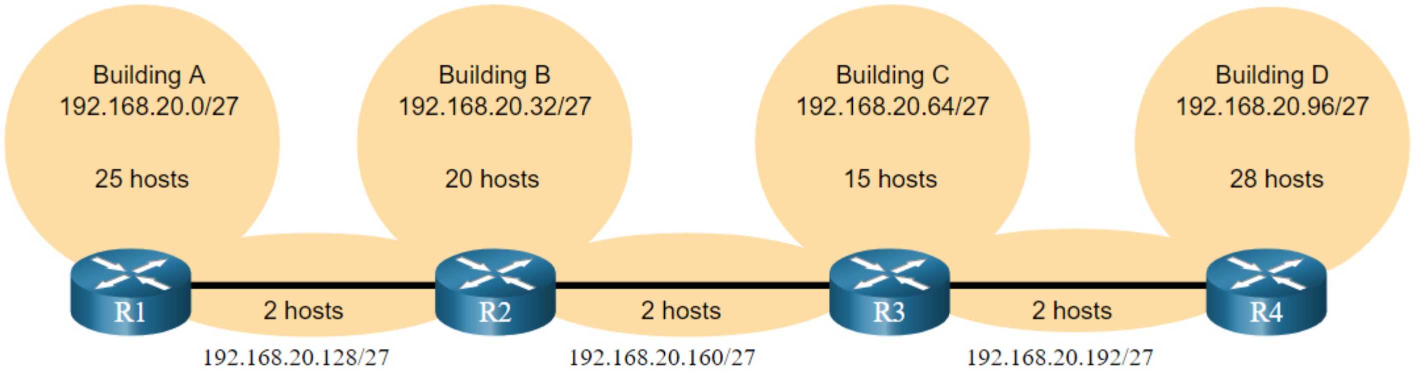
IPv4 Address Conservation (Cont.)

However, the point-to-point WAN links only require two addresses and therefore waste 28 addresses each for a total of 84 unused addresses.

Host portion
2^5 – 2 = 30 host IP addresses per subnet

30 – 2 = 28
Each WAN subnet wastes 28 addresses

28 x 3 = 84
84 addresses are unused

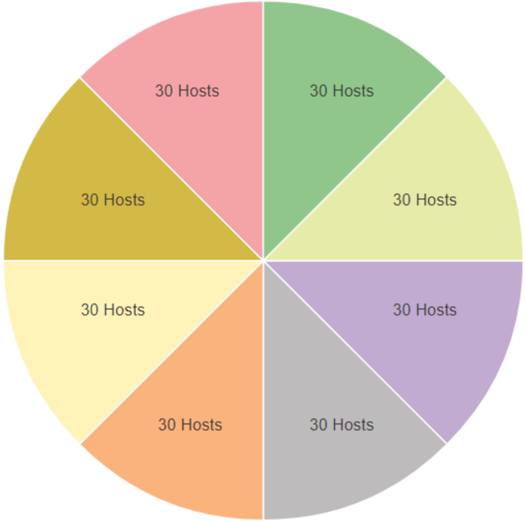


- Applying a traditional subnetting scheme to this scenario is not very efficient and is wasteful.
- VLSM was developed to avoid wasting addresses by enabling us to subnet a subnet.

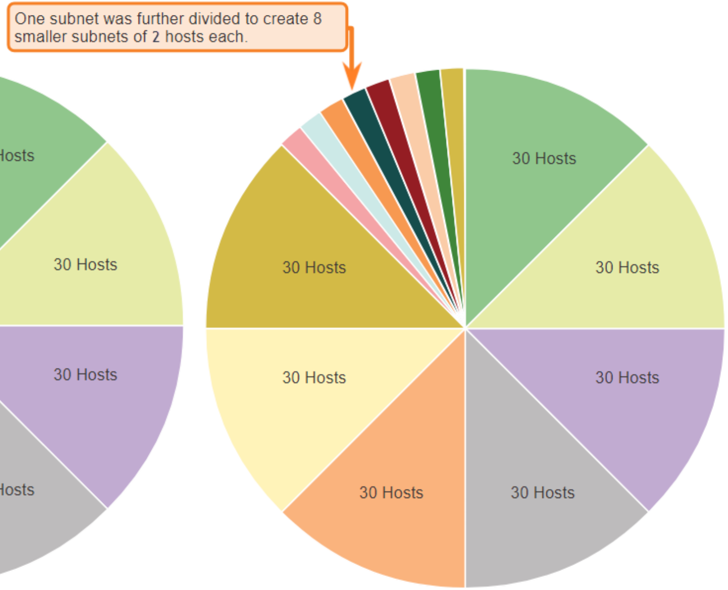
VLSM
VLSM

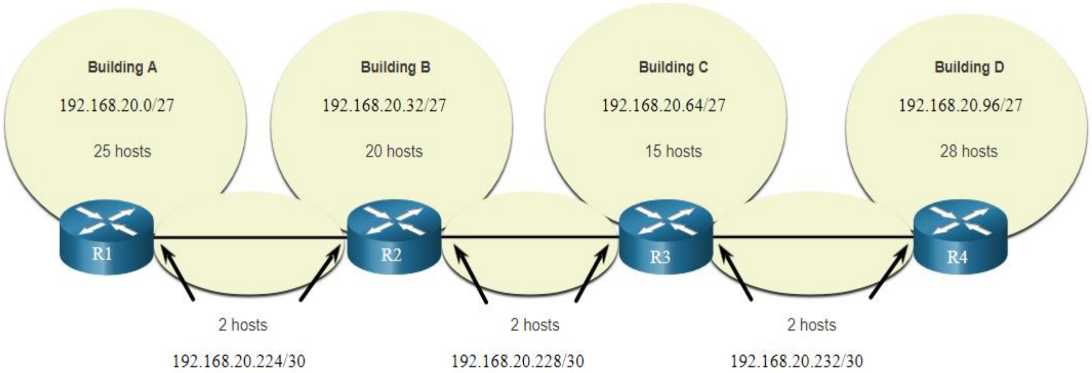
- The left side displays the traditional subnetting scheme (i.e., the same subnet mask) while the right side illustrates how VLSM can be used to subnet a subnet and divided the last subnet into eight /30 subnets.
- When using VLSM, always begin by satisfying the host requirements of the largest subnet and continue subnetting until the host requirements of the smallest subnet are satisfied.
- The resulting topology with VLSM applied.

Traditional Subnetting Creates Equal Sized Subnets



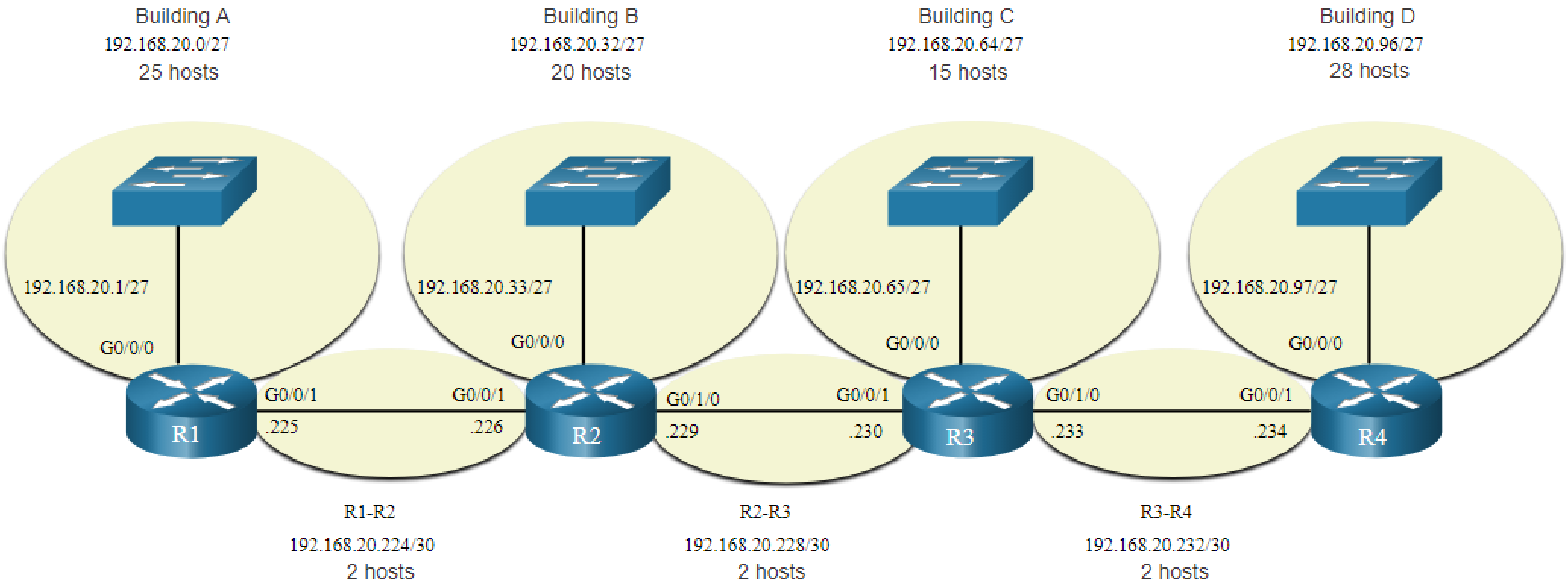
Subnets of Varying Sizes





VLSM Topology Address Assignment

- Using VLSM subnets, the LAN and inter-router networks can be addressed without unnecessary waste as shown in the logical topology diagram.

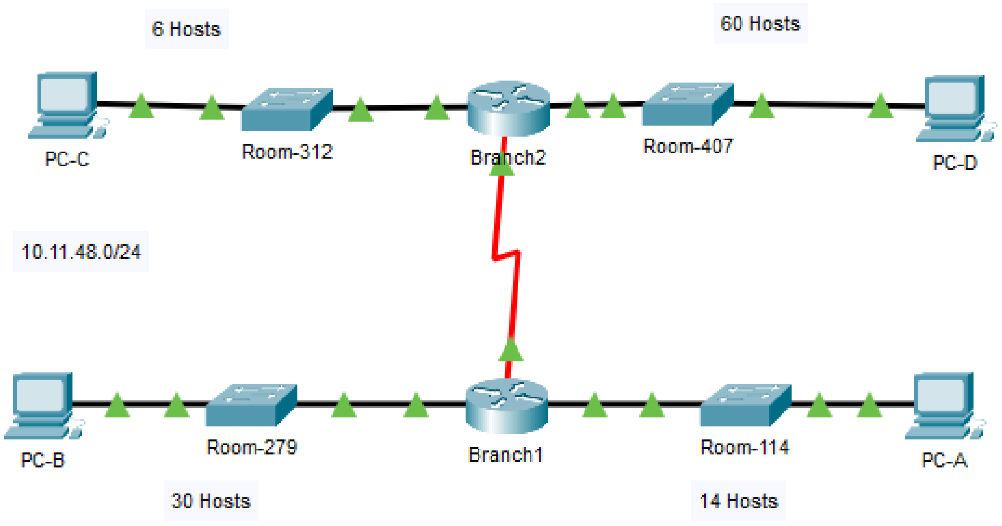


Example: VLSM

Example: Refer to the exhibit below. Identify the Network ID and subnet mask for the following subnets. Given the IP address is 10.11.48.0/24.

Answers:

1. Room-407 [60 Hosts] – Network ID is 10.11.48.0 and Subnet Mask is 255.255.255.192
2. Room-279 [30 Hosts] – Network ID is 10.11.48.64 and Subnet Mask is 255.255.255.224
3. Room-114 [14 Hosts] – Network ID is 10.11.48.96 and Subnet Mask is 255.255.255.240
4. Room-312 [6 Hosts] – Network ID is 10.11.48.112 and Subnet Mask is 255.255.255.248
5. Branch 1 to Branch 2 [2 Hosts] – Network ID is 10.11.48.120 and Subnet Mask is 255.255.255.252



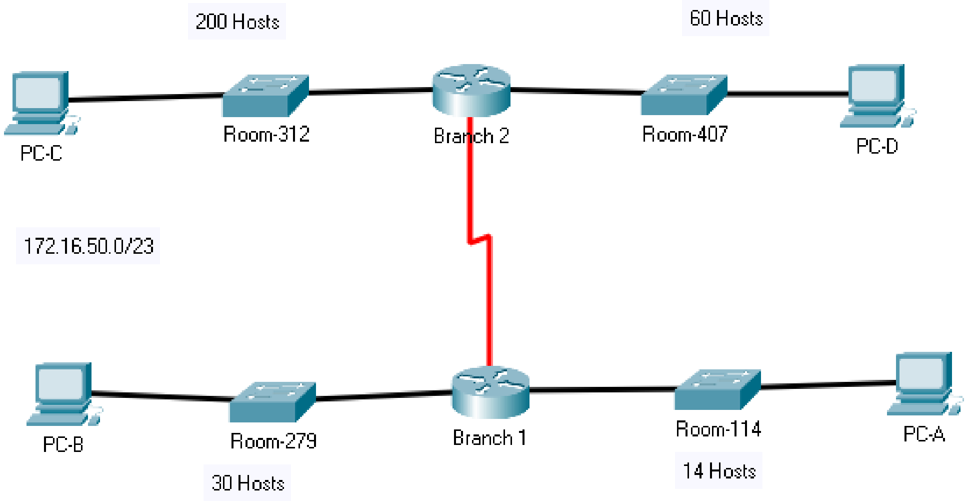
Example: VLSM

Example: Refer to the exhibit below. Answer the following questions.

a. State the Network ID and subnet mask for the above subnets. Given the IP address is 172.16.50.0/23. [5 Marks]

b. Identify the IP address of PC-A and PC-B if the second valid IP address is being assigned to them. [2 Marks]

c. Briefly explain the potential issue that will occur if the default gateway IP address is wrongly configured on both PC-A and PC-B.[3 Marks]



Answers:

a.

1. Room-312 [200 Hosts] – Network ID is 172.16.50.0/24 and Subnet Mask is 255.255.255.0
2. Room-407 [60 Hosts] – Network ID is 172.16.51.0/26 and Subnet Mask is 255.255.255.192
3. Room-279 [30 Hosts] – Network ID is 172.16.51.64/27 and Subnet Mask is 255.255.255.224
4. Room-114 [14 Hosts] – Network ID is 172.16.51.0/28 and Subnet Mask is 255.255.255.240
5. Branch 1 to Branch 2 [2 Hosts] – Network ID is 10.11.48.120 and Subnet Mask is 255.255.255.252

b.

PC-A IP address: 172.16.51.98/28

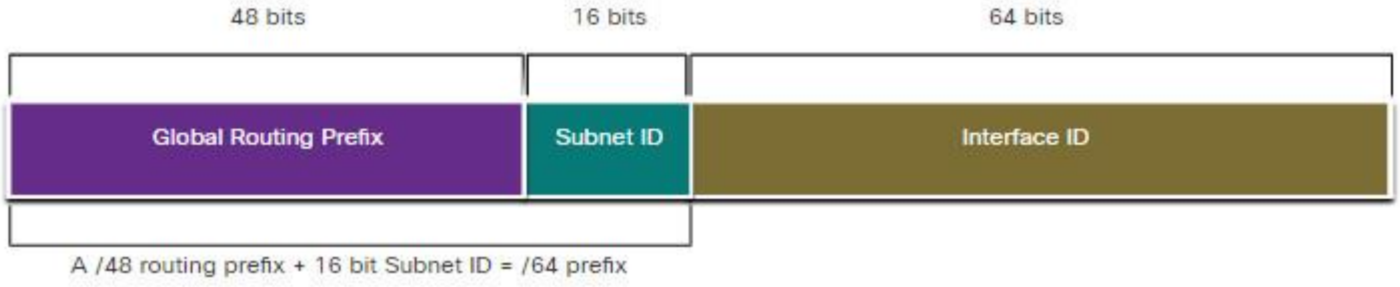
PC-B IP address: 172.16.51.66/27

Subnet an IPv6 Network

Subnet Using the Subnet ID

IPv6 was designed with subnetting in mind.

- A separate subnet ID field in the IPv6 GUA is used to create subnets.
- The subnet ID field is the area between the Global Routing Prefix and the interface ID.



Note:
16 bits Subnet ID – Creates up to 65536 Subnets
64-bit Interface ID – Creates up to 18 quintillion ($18x10^{18}$) host IPv6 Addresses
Subnetting of 64-bit interface is also possible but is rarely required

Subnet Using the Subnet ID

Typical IPv6 Prefix Assignment	
Description	No of Subnets
RIR /23	2,109,023,255,552 (2 Trillion)
Service Providers /32	4,294,967,296 (4 Billion)
Large End Users /48	65536
Medium End Users /56	256
Small/Home/SOHO /60	16
Small/Home/SOHO /64	1

Nibble Boundary Subnets – To keep subnetting as simple as possible it is a best practice to borrow 4 bits or one Nibble at a time	
Prefix	# of /64 Subnets
/48	65536
/52	4096
/56	256
/60	16
/64	1

Subnet an IPv6 Network
Subnet Using the Subnet ID

Subnet Based on Individual Binary Bits	
Prefix	# of /64 Subnets
/48	65536
/49	32768
/50	16384
/51	8192
/52	4096
/53	2048
/54	1024
/55	512
/56	256
/57	128
/58	64
/59	32
/60	16
/61	8
/62	4
/63	2
/64	1

Examples:	
a	Subnetting 2001:acad:1234::/48 IPv6 Address to /64
1st Subnet :	2001:acad:1234:**0000**:0000:0000:0000:0000/64
2nd Subnet :	2001:acad:1234:**0001**:0000:0000:0000:0000/64
65536th Subnet :	2001:acad:1234:**ffff**:0000:0000:0000:0000/64
b	Subnetting 2001:acad:1234:12**00**::/56 IPv6 Address to /64
1st Subnet :	
2nd Subnet :	
256th Subnet :	
c	Subnetting 2001:acad:1234:123**0**::/60 IPv6 Address to /64
1st Subnet :	
2nd Subnet :	
16th Subnet :	
Note: Each subnet provides with the 18 quintillion addresses	

Subnet an IPv6 Network

Subnet Using the Subnet ID

Subnet Based on Individual Binary Bits

Prefix	# of /64 Subnets
/48	65536
/49	32768
/50	16384
/51	8192
/52	4096
/53	2048
/54	1024
/55	512
/56	256
/57	128
/58	64
/59	32
/60	16
/61	8
/62	4
/63	2
/64	1

Examples:

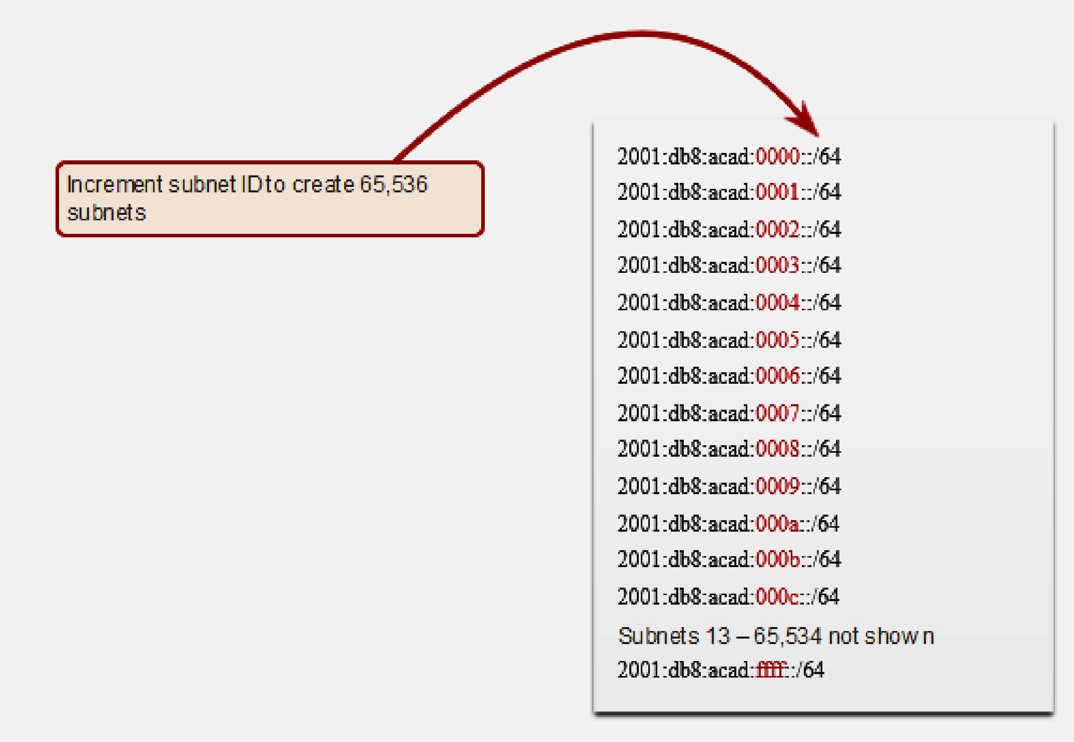
a	Subnetting 2001:acad:1234::/48 IPv6 Address to /64
1st Subnet :	2001:acad:1234:**0000**:0000:0000:0000:0000/64
2nd Subnet :	2001:acad:1234:**0001**:0000:0000:0000:0000/64
65536th Subnet :	2001:acad:1234:**ffff**:0000:0000:0000:0000/64
b	Subnetting 2001:acad:1234:12**00**::/56 IPv6 Address to /64
1st Subnet :	2001:acad:1234:12**00**:0000:0000:0000:0000/64
2nd Subnet :	2001:acad:1234:12**01**:0000:0000:0000:0000/64
256th Subnet :	2001:acad:1234:12**ff**:0000:0000:0000:0000/64
c	Subnetting 2001:acad:1234:123**0**::/60 IPv6 Address to /64
1st Subnet :	2001:acad:1234:123**0**:0000:0000:0000:0000/64
2nd Subnet :	2001:acad:1234:123**1**:0000:0000:0000:0000/64
16th Subnet :	2001:acad:1234:123**f**:0000:0000:0000:0000/64
Note: Each subnet provides with the 18 quintillion addresses	

Subnet an IPv6 Network

IPv6 Subnetting Example

Given the 2001:db8:acad::/48 global routing prefix with a 16 bit subnet ID.

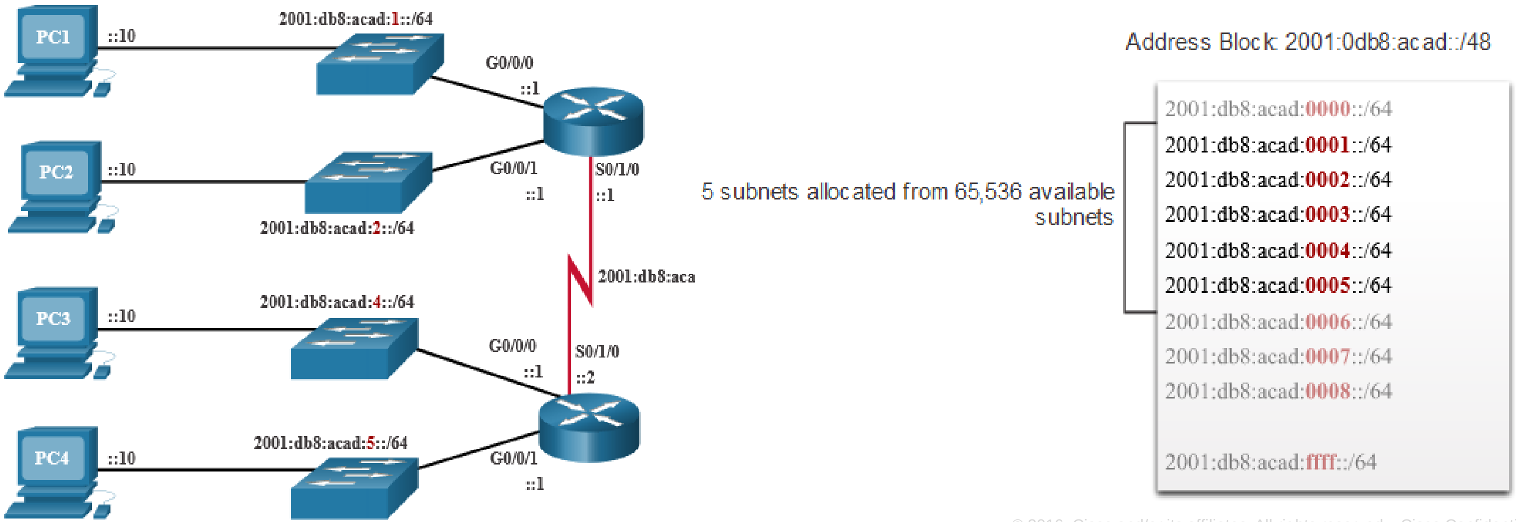
- Allows 65,536 /64 subnets
- The global routing prefix is the same for all subnets.
- Only the subnet ID hextet is incremented in hexadecimal for each subnet.



IPv6 Subnet Allocation

The example topology requires five subnets, one for each LAN as well as for the serial link between R1 and R2.

The five IPv6 subnets were allocated, with the subnet ID field 0001 through 0005. Each /64 subnet will provide more addresses than will ever be needed.



Router Configured with IPv6 Subnets

The example shows that each of the router interfaces on R1 has been configured to be on a different IPv6 subnet.

```
R1(config)# interface gigabitethernet 0/0/0
R1(config-if)# ipv6 address 2001:db8:acad:1::1/64
R1(config-if)# no shutdown
R1(config-if)# exit
R1(config)# interface gigabitethernet 0/0/1
R1(config-if)# ipv6 address 2001:db8:acad:2::1/64
R1(config-if)# no shutdown
R1(config-if)# exit
R1(config)# interface serial 0/1/0
R1(config-if)# ipv6 address 2001:db8:acad:3::1/64
R1(config-if)# no shutdown
```

Summary

Summary of Main Teaching Points

- Define Network Segmentation
- Briefly discuss subnet in IPv4.
- Subnet Private versus Public IPv4 Address Space
- VLSM
- Subnetting IPv6 Network

Question and Answer Session

Q & A

What We Will Cover Next:

Transport Layer and Application Layer