Problems with Classful IP Addressing

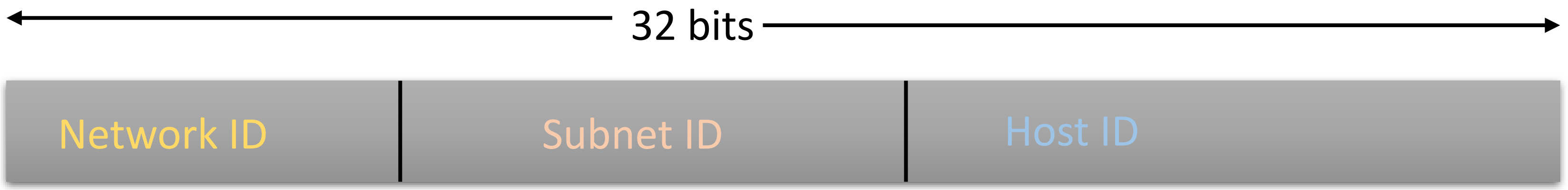
- Several problems with classful addressing are:
- Not having a network class that can efficiently support a medium sized domain/organization. If an organization is assigned Class B or Class A block of addresses, it will be considered as a single network with one network ID by the Internet router. A Class B network supports 65,534 hosts which is too large for a medium sized organization with the requirement of few hundred hosts. Thus wasting several thousand potential host addresses.
- There are few choices in the sizes of networks available. Class C has 254 hosts and class B has 65534 hosts. There are many companies that need more than 254 IP address but a lot fewer than 65,000.
- Consider a company with 5,000 computers, what class network should be used? If it is assigned a Class B network, 90% IP addresses are wasted. In order to avoid wasting all these IP addresses, if the same company is given some Class C addresses, 20 Class C network address will be required to meet company's need. Thus every router on the Internet replaces the single Class B router table entry with 20 Class C router entries. This method would add to the size of router tables. Router tables have already been growing quickly as the Internet has expanded. The larger these tables, the more time it takes for routers to make routing decisions.

IP Subnet Addressing

- In order to address the problem of classful addressing a new addressing procedure called subnet addressing or subnetting was proposed.
- The basic idea behind subnet addressing is to add an additional hierarchical level in the way IP addresses are interpreted. The concept of a network remains unchanged, but instead of having just hosts within a network, a new hierarchy is created - subnets and hosts.
- Each subnet is a subnetwork, and functions the way a full network does. A three level hierarchy is thus created: networks, which contain subnets, each of which then has a number of hosts.
- Subnetting provides numerous advantages:
  - Hosts can be grouped into subnets that reflect the way they are actually structured in the organization's physical network.
  - The number of subnets and number of hosts per subnet can be customized for each organization.
  - Since the subnet structure exists only within the organization, routers outside that organization know nothing about it. The organization still maintains a single routing table entries for all of its devices. Only routers inside the organization need to worry about routing between subnets.

Subnet Mask

- To create subnetworks, take bits from the host portion of the IP address and reserve them to define the subnet address.
- In a classful environment, routers use the first octet of the IP address to determine the class is of the address, and from this they know which bits are the network ID and which are the host ID.
- When subnetting is used, these routers also need to know how that host ID is divided into subnet ID and host ID. However, this division can be arbitrary for each network. Furthermore, there is no way to tell how many bits belong to each simply by looking at the IP address.
- So additional information about which bits are for the subnet ID and which for the host ID must be communicated to devices that interpret IP addresses. This information is given in the form of a 32 bit binary number called a subnet mask.
- The network administrator creates a 32 bit subnet mask composed of 1s and 0s. The 1s in the subnet mask represent the positions that refer to the network or subnet addresses.



How Subnet Masks are Used to Determine the Network Number?

- The router extracts the IP destination address from the incoming packet and retrieves the internal subnet mask. It then performs a logical AND operation to obtain the network number. This causes the host portion of the IP destination address to be removed, while the destination network number remains.
- Mask Bit is 1 - If the IP address bit is a 0, the result of the AND will be 0, and if it is a 1, the AND will be 1. In other words, where the subnet bit is a 1, the IP address is preserved unchanged.
- Mask Bit is 0 – If we AND with a 0, so the result is always 0 regardless of what the IP address is. Thus, when the subnet bit is a 0, the IP address bit is always cleared to 0.
- Any address bits which have corresponding mask bit set to '1' represent the Network ID. Any address bits that have corresponding mask bits set to '0' represent a Host ID.
- So when we use the subnet mask on an IP address, the bits in the network ID and subnet ID are left intact, while the host ID bits are removed.
- Default masks of classes are:
- Class A → 255.0.0.0
- Class B → 255.255.0.0
- Class C→ 255.255.255.0

Classless Interdomain Routing

- Classless Inter-Domain Routing (CIDR) is a method that ISPs use to allocate a number of addresses to a company, a home or a customer. For example 192.168.10.32/28.
- The slash notation (/) means how many bits are turned on (1s).
- The maximum could be /32 but the largest subnet mask available can only be a /30 because at least 2 bits have to be reserved for host bits.

Subnet Mask	CIDR Value
255.0.0.0	/8
255.128.0.0	/9
255.192.0.0	/10
255.224.0.0	/11
255.240.0.0	/12
255.248.0.0	/13
255.252.0.0	/14
255.254.0.0	/15

Subnet Mask	CIDR Value
255.255.0.0	/16
255.255.128.0	/17
255.255.192.0	/18
255.255.224.0	/19
255.255.240.0	/20
255.255.248.0	/21
255.255.252.0	/22
255.255.254.0	/23
255.255.255.0	/24
255.255.255.128	/25
255.255.255.192	/26
255.255.255.224	/27
255.255.255.240	/28
255.255.255.248	/29
255.255.255.252	/30

Subnetting Class C Addresses

- In a Class C address, only 8 bits are available for defining the hosts.
- The subnet bits start at the left and move to the right, without skipping bits.
- We need to answer five simple questions:
- How many subnets does the chosen subnet mask produce?

Answer : 2^x where x is the number of masked bits or 1's.

- How many valid hosts per subnet are available?

Answer : $2^y - 2$ where y is the number of unmasked bits or 0's.

- What are the valid subnets?

Answer : $256 - subnet\ mask = block\ size$

- What's the broadcast address of each subnet?

Answer : $The\ broadcast\ address\ is\ always\ the\ number\ right\ before\ the\ next\ subnet$

- What are the valid hosts in each subnet?

Answer : $Valid\ hosts\ are\ the\ numbers\ between\ the\ subnets, except\ all\ 0s\ and\ all\ 1s.$

Subnetting Class C Addresses

Subnet the following address Network address 192.168.10.0 ; Subnet Mask 255.255.255.128 (/25)

No. of subnets = $2^x = 2^1 = 2$

No. of valid hosts per subnet = $2^y - 2 = 2^7 - 2 = 126$

Valid subnets = $256 - subnet\ mask = 256 - 128 = 128\ is\ block\ size$

$$\therefore Two\ subnets\ are\ subnet\ 0\ and\ subnet\ 128$$

Broadcast address for each subnet is the number right before the value of the next subnet

$$\therefore For\ subnet\ 0\ broadcast\ address\ is\ 127$$

$$For\ subnet\ 128\ the\ broadcast\ address\ is\ 255$$

Valid Hosts per subnet are the numbers between subnet address and broadcast address

$$\therefore For\ Subnet\ 0 \rightarrow 1 - 126$$

$$For\ Subnet\ 128 \rightarrow 129 - 254$$

Subnet	**0**	**128**
Network Address	192.168.10.0	192.168.10.128
First Host Address	192.168.10.1	192.168.10.129
Last Host Address	192.168.10.126	192.168.10.254
Broadcast Address	192.168.10.127	192.168.10.255

Subnetting Class C Addresses

Subnet the following address   Network address 192.168.10.0 ; Subnet Mask 255.255.255.192 (/26)

No. of subnets = $2^x = 2^2 = 4$; No. of valid hosts per subnet = $2^y - 2 = 2^6 - 2 = 62$

Valid subnets = $256 - subnet\ mask = 256 - 192 = 64\ is\ block\ size$

$$\therefore Four\ subnets\ are\ subnet\ 0, subnet\ 64, subnet\ 128\ and\ subnet\ 192$$

Broadcast address for each subnet is the number right before the value of the next subnet

$$\therefore For\ subnet\ 0\ broadcast\ address\ is\ 63$$
$$For\ subnet\ 64\ the\ broadcast\ address\ is\ 127$$
$$For\ subnet\ 128\ broadcast\ address\ is\ 191$$
$$For\ subnet\ 192\ broadcast\ address\ is\ 255$$

Valid Hosts per subnet are the numbers between subnet address and broadcast address

$$\therefore For\ subnet\ 0 \rightarrow 1 - 62$$
$$For\ subnet\ 64 \rightarrow 65 - 126$$
$$For\ subnet\ 128 \rightarrow 129 - 190$$
$$For\ subnet\ 192 \rightarrow 193 - 254$$

Subnet	**0**	**64**	**128**	**192**
Network Address	192.168.10.0	192.168.10.64	192.168.10.128	192.168.10.192
First Host Address	192.168.10.1	192.168.10.65	192.168.10.129	192.168.10.193
Last Host Address	192.168.10.62	192.168.10.126	192.168.10.190	192.168.10.254
[illegible]ess	192.168.10.63	192.168.10.127	192.168.10.191	192.168.10.255

Subnetting Class B Addresses

- The process of subnetting a Class B network is same as it is for a Class C, except that we have more host bits and we start in the third octet. Class B network address has 16 bits available for host addressing. This means we can use up to 14 bits for subnetting.

Subnet the following address   Network address 172.16.0.0 ; Subnet Mask 255.255.128.0 (/17)

No. of subnets = $2^x = 2^1 = 2$

No. of valid hosts per subnet = $2^y - 2 = 2^{15} - 2 = 32{,}766$

Valid subnets = $256 - subnet\ mask = 256 - 128 = 128\ is\ block\ size$

$\therefore Two\ subnets\ are\ subnet\ 0.0\ and\ subnet\ 128.0$

Broadcast address for each subnet is the number right before the value of the next subnet.

Valid Hosts per subnet are the numbers between subnet address and broadcast address.

Subnet	**0.0**	**128.0**
Network Address	172.16.0.0	172.16.128.0
First Host Address	172.16.0.1	172.16.128.1
Last Host Address	172.16.127.254	172.16.255.254
Broadcast Address	172.16.127.255	172.16.255.255

Subnetting Class B Addresses

Subnet the following address   Network address 172.16.0.0 ; Subnet Mask 255.255.240.0 (/20)

No. of subnets = $2^x = 2^4 = 16$

No. of valid hosts per subnet = $2^y - 2 = 2^{12} - 2 = 4094$

Valid subnets = $256 - subnet\ mask = 256 - 240 = 16\ is\ block\ size$

Broadcast address for each subnet is the number right before the value of the next subnet

Valid Hosts per subnet are the numbers between subnet address and broadcast address

Subnet	**0.0**	**16.0**	**…**	**208.0**	**224.0**	**240.0**
Network Address	172.16.0.0	172.16.16.0	…	172.16.208.0	172.16.224.0	172.16.240.0
First Host Address	172.16.0.1	172.16.16.1	…	172.16.208.1	172.16.224.1	172.16.240.1
Last Host Address	172.16.15.254	172.16.31.254	…	172.16.223.254	172.16.239.254	172.16.255.254
Broadcast Address	172.16.15.255	172.16.31.255	…	172.16.223.255	172.16.239.255	172.16.255.255

Subnetting Class A Addresses

- The process of subnetting a Class A network is same as it is for a Class B and Class C, except that we start in the second octet. Class A network address has 24 bits available for host addressing. This means we can use up to 22 bits for subnetting.

Subnet the following address   Network address 10.0.0.0 ; Subnet Mask 255.255.0.0 (/16)

No. of subnets = $2^x = 2^8 = 256$

No. of valid hosts per subnet = $2^y - 2 = 2^{16} - 2 = 65{,}534$

Valid subnets = $256 - subnet\ mask = 256 - 255 = 1\ is\ block\ size(all\ in\ the\ second\ octet)$

Broadcast address for each subnet is the number right before the value of the next subnet.

Valid Hosts per subnet are the numbers between subnet address and broadcast address.

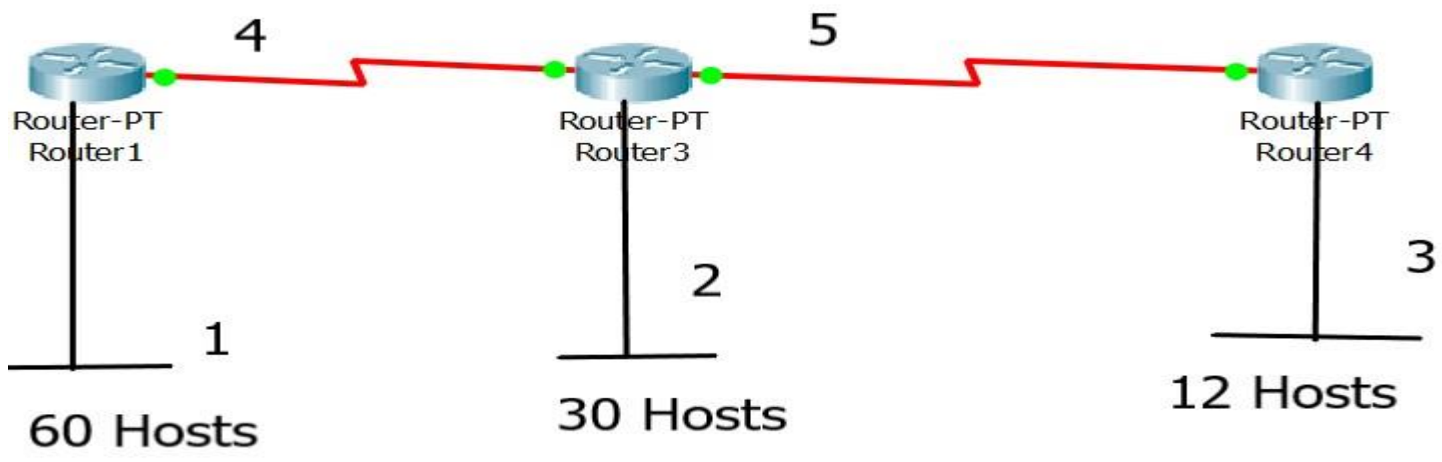
Subnet	**0.0.0**	**1.0.0**	**…**	**254.0.0**	**255.0.0**
Network Address	10.0.0.0	10.1.0.0	…	10.254.0.0	10.255.0.0
First Host Address	10.0.0.1	10.1.0.1	…	10.254.0.1	10.255.0.1
Last Host Address	10.0.255.254	10.1.255.254	…	10.254.255.254	10.255.255.254
Broadcast Address	10.0.255.255	10.1.255.255	…	10.254.255.255	10.255.255.255

VLSM

- Subnetting replaces the two level IP addressing scheme with a three level hierarchy and subnet ID is the same length throughout the network(Fixed Length Subnet Mask).
- This can be a problem if we have subnetworks with very different numbers of hosts on them. If we choose the subnet ID based on whichever subnet has the greatest number of hosts, even if most of subnets have far fewer host requirement.
- This will be inefficient as much of the valuable IP address space will be wasted in subnets with fewer host requirements.
- VLSM allows designers to reduce number of wasted IP addresses in each subnet by creating many subnetworks using subnet mask of different lengths.
- The idea is to subnet the network, and then subnet the subnets just the way the original network was sub-netted. Also called sub – subnetting.

VLSM

- Example



- Network Address 192.168.10.0 Default Mask 255.255.255.0(/24)
- Start with network having maximum host requirement.
- In our case , it is Network # 1
- If we subnet using 2 bits then,
- Total Number of subnets = $2^2 = 4$; Valid Hosts per subnet = $2^y - 2 = 2^6 - 2 = 62\ Hosts$
- Our requirement for network # 1 is of 60 hosts so this subnet mask fulfils the requirement.
- Subnet Mask will be 255.255.255.192(/26)

VLSM

Four subnets will be:

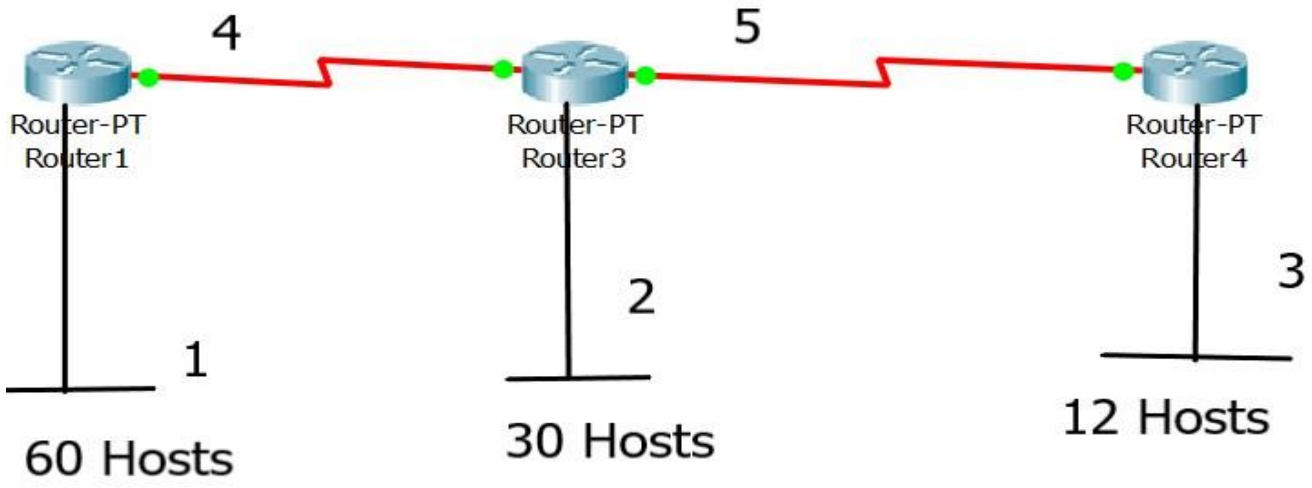
Subnet 0: 192.168.10.00000000 (192.168.10.0)

Subnet 64: 192.168.10.01000000 (192.168.10.64)

Subnet 128: 192.168.10.10000000 (192.168.10.128)

Subnet 192:192.168.10.11000000 (192.168.10.192)

We choose subnet 64 and assign it to network # 1



192.168.10.64 (/26)
Possible Hosts = 62
No of wasted IP Addresses = 2

Network Address	**192.168.10.64(/26)**
Subnet Mask	255.255.255.192(/26)
First Host Address	192.168.10.65
Last Host Address	192.168.10.126
Broadcast Address	192.168.10.127

VLSM

For Network # 2

We choose subnet 128 for sub-subnetting

We choose to further subnet on 1 bit ;

Total Number of sub-subnet = $2^1 = 2$

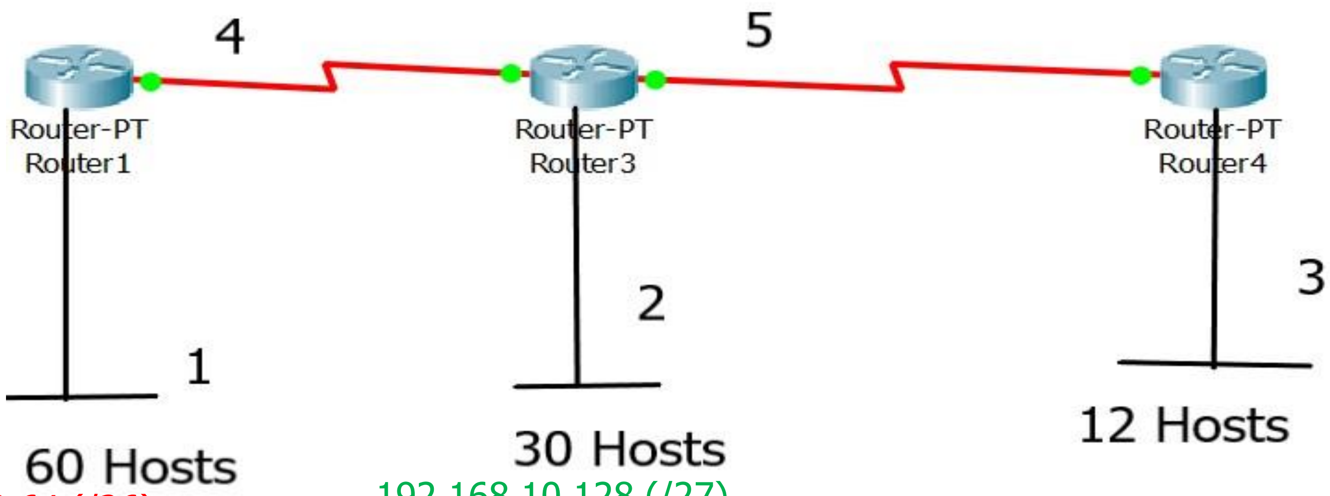
Valid Hosts per sub-subnet = $2^y - 2 = 2^5 - 2 = 30\ Hosts$

Two sub-subnets:

Network Address	192.168.10.128(/27)
Subnet Mask	255.255.255.224(/27)
First Host Address	192.168.10.129
Last Host Address	192.168.10.158
Broadcast Address	192.168.10.159

Subnet 128: 192.168.10.10000000 (192.168.10.128) (Assign it to Network # 2)

Subnet 160: 192.168.10.10100000 (192.168.10.160)



192.168.10.64 (/26)
Possible Hosts = 62
No of wasted IP Addresses = 2

192.168.10.128 (/27)
Possible Hosts = 30
No of wasted IP Addresses = 0

VLSM

For Network # 3

We choose subnet 160 for sub-subnetting

We choose to further subnet on 1 bit ;

Total Number of sub-subnet = $2^1 = 2$

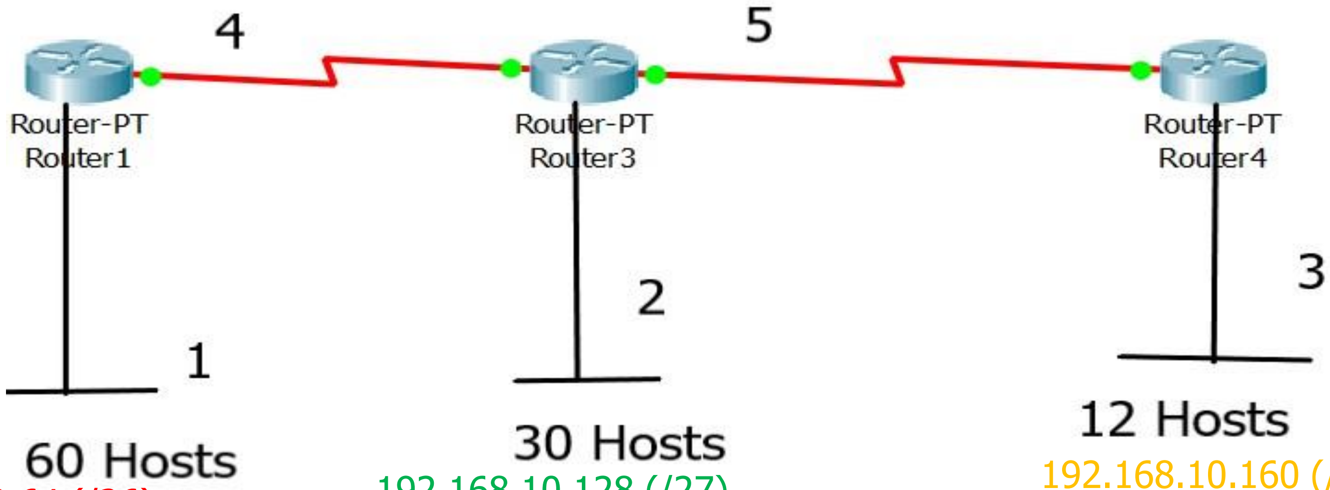
Valid Hosts per sub-subnet = $2^y - 2 = 2^4 - 2 = 14\ Hosts$

Two sub-subnets:

Subnet 160: 192.168.10.10100000 (192.168.10.160) (Assign it to Network # 3)

Subnet 176: 192.168.10.10110000 (192.168.10.176)

Network Address	**192.168.10.160(/28)**
Subnet Mask	255.255.255.240(/28)
First Host Address	192.168.10.161
Last Host Address	192.168.10.174
Broadcast Address	192.168.10.175



192.168.10.64 (/26)
Possible Hosts = 62
No of wasted IP Addresses = 2

192.168.10.128 (/27)
Possible Hosts = 30
No of wasted IP Addresses = 0

192.168.10.160 (/28)
Possible Hosts = 14
No of wasted IP Addresses = 2

VLSM

For Network # 4 & 5

We choose subnet 176 for sub-subnetting

We choose to further subnet on 2 bits ;

Total Number of sub-subnet = $2^2 = 4$

Valid Hosts per sub-subnet = $2^y - 2 = 2^2 - 2 = 2\ Hosts$

Four sub-subnets:

Subnet 176: 192.168.10.10110000 (192.168.10.176)

Subnet 180: 192.168.10.10110100 (192.168.10.180) (Assign it to Network # 4)

Subnet 184: 192.168.10.10111000 (192.168.10.184) (Assign it to Network # 5)

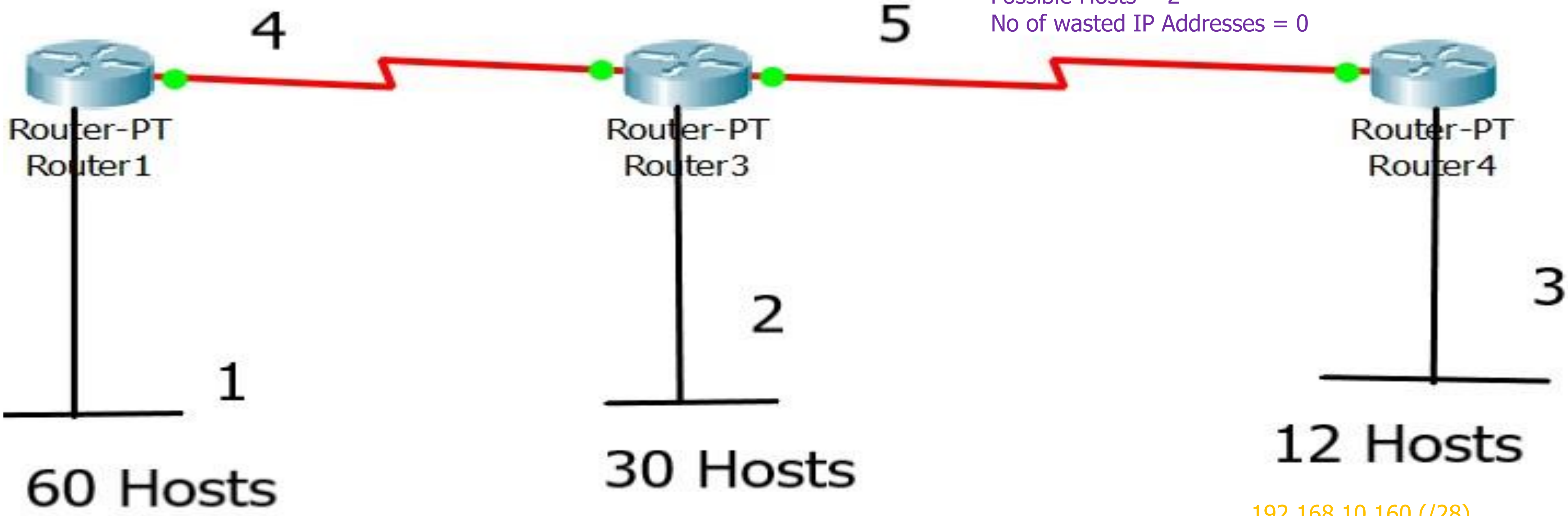
Subnet 188: 192.168.10.10111100 (192.168.10.188)

Network Address (4)	**192.168.10.180(/30)**
Subnet Mask	255.255.255.252(/30)
First Host Address	192.168.10.181
Last Host Address	192.168.10.182
Broadcast Address	192.168.10.183

Network Address (5)	**192.168.10.184(/30)**
Subnet Mask	255.255.255.252(/30)
First Host Address	192.168.10.185
Last Host Address	192.168.10.186
Broadcast Address	192.168.10.187

192.168.10.180 (/30)
Possible Hosts = 2
No of wasted IP Addresses = 0

192.168.10.184 (/30)
Possible Hosts = 2
No of wasted IP Addresses = 0



192.168.10.64 (/26)
Possible Hosts = 62
No of wasted IP Addresses = 2

192.168.10.128 (/27)
Possible Hosts = 30
No of wasted IP Addresses = 0

192.168.10.160 (/28)
Possible Hosts = 14
No of wasted IP Addresses = 2