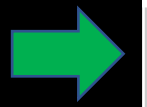
Computer Networks

Addressing and Subnetting



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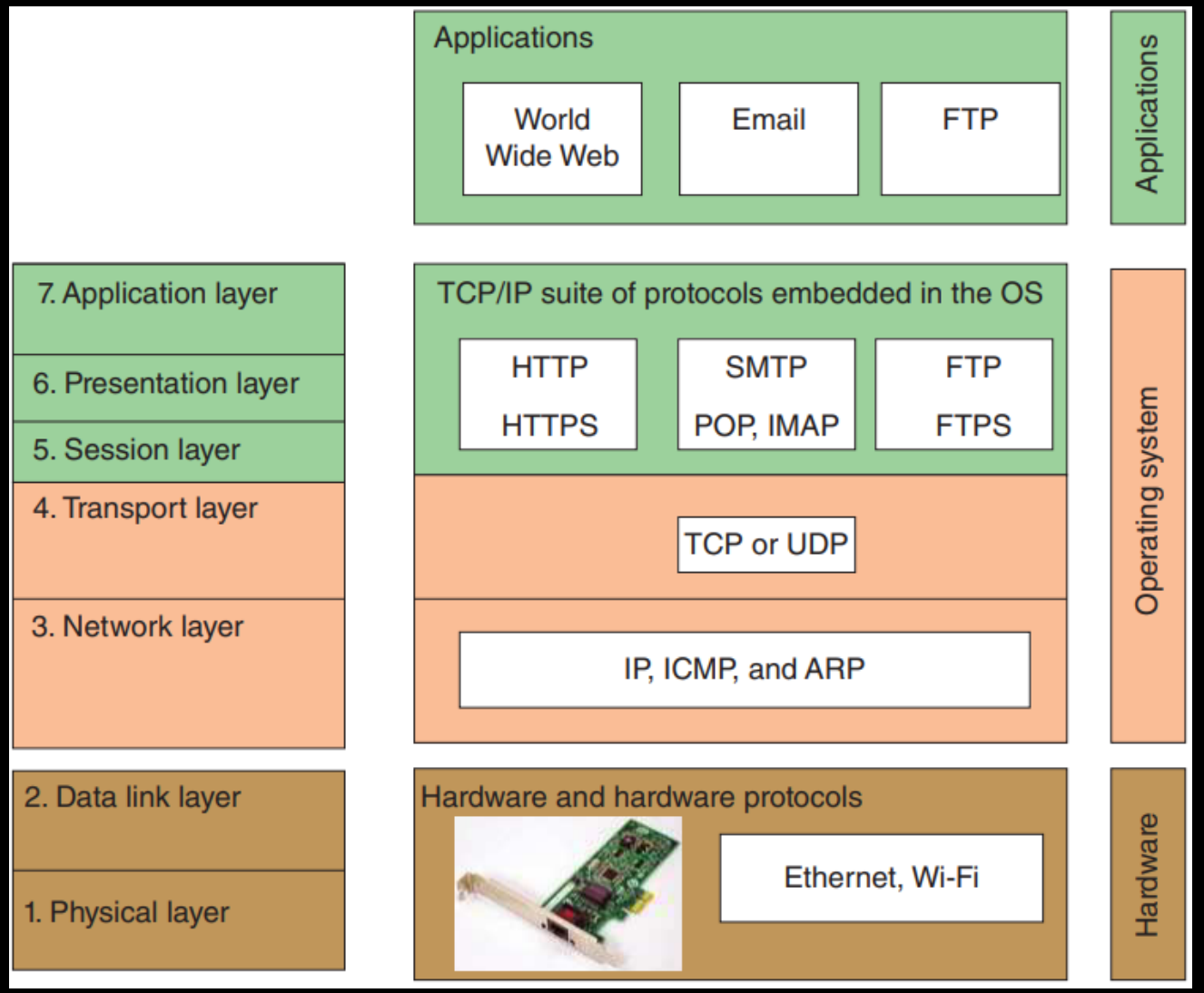
Addressing Overview

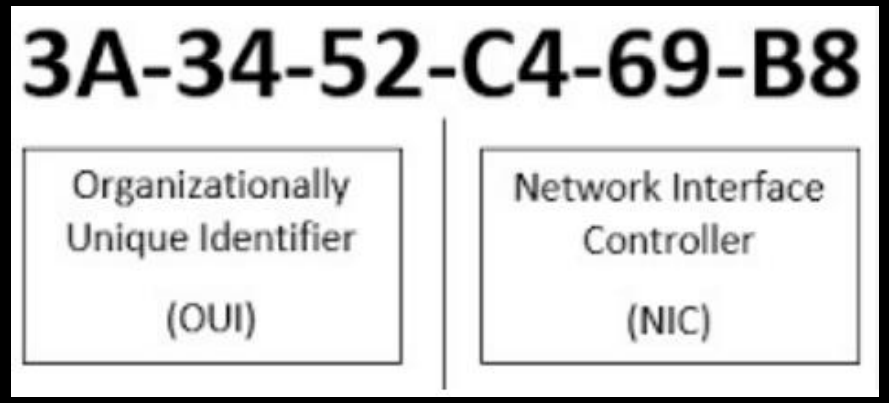
- Addressing methods operate at the **data link**, **network**, **transport**, and **application** layers of the OSI model.

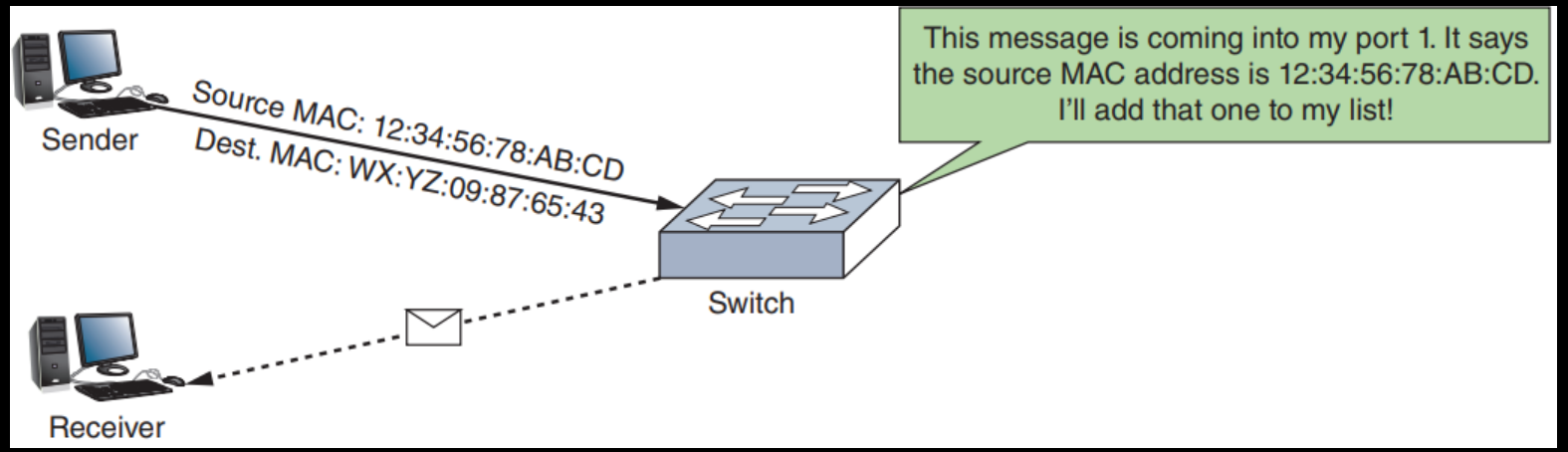


Addressing Overview

Data link layer - Media Access Control (MAC) address.

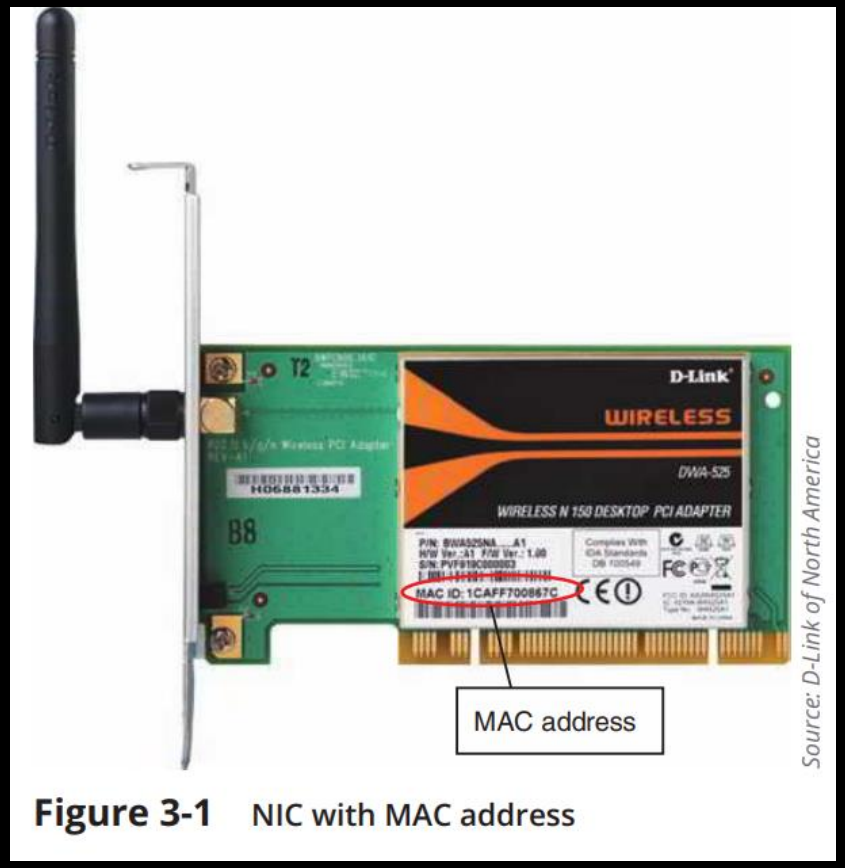
- MAC address is a unique address embedded on the NIC.
- A MAC address is 48 bits, written as six hex numbers separated by colons
  - Example: 00:60:8C:00:54:99.
- Switches use MAC addresses to decide where to send messages on the LAN.





Addressing Overview

Data link layer - Media Access Control (MAC) address.



Source: D-Link of North America

Figure 3-1 NIC with MAC address

https://i0.wp.com/learntomato.flashrouters.com/wp-content/uploads/MAC-address-hardware.jpg?resize=560%2C315&ssl=1

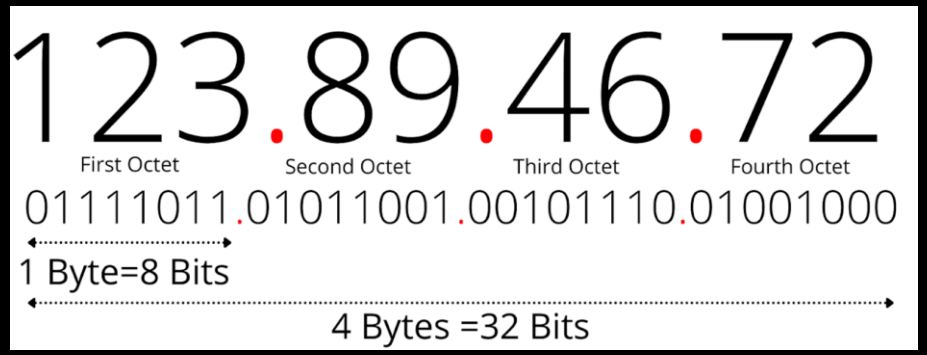
Addressing Overview

Network layer – IP (Internet Protocol) address

- An IP address is assigned to **interfaces**
  - An interface is a network connection made by a node on a network.
- An IP address can be used to find any computer in the world if the IP address is public on the Internet.
- Routers check IP addresses to determine which network a message is destined for.

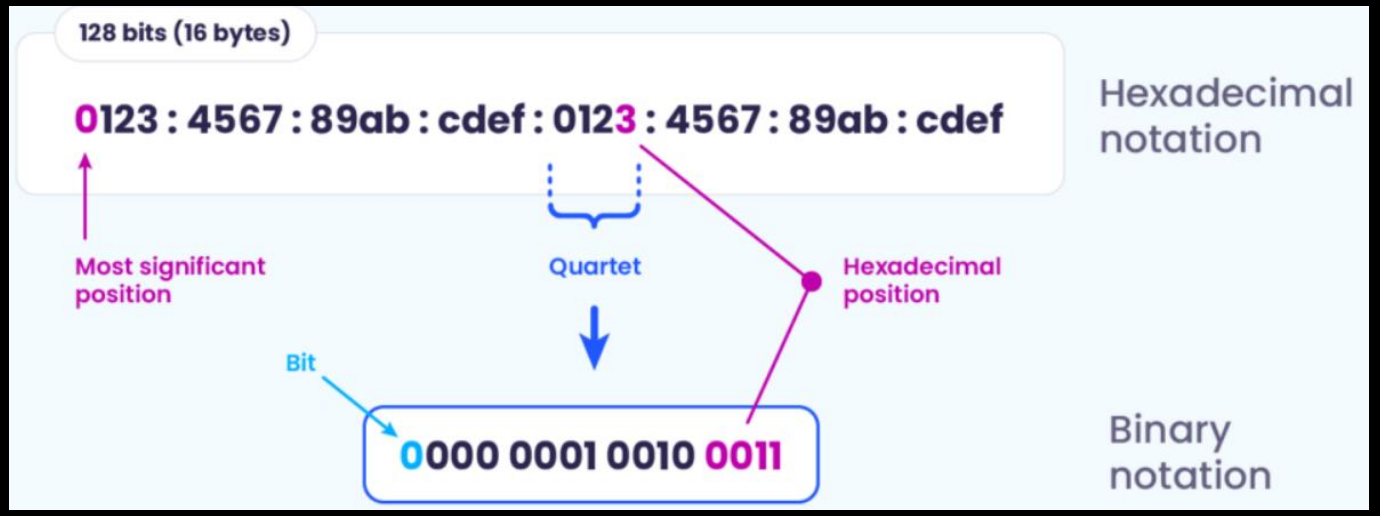
Addressing Overview

- There are two types of IP addresses:
  - **IPv4**



https://whatwherebest.com/wp-content/uploads/2022/10/Figure-1-IPv4Addressformatwithdotteddecimalnotation-29c824f6a451d48d8c27759799f0c995.png

  - **IPv6**

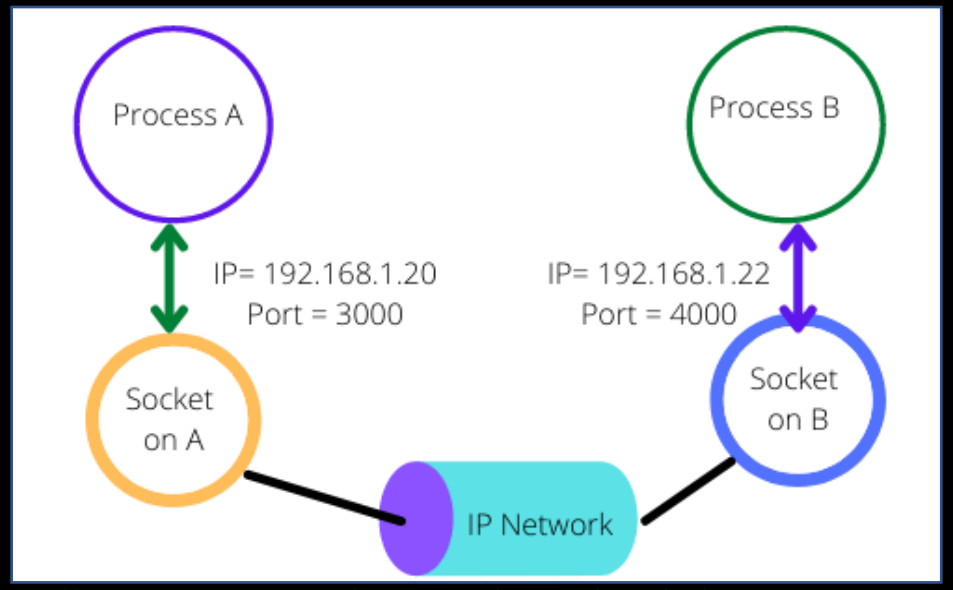


https://www.ipxo.com/app/uploads/2021/08/IPv6-1024x576.png

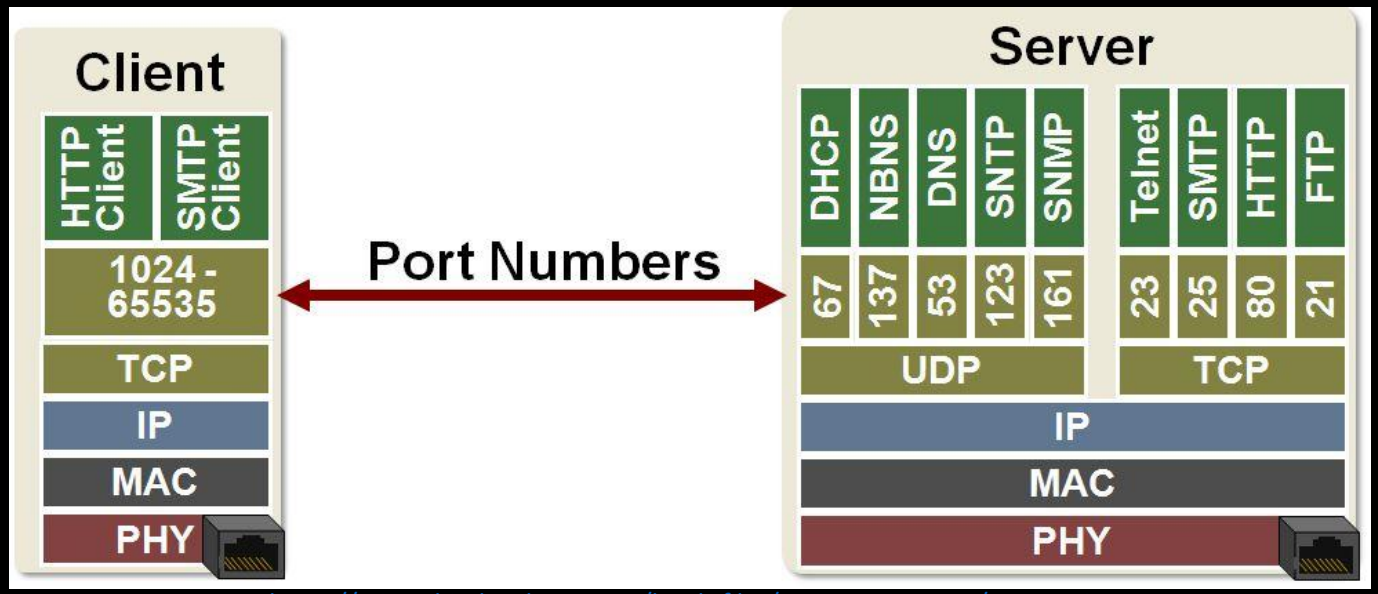
Addressing Overview

Transport layer – Port number

- A port is a number used by the transport layer to find an application.
- It identifies one application among several that might be running on a host.
  - Example, a web application listens for incoming requests at port 80 or port 443.



https://www.cspsprotocol.com/wp-content/uploads/2021/08/Process-and-socket.png

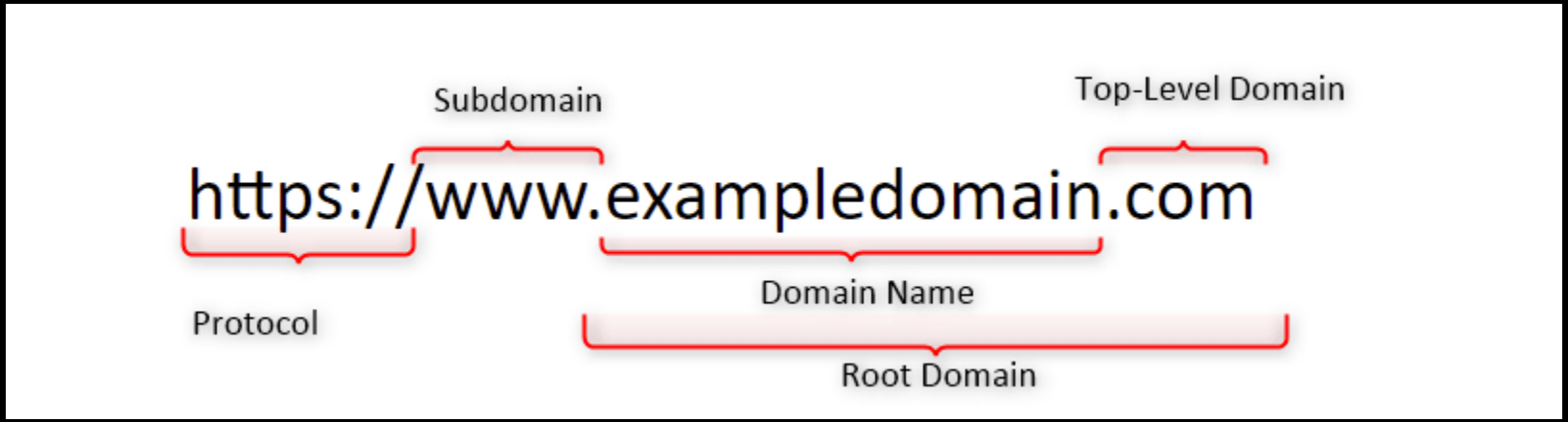


https://microchipdeveloper.com/local--files/tcpip:tcp-ip-ports/ports.JPG

Addressing Overview

Application layer – domain names, computer names, and host names

- Every host on a network is assigned a unique character-based name called the **FQDN** (fully qualified domain name)
  - Example, susan.mycompany.com, ftp.mycompany.com, and www.mycompany.com.



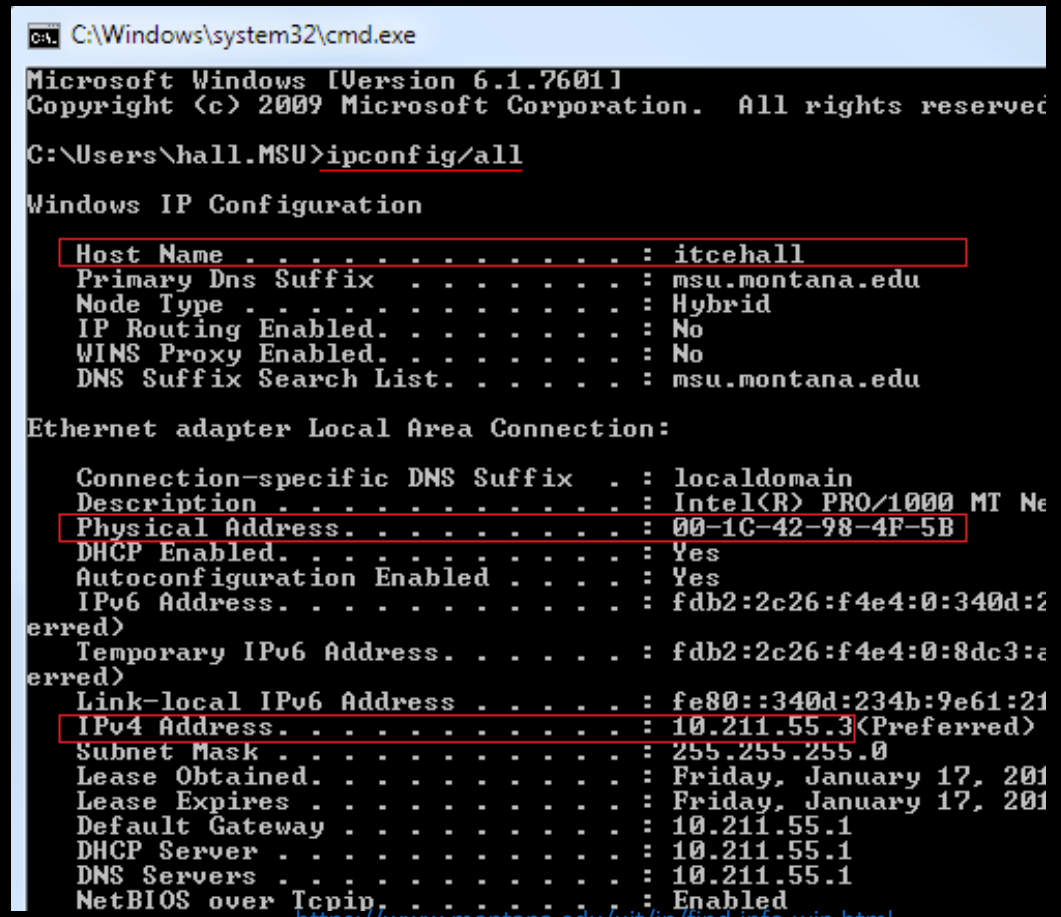
https://res.cloudinary.com/lwgatsby/f_auto/www/uploads/2021/08/fqdn-1-fqdn.png

Addressing Overview

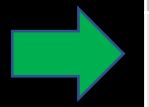
- The organization responsible for tracking the assignments of IP addresses, port numbers, and domain names is **IANA** (Internet Assigned Numbers Authority).
- IANA is a department of **ICANN** (Internet Corporation for Assigned Names and Numbers).
- ICANN is a non-profit organization charged with setting many policies that guide how the Internet works.

Addressing Overview

- To find the hostname, IP address and MAC address:
  1. Open CMD
  2. Write $ipconfig\ /all$



https://www.montana.edu/uit/ip/find-info-win.html



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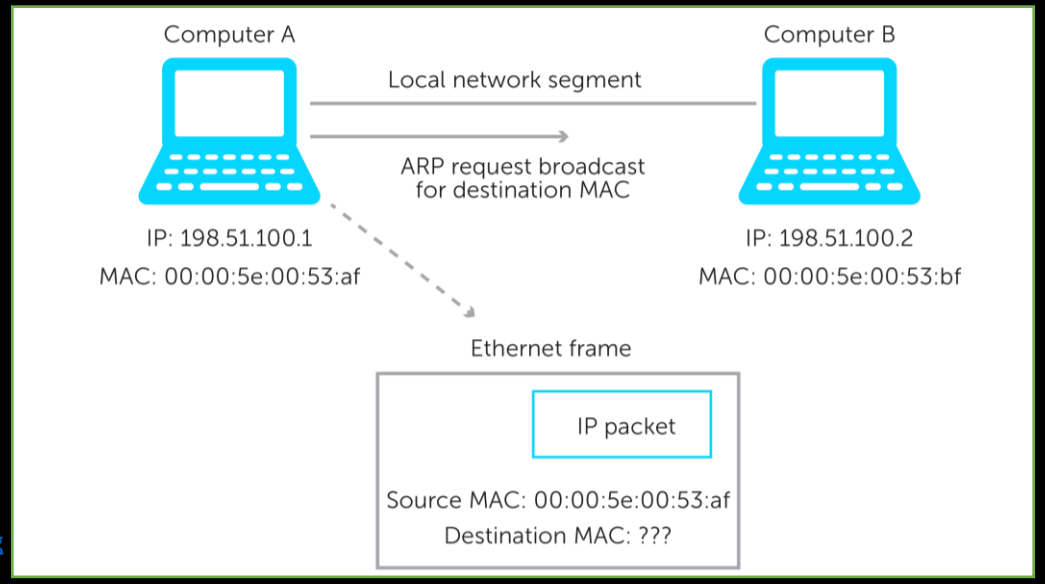
IPv4 Address

- MAC addresses are used for communication inside a local network.
  - Switches need MAC addresses to identify devices in a network.
- IP address is used to communicate outside the local network through a gateway device such as a router.
  - Routers rely on IP addresses to locate devices across networks.



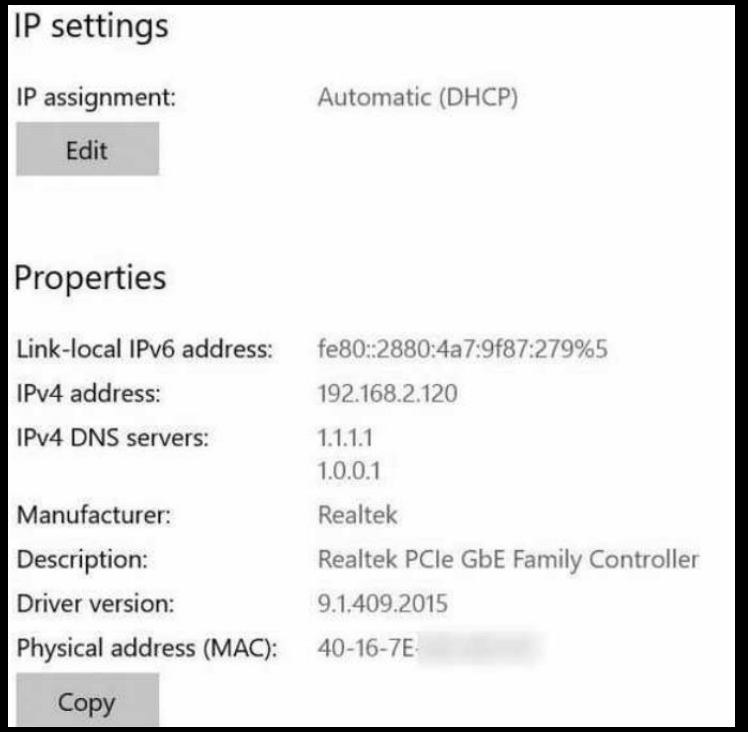
https://bluecatnetworks.com/wp-content/uploads/2021/05/MAC-address-vs-IP-address.png

IPv4 Address

- IPs can be:
  - **Static**: persistent IP address assigned to a device.
  - **Dynamic**: a device receives an IP each time it connects to the network from the DHCP server.
- A DHCP server manages the dynamic distribution of IP addresses to devices on a network.

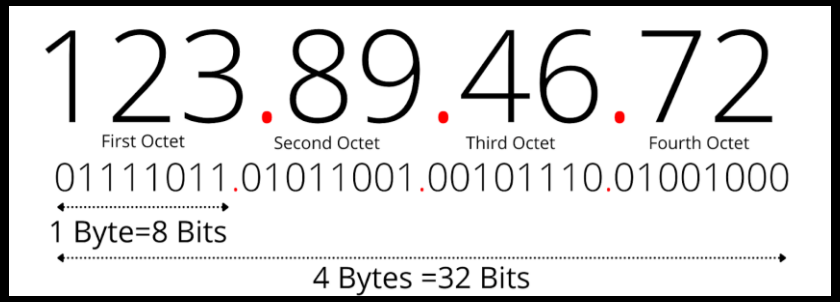
IPv4 Address

- To check TCP/IP settings on your Windows computer:
  1. Right-click the active network connection icon on the right side of your taskbar near the date and time and then click **Open Network & sharing center**.
  2. On the left pane, click on **Change adapter settings**.
  3. Select the network device, right-click, select **Properties**.
     1. Alternatively, select the **Status** to view the details of the network.
  4. Scroll down to the **TCP/IPv4**, click **Properties**.



IPv4 Address

- A 32-bit IP address is organized into four groups of 8 bits each.
  - The 8 bits groups are presented as four decimal numbers separated by periods.
  - Each of these four groups is called an octet.

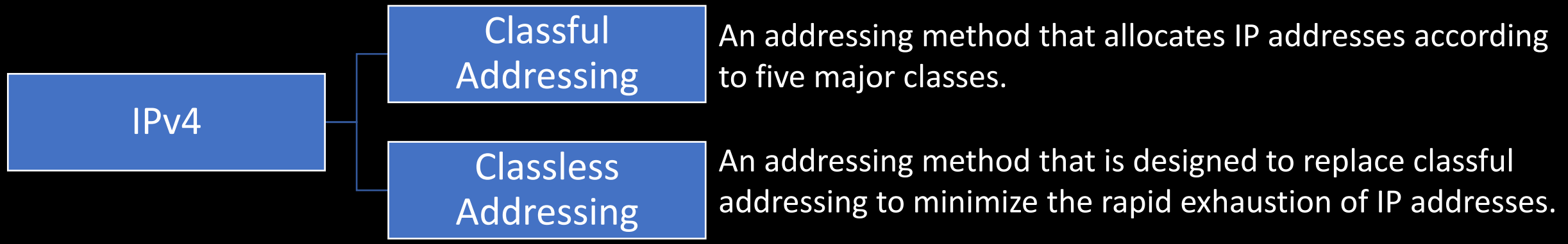


https://whatwherebest.com/wp-content/uploads/2022/10/Figure-1-IPv4Addressformatwithdotteddecimalnotation-29c824f6a451d48d8c27759799f0c995.png

- The largest possible 8-bit number is 11111111, which is equal to 255 in decimal.
  - The largest possible IP address is 255.255.255.255 (11111111. 11111111. 11111111. 11111111).
- Each of the four octets can be any number from 0 to 255, making a total of 4.3 billion IPv4 addresses (256 × 256 × 256 × 256).

IPv4 Address

- IPv4 addresses are divided into two parts
  - The first part identifies the network.
  - The second part identifies the hosts inside the network.
- There are two methods for formatting IPv4 address.



IPv4 Address – Classful Addressing

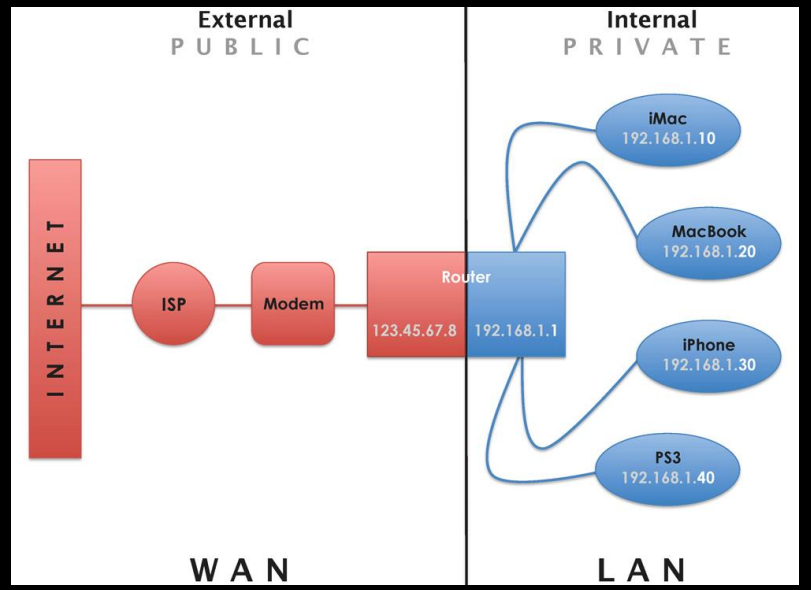
- Classful IPv4 addresses are categorized into five classes: A, B, C, D, E.
  - Classes A, B, and C addresses are used to connect to and access Internet resources.
  - Class D used for multicasting – one host sends messages to multiple hosts.
  - Class E used for research.
- A subnet mask is a 32 bits address used to distinguish between a network address and a host address in IP address.

Class	First Octet decimal (range)	First Octet binary (range)	IP range	Subnet Mask	Hosts per Network ID	# of networks
Class A	0 – 127	0XXXXXXX	0.0.0.0-127.255.255.255	255.0.0.0	$2^{24}-2$	2^{7}
Class B	128 – 191	10XXXXXX	128.0.0.0-191.255.255.255	255.255.0.0	$2^{16}-2$	2^{14}
Class C	192 – 223	110XXXXX	192.0.0.0-223.255.255.255	255.255.255.0	$2^{8}-2$	2^{21}

https://miro.medium.com/max/1400/1*wbYRk65-lnwsWYSFJ656xw.png

IPv4 Address – Classful Addressing

- Although IPv4 allows 4.3 billion addresses, the number of devices communicating on the Internet far exceeds this number.
- To conserve its **public IP** addresses, a company can instead use **private IP** addresses for devices on its private networks
  - Devices that do not directly connect to the Internet but instead communicate through a representative device such as a router.



http://www.tech-otaku.com/wp-content/uploads/1351-01-a-home-local-area-network-lan.png

IPv4 Address – Classful Addressing

- Other reserved IP addresses

IP address(es)	Function
255.255.255.255	Used for broadcast messages by TCP/IP background processes. A **broadcast** message is read by every node on the network. Recall that a LAN is defined as a group of computers and other devices that can directly address each other without going through a router. Technically, a LAN, which consists of all the nodes a broadcast reaches, can be referred to as a **broadcast domain**. Routers don't forward broadcast messages, thus, creating a boundary for a LAN.
0.0.0.0	Currently unassigned
127.0.0.1 through 127.255.255.254	Used for research or can indicate your own computer, in which case it is called the **loopback address**. Later in this module, you will learn to use the loopback address to verify that TCP/IP is configured correctly on a computer when it can talk to and hear itself on the loopback interface.
169.254.0.1 through 169.254.255.254	Used to create an **APIPA (Automatic Private IP Addressing)** address when a computer configured for DHCP first connects to the network and is unable to lease an IPv4 address from the DHCP server. Notice that nearly any IP address starting with 169.254. is identified as an APIPA address.

IPv4 Address – Classful Addressing

The disadvantage of classful addressing – IP addresses wastage

- Suppose you are designing a network for an enterprise for 5000 end hosts.
- You have to choose the best-fit network class to avoid wasting IP addresses.
- Class C network will not fit, since it allows a maximum of 254 end host.
- Class B network will be a good option, as it allows a maximum of 65,000 end host.
- But class B will waste 65,000 – 5000 = 60,000 addresses.

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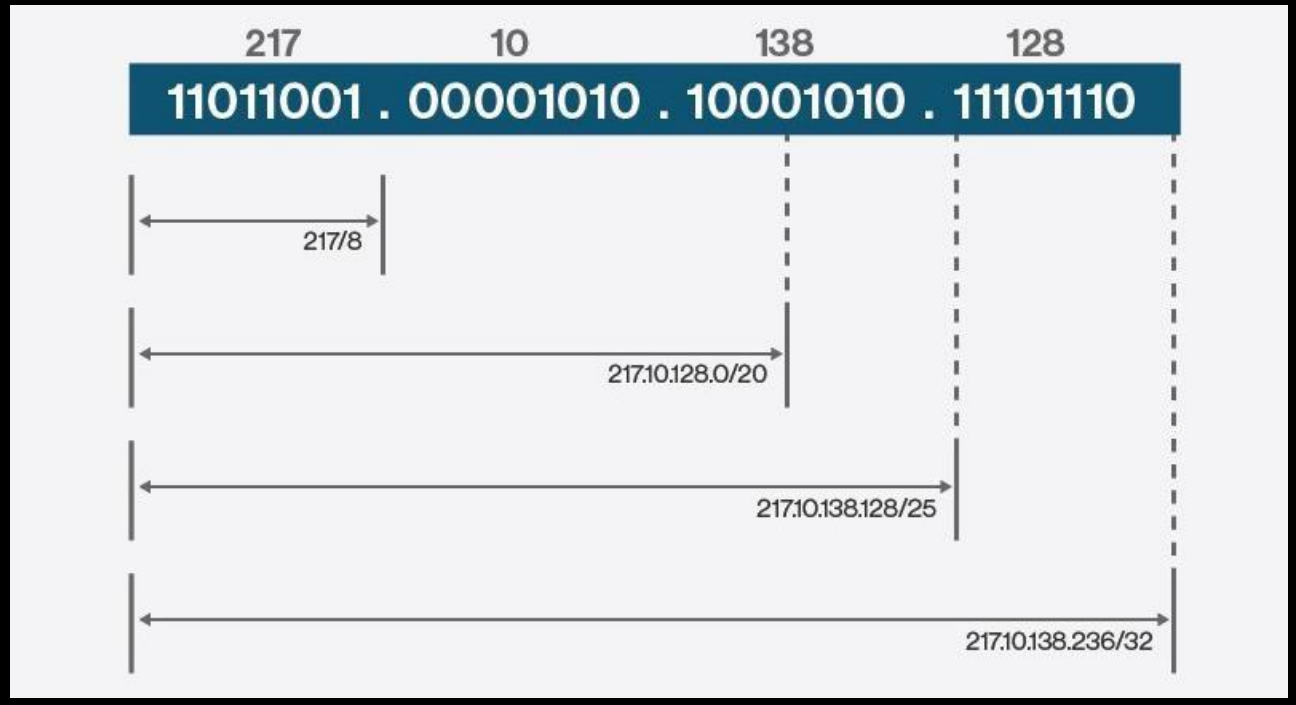
We need a more flexible addressing approach,,,
classless addressing / **CIDR** (Classless Inter-Domain Routing)

IPv4 Address – Classless Addressing

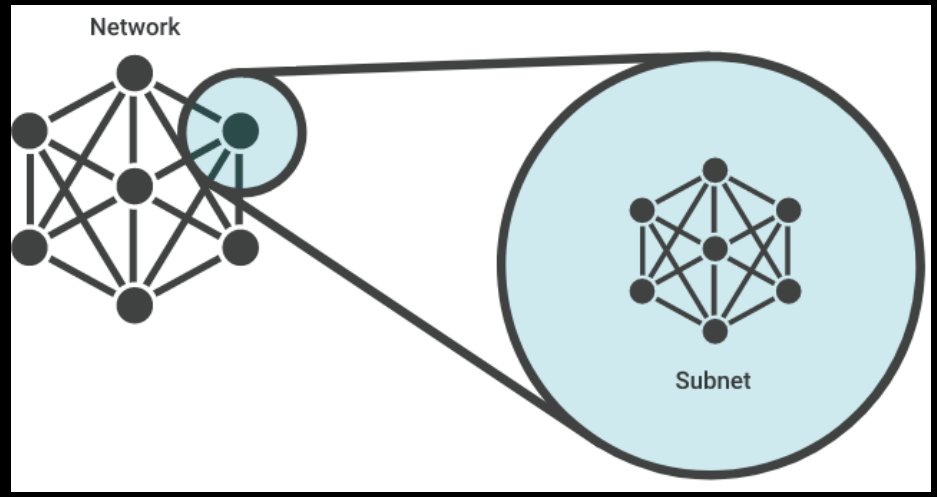
- In classless addressing, you don't look at an IP numerical range and know how many octets identify the network and the host.
  - You rely on a variety of subnet mask values to communicate any number of bits used for the network or host portions.
  - In CIDR notation, the IP address is written as: *IP address/subnet mask*, where subnet mask defines the number of bits in the network ID.



IPv4 Address – Classless Addressing

What is a subnet?

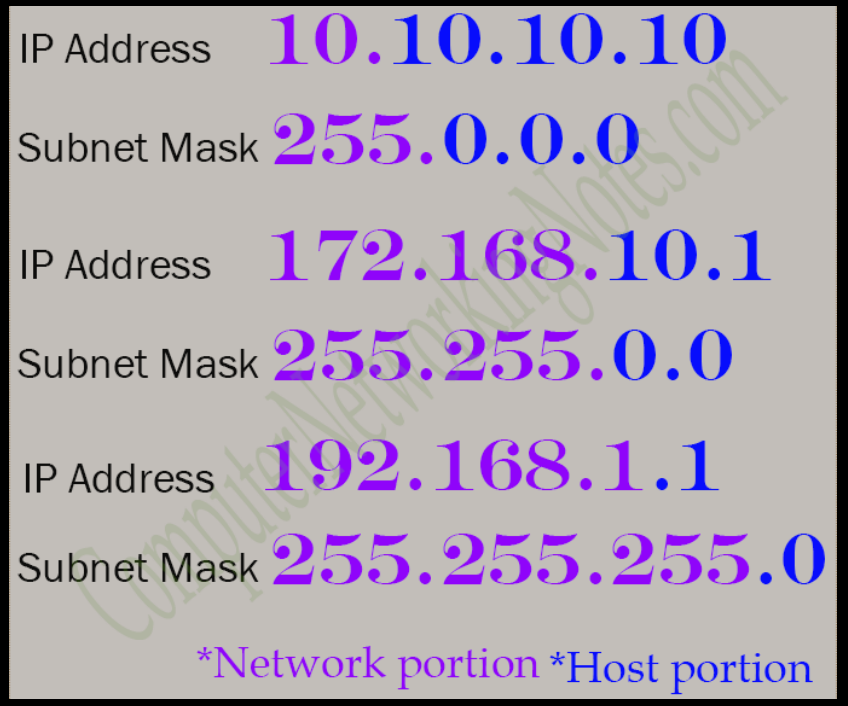
- A subnetwork, is a network inside a network.
- Subnets make networks more efficient.
  - Network traffic can travel a shorter distance without passing through unnecessary routers to reach its destination.
  - Prevent consuming a large number of IP addresses.



IPv4 Address – Classless Addressing

What is a subnet mask?

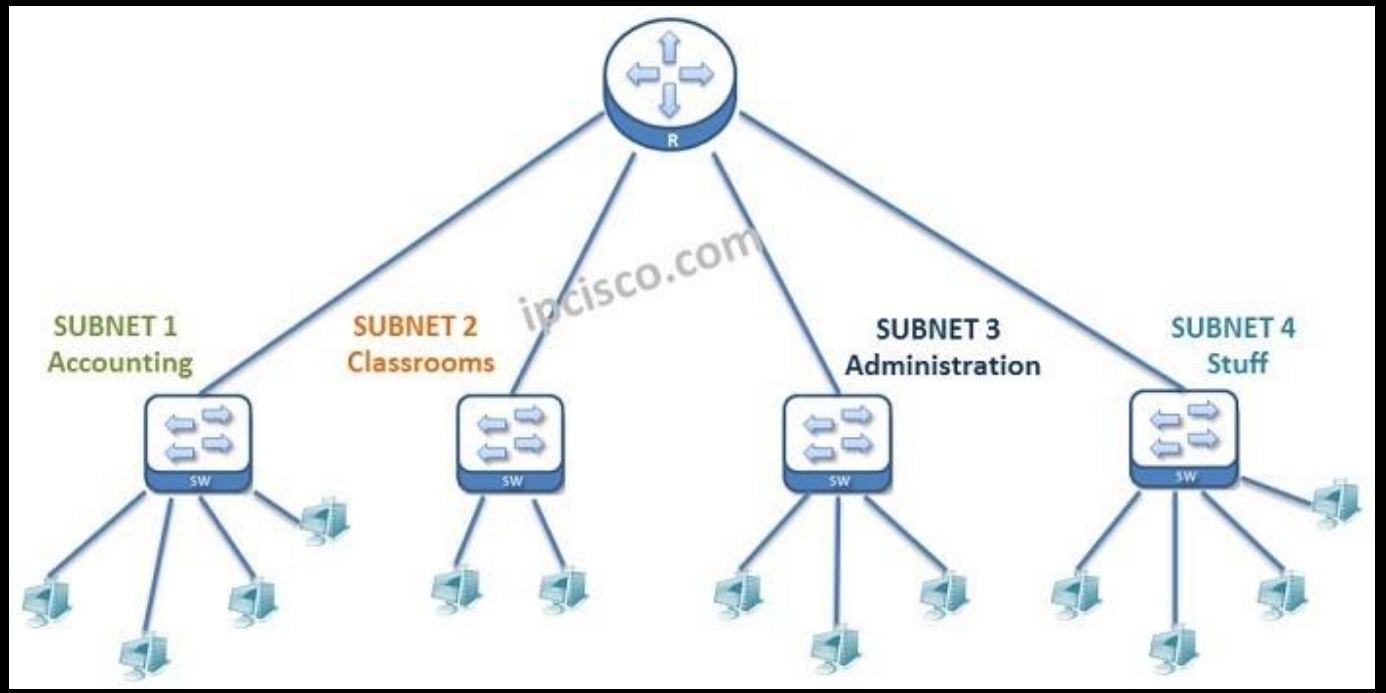
- A subnet mask is a 32 bits are used to indicate what part of an IP address's bits are the network portion (network ID), and which bits consist of the host portion (host ID).



IPv4 Address – Classless Addressing

What is a subnetting?

- The process of dividing an IP address into a network portion and a host portion – i.e., deciding the number of subnetworks and the number of hosts.



https://ipcisco.com/wp-content/uploads/2019/10/subnetting-mask.jpg

IPv4 Address – Classless Addressing

How subnet masks work?

How to segment your network?

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Subnetting

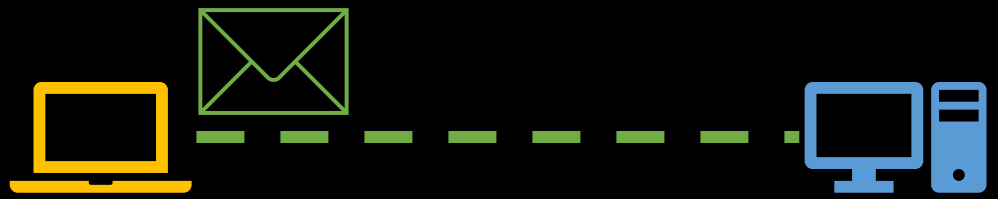
- A device uses a subnet mask to determine which subnet or network it belongs to.
- You can know which part of the IP identifies the network and which part identifies the host by looking at the subnet mask.
  - For example: 255.255.255.0 (/24)

IP Address	142 . 110 . 237 . 1
Network Mask	255 . 255. 255 . 0
Network Address	142 . 110 . 237 . 0
Host Address	0 . 0 . 0 . 1

https://www.telecomworld101.com/images/Reference/NetworkMask.jpg

Subnetting

- Suppose computer A is ready to transmit a message to compute B.
  - Computer A first compares the bits in its own network ID to the bits in the network ID of computer B.
  - If the bits match, then A and B are in the same network, so A sends the message to B directly.
  - If the bits don’t match, then B is in another network, so A sends the message to the default gateway.
  - The gateway is responsible for sending the message to the correct network.



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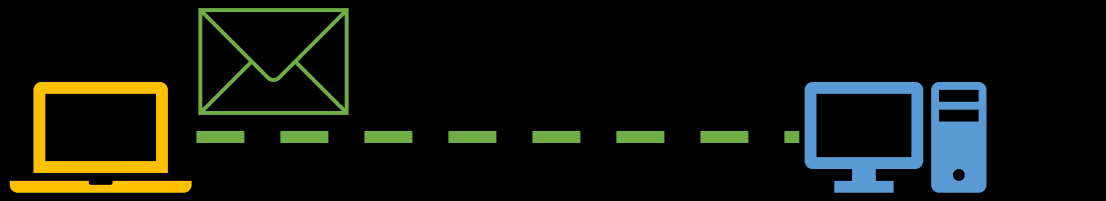
abc.abc.abc.abc/24
==
xyz.xyz.xyz.xyz/24
?



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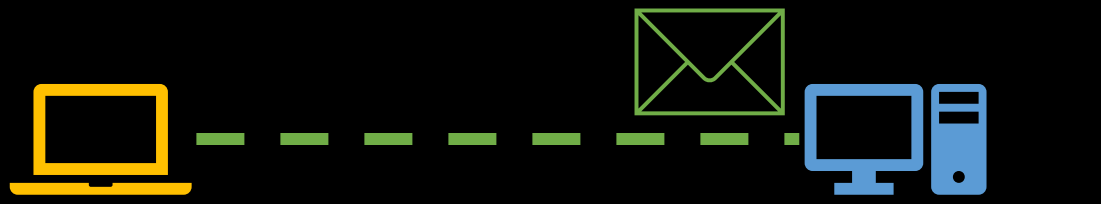
abc.abc.abc.abc/24
==
xyz.xyz.xyz.xyz/24
? YES ☺



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abc.abc.abc.abc/24
==
xyz.xyz.xyz.xyz/24
? NO ☹

xyz.xyz.xyz.xyz/24

abc.abc.abc.abc/24

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abc.abc.abc.abc/24
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Subnetting

How does a computer use a subnet mask to determine how many bits of its IP address is the network ID?

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How does a computer use a subnet mask to determine how many bits of its IP address is the network ID?

- The number of 1s in the subnet mask's bits determines the number of bits in the IP address that belong to the network ID.
- Example: given an IP address of 192.168.123.132 and subnet mask 255.255.255.0 (/24)

IP address	192.168.123.132	11000000.10101000.01111011.10000100
Subnet mask	255.255.255.0	11111111.11111111.11111111.00000000
Logical AND = network ID	192.168.123.0	11000000.10101000.01111011.00000000

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Subnet mask	255.255.255.0	11111111.11111111.11111111.00000000
Logical AND = network ID	192.168.123.0	11000000.10101000.01111011.00000000

Subnetting

- Now suppose that computer A has IP of 192.168.123.132/24 and computer B has IP of 192.168.30.140/24
- Because the network IDs don’t match, A sends the message to the gateway.
- Then, the gateway forwards the message to the network that contains computer B.

Subnetting

- In classful addressing, each network class is associated with a default subnet mask

Network class	Default subnet mask (binary)	Number of bits used for network information	Default subnet mask (dotted decimal notation)
A	**11111111** 00000000 00000000 00000000	8	**255**.0.0.0
B	**11111111 11111111** 00000000 00000000	16	**255.255**.0.0
C	**11111111 11111111 11111111** 00000000	24	**255.255.255**.0

Checkpoint

- Which of the following is *not* a benefit of subnetting?
    a. Problems are easier to locate and resolve.
    b. Available IP address space is managed more efficiently.
    c. Network documentation is easier to manage.
    d. Routers more easily manage IP address spaces that overlap.
- What is the network ID of the IP address 192.168.72.149/16?
    a. 0.0.0.149
    b. 192.168.0.0
    c. 0.0.72.149
    d. 192.168.72.0

Checkpoint

- Which of the following is *not* a benefit of subnetting?
  - a. Problems are easier to locate and resolve.
  - b. Available IP address space is managed more efficiently.
  - c. Network documentation is easier to manage.
  - d. Routers more easily manage IP address spaces that overlap.
- What is the network ID of the IP address 192.168.72.149/16?
  - a. 0.0.0.149
  - b. 192.168.0.0
  - c. 0.0.72.149
  - d. 192.168.72.0

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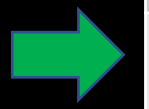
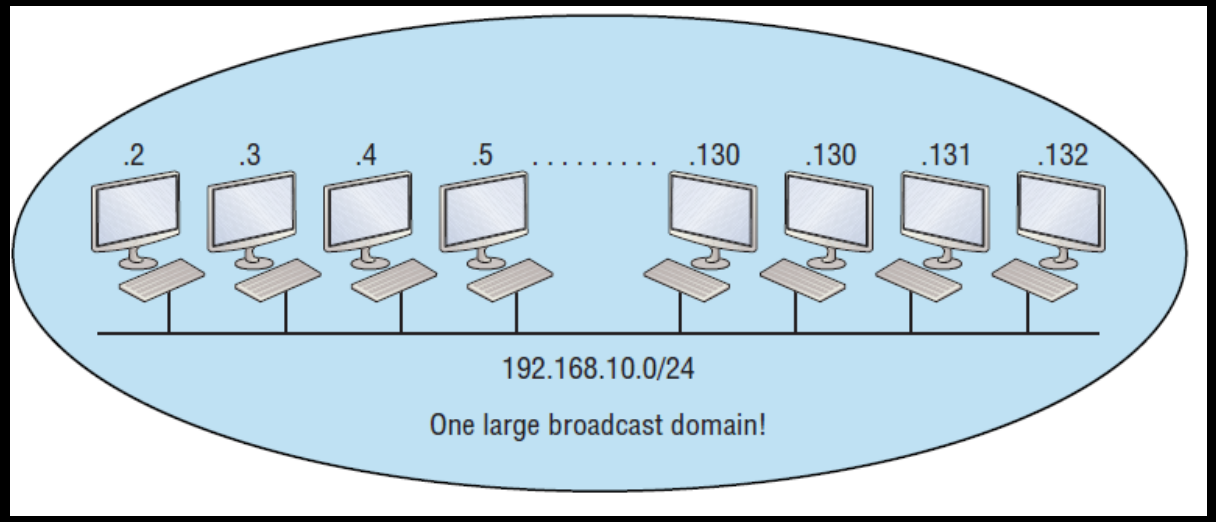
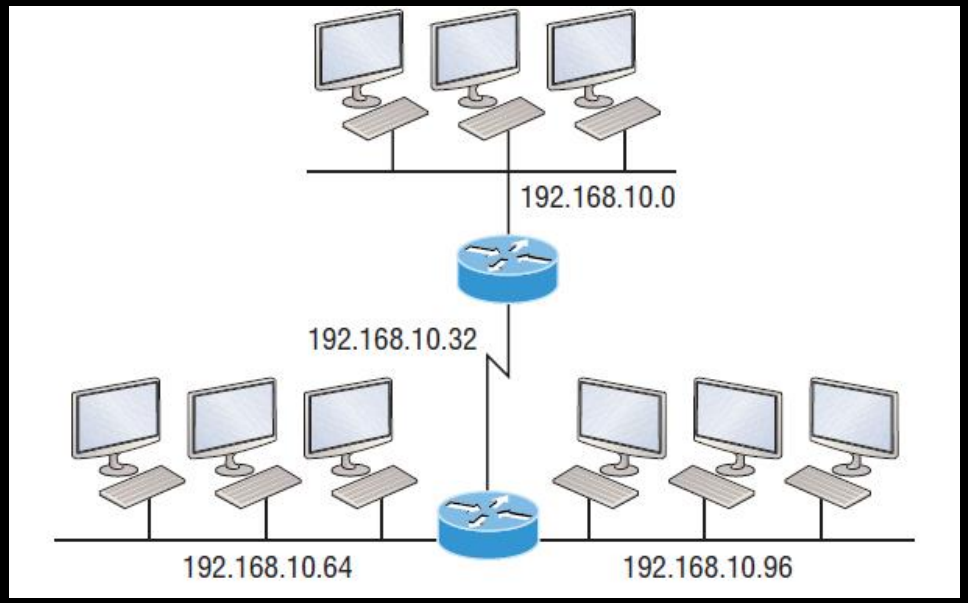


Calculating Subnets

- The goal of subnetting is increase the number of networks and reduce the number of hosts in each subnetwork.





Calculating Subnets

- Subnetting is done by borrowing bits from the host ID into the network ID.
  - The number of networks increases, while the number of hosts reduces.

IP	192.	168.	90.	100
IP binary	11000000	10101000	01100100	01011010
Subnet mask	255	255	255	0
Subnet mask binary	11111111	11111111	11111111	00000000

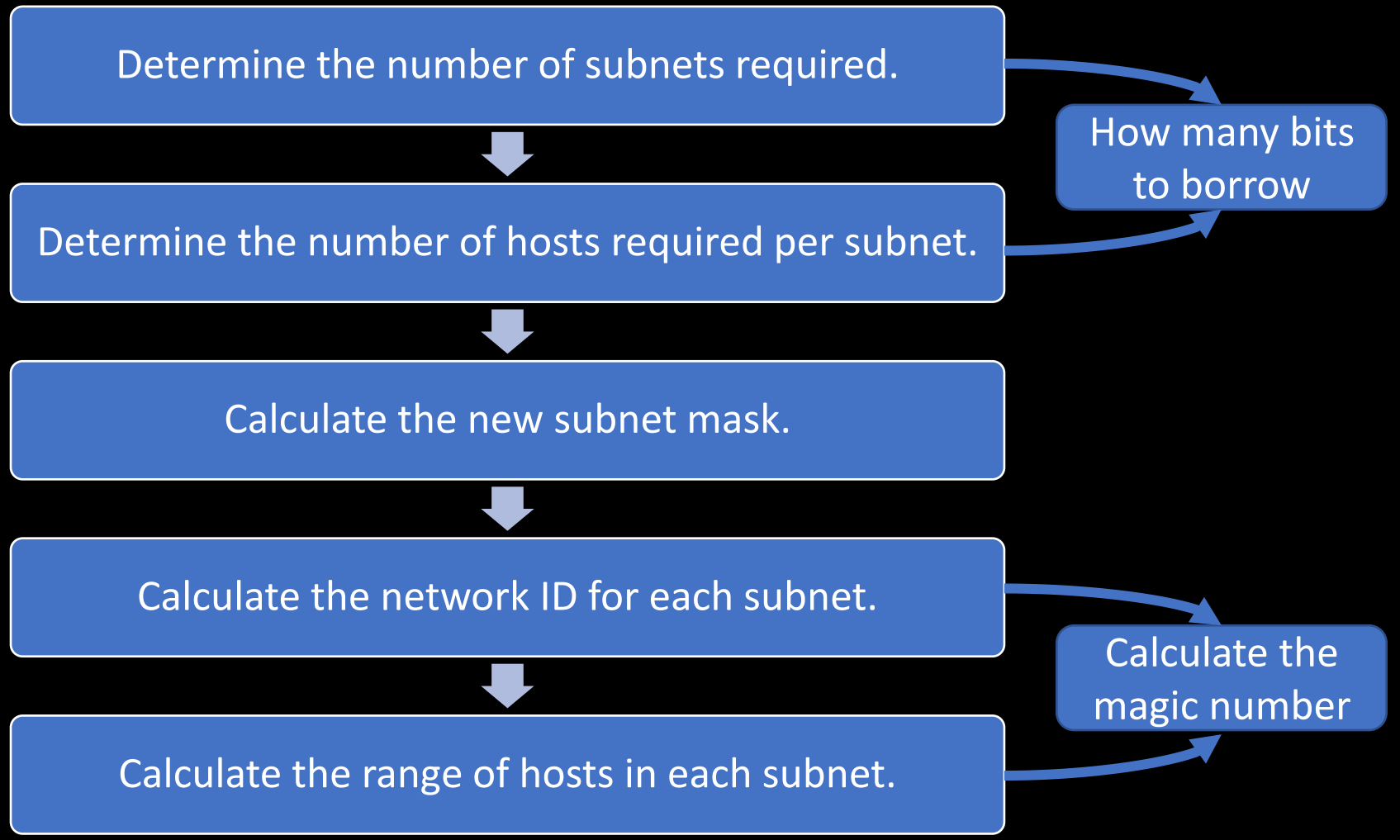
IP	192.	168.	90.	90
IP binary	11000000	10101000	01100100	01011010
Subnet mask	255	255	255	128
Subnet mask binary	11111111	11111111	11111111	10000000

- This class C network.
- It allows $2^8 = 256$ host.
- The IP address is **192.168.90.100/24**

- It allows $2^7 = 128$ host.
- The IP address is **192.168.90.100/25**
- The number of networks is increased by 2, while the number of hosts reduced by 128.

Calculating Subnets

- To perform subnetting:



Calculating Subnets

Example: Suppose you want to divide your local network, which has a network ID of 192.168.89.0, into six subnets.

Calculating Subnets

1. **How many bits to borrow?**

- Use the formula $2^n = Y$, where n is the number of bits to borrow from the host portion, and Y is the number of resulting subnets.
- We want 6 subnets, experiment different values for n.
- If we select $n = 2$, then $2^2 = 4$. Not enough.
- If we select $n = 3$, then $2^3 = 8$. This is will give you enough subnets to meet your needs.

Now, we have $n = 3$. We will borrow 3 bits form the host portion.

Calculating Subnets

2. Determine the new subnet mask.

- We know that the given IP is of class C network, so its default subnet mask is

  255.255.255.0 → 11111111 11111111 11111111 00000000 → (/24)

- We decided to borrow 3 bits from the host portion, so the new mask is

  11111111 11111111 11111111 11100000 → 255.255.255.224 → (/27)

Calculating Subnets

3. Calculate the network ID for each subnet.

- To do this, we first need to compute the *magic number*. $magic\ number\ =\ 2^h$. h is number of bits remaining in the host portion.
- There are 5 bits remaining in the host ID, so $magic\ number = 2^5 = 32$
- The magic number is used to calculate the network ID of each subnet.

Subnet 1: 192.168.89.0	**Subnet 2**: 192.168.89.0 + 32 = 192.168.89.32	**Subnet 3**: 192.168.89.32 + 32 = 192.168.89.64	**Subnet 4**: 192.168.89.64 + 32 = 192.168.89.96
Subnet 5: 192.168.89.96 + 32 = 192.168.89.128	**Subnet 6**: 192.168.89.128 + 32 = 192.168.89.160	**Subnet 7**: 192.168.89.160 + 32 = 192.168.89.192	**Subnet 8**: 192.168.89.192 + 32 = 192.168.89.224

Calculating Subnets

4. Determine the IP address range for hosts in each subnet.

- The number of **valid** hosts in each subnet is calculated by

$$magic\ number\ -2$$

We subtract two, because the first IP in the range is reserved for the network ID, and the last IP address is reserved for the broadcast address.

- So, the number of valid hosts in each subnet is $2^5 - 2 = 30$.
- You get the total number of hosts over the whole network

$$8 \text{ subnets} * 30 \text{ host/subnet} = 240 \text{ host}.$$

Calculating Subnets

Subnet number	Network ID (extended network prefix)	Range of host addresses	Broadcast address
1	192.168.89.0 or **11000000 10101000 01011001 000**00000	192.168.89.1-30	192.168.89.31 or **11000000 10101000 01011001 000**11111
2	192.168.89.32 or **11000000 10101000 01011001 001**00000	192.168.89.33-62	192.168.89.63 or **11000000 10101000 01011001 001**11111
3	192.168.89.64 or **11000000 10101000 01011001 010**00000	192.168.89.65-94	192.168.89.95 or **11000000 10101000 01011001 010**11111
4	192.168.89.96 or **11000000 10101000 01011001 011**00000	192.168.89.97-126	192.168.89.127 or **11000000 10101000 01011001 011**11111
5	192.168.89.128 or **11000000 10101000 01011001 100**00000	192.168.89.129-158	192.168.89.159 or **11000000 10101000 01011001 100**11111
6	192.168.89.160 or **11000000 10101000 01011001 101**00000	192.168.89.161-190	192.168.89.191 or **11000000 10101000 01011001 101**11111
7	192.168.89.192 or **11000000 10101000 01011001 110**00000	192.168.89.193-222	192.168.89.223 or **11000000 10101000 01011001 110**11111
8	192.168.89.224 or **11000000 10101000 01011001 111**00000	192.168.89.225-254	192.168.89.255 or **11000000 10101000 01011001 111**11111

Calculating Subnets

- The numbers of subnets and hosts that can be created by subnetting a class C network.

Subnet mask	CIDR block	Number of subnets on network	Number of hosts per subnet
255.255.255.128 or 11111111 11111111 11111111 10000000	/25	2	126
255.255.255.192 or 11111111 11111111 11111111 11000000	/26	4	62
255.255.255.224 or 11111111 11111111 11111111 11100000	/27	8	30
255.255.255.240 or 11111111 11111111 11111111 11110000	/28	16	14
255.255.255.248 or 11111111 11111111 11111111 11111000	/29	32	6
255.255.255.252 or 11111111 11111111 11111111 11111100	/30	64	2

Calculating Subnets

- The numbers of subnets and hosts that can be created by subnetting a class B network.

Subnet mask	CIDR block	Number of subnets on network	Number of hosts per subnet
255.255.128.0 or 11111111 11111111 10000000 00000000	/17	2	32,766
255.255.192.0 or 11111111 11111111 11000000 00000000	/18	4	16,382
255.255.224.0 or 11111111 11111111 11100000 00000000	/19	8	8190
255.255.240.0 or 11111111 11111111 11110000 00000000	/20	16	4094
255.255.248.0 or 11111111 11111111 11111000 00000000	/21	32	2046
255.255.252.0 or 11111111 11111111 11111100 00000000	/22	64	1022
255.255.254.0 or 11111111 11111111 11111110 00000000	/23	128	510
255.255.255.0 or 11111111 11111111 11111111 00000000	/24	256	254
255.255.255.128 or 11111111 11111111 11111111 10000000	/25	512	126
255.255.255.192 or 11111111 11111111 11111111 11000000	/26	1024	62
255.255.255.224 or 11111111 11111111 11111111 11100000	/27	2048	30
255.255.255.240 or 11111111 11111111 11111111 11110000	/28	4096	14
255.255.255.248 or 11111111 11111111 11111111 11111000	/29	8192	6
255.255.255.252 or 11111111 11111111 11111111 11111100	/30	16,384	2

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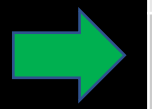

Exercises

Subnet the Class C IP Address 205.11.2.0 so that you have 30 subnets.

- What is the subnet mask for the maximum number of hosts?
- How many hosts can each subnet have?
- What is the IP address of host 3 on subnet 2 ?

Exercises

Solution:

1. How many bits to borrow from host ID?
   $2^n = 30$, so $n = 5$.
2. The new subnet mask is
   11111111. 11111111. 11111111. 11111000 → 255.255.255.248 → 205.11.2.0/29
3. The magic number is $2^h = \ \ 2^3 = 8$
4. The valid number of hosts in each subnet is 8 – 2 = 6.
5. The subnets: 205.11.2.0 to 205.11.2.7 – 205.11.2.8 to 205.11.2.15 – 205.11.2.16 to 205.11.2.31 – 205.11.2.32 to 205.11.2.63 – …
6. The IP address of host 3 in subnet 2 is **205.11.2.11**

Exercises

Given the IP 192.168.10.0/27

1. How many subnets are allowed?
2. How many hosts are allowed in each subnet?
3. What are the addresses of the subnets?
4. What is the broadcast address of each subnet?
5. What are the valid address for hosts?

Exercises

1. How many subnets are allowed?
   This is a class C network, we borrowed 3 bits. So, the number of subnets is $2^3 = 8$.
2. How many hosts in each subnet?
   We have 5 bits remaining in the host portion. So, the number of hosts is $2^5 = 32$.
3. What are the addresses of the subnets?
   The magic number is 32. So, the addresses are 0, 32, 64, 96, 128, 160, 192, and 224.
4. What is the broadcast address of each subnet?
   31, 63, 95, 127, 159, 191, and 223.
5. What are the valid address for hosts?
   $2^5 - 2 = 30$. (1 to 30), (33 to 62), (65 to 94), (97 to 126), (128 to 158), …

TASK

1. Given the IP 192.168.10.0/28
    1. How many subnets are allowed?
    2. How many hosts are allowed in each subnet?
    3. What are the addresses of the subnets?
    4. What is the broadcast address of each subnet?
    5. What are the valid address for hosts?
2. Given a class C IP address 195.10.10.0. How to subnet your network into at least 2 subnets, each has 48 host.

References

- CompTIA Network+ Guide to Networks
- CCNA – Understanding Cisco Networking Technologies
- https://www.techtarget.com/searchnetworking/definition/CIDR
- https://www.cloudflare.com/learning/network-layer/what-is-a-subnet/