IP Addressing and Subnetting

1. Introduction

In today's hyper-connected digital world, the ability to identify, locate, and route data across billions of devices hinges on a core component of networking, **IP addressing and subnetting**. These are not just technical protocols, they are the very framework that ensures seamless communication between systems, both within private networks and across the global internet.

At its core, an **IP address** is like a digital home address for a device. Just as mail is routed to a specific house via its street address, data packets are routed across networks to reach the correct device using IP addresses. But as networks grew larger and more complex, simply assigning addresses wasn't enough, we needed a structured, scalable, and efficient method to organize them. That's where **subnetting** comes in.

Subnetting allows us to logically divide a large IP network into smaller, more manageable sub-networks. This not only optimizes the use of limited IP address space (especially crucial with IPv4), but also enhances network performance, improves security through isolation, and minimizes congestion by controlling broadcast traffic.

This document dives deep into:

- The foundational concepts behind both **IPv4 and IPv6** addressing, the syntax, structure, and purpose of each.
- The **subnetting techniques** that allow network administrators to design scalable and efficient architectures.
- The use of **CIDR (Classless Inter-Domain Routing)** to break free from rigid IP address classes and enable flexible network design.
- **Real-world examples** and binary-level calculations that demystify the process and provide hands-on understanding.
- The **transition to IPv6**, exploring how it resolves IPv4 limitations, especially the exhaustion of available IP addresses.

Whether we are configuring a home router, managing a corporate LAN, or designing the next-gen cloud infrastructure, mastering IP addressing and subnetting isn't just a checkbox on your resume, it's an essential skill that defines how well you understand and control your digital landscape.

2. Understanding IP Addressing

An **IP address** is a numerical label assigned to each device connected to a computer network that uses the Internet Protocol for communication. An IP address serves two main functions,i.e. **identification** and **location addressing**.

- **IPv4 (Internet Protocol version 4)**
    - Comprises **32 bits** divided into 4 octets.
    - Represented in dotted decimal format (e.g., 192.168.1.1).
    - Maximum number of unique IPs: approx 4.29 billion (2^32).
    - IPv4 addresses consist of a network portion and a host portion, dictated by the subnet mask.
    - Binary Representation Example:
      192.168.1.1 → 11000000.10101000.00000001.00000001

- **IPv6 (Internet Protocol version 6)**
    - IPv4 address space is limited and could not fulfill the demand of IP addresses with an increasing number of devices.
    - This is where IPv6 came into play.
    - It uses **128-bit** addressing.
    - Represented in hexadecimal and colon-separated
        - (e.g., 2001:0db8:85a3:0000:0000:8a2e:0370:7334).
    - Supports 2^128 addresses, solving IPv4 exhaustion.
    - Simplifies routing, eliminates the need for NAT, and supports auto-configuration.

Terminologies

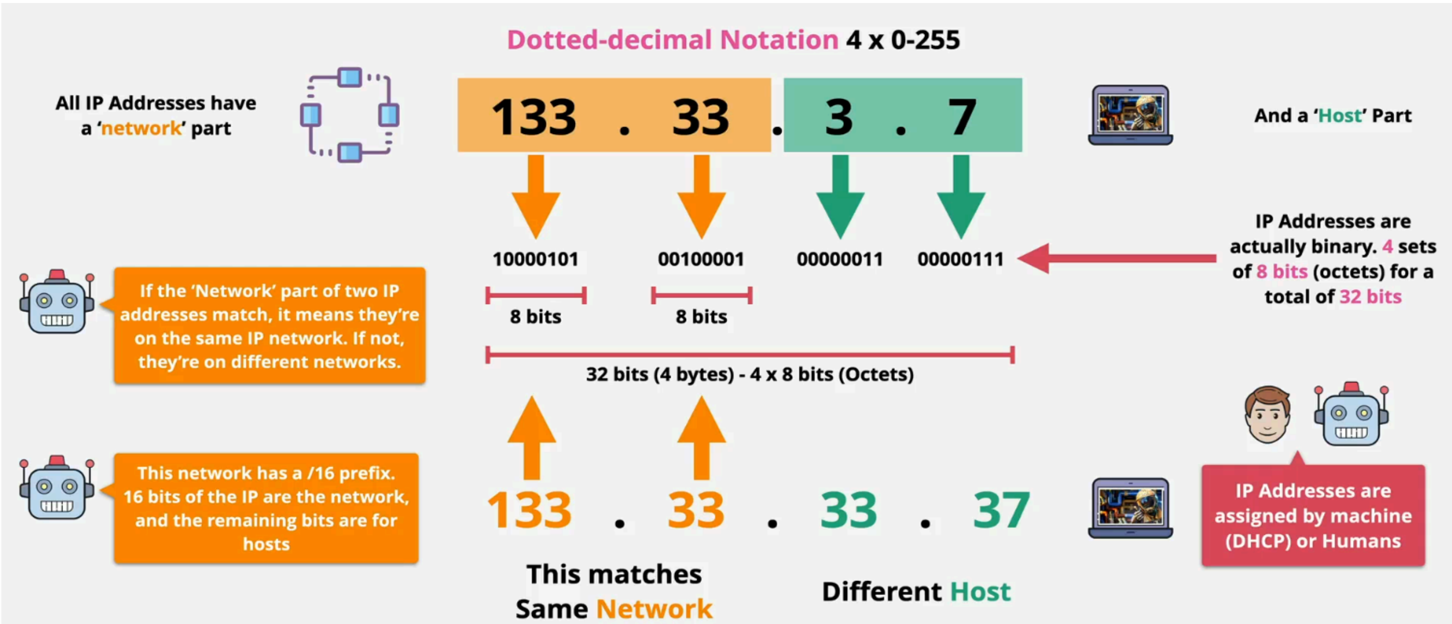
- **Address:** Unique identifier for a device or interface.
- **Subnet:** A logically visible subdivision of an IP network.
- **Subnet Mask:** A 32-bit mask used to divide an IP address into network and host parts.
- **Interface:** A network connection point.
- **CIDR Notation:** Classless representation of IP address and its prefix length (e.g., /24).

3. Classes of IPv4 Addresses

Class	First Octet Range	Default Subnet Mask	Hosts/Network
A	1 – 126	255.0.0.0	~16 million
B	128 – 191	255.255.0.0	~65,000
C	192 – 223	255.255.255.0	254

- Class D: 224–239 (Multicast)
- Class E: 240–255 (Experimental)

Note: Classful addressing is obsolete and is now replaced by CIDR.



* **IPv4** (32 bits) 4 parts (octets) of 8 bits
- range 0.0.0.0 → 255.255.255.255
- popularized in 1981.
- originally managed by IANA (Internet Assigned No. Authority now regional authorities manage.
- A total of 4.3 Billion (4,294,967,296 IPv4 Addresses)
- **Class A** (0.0.0.0 to 127.255.255.255) ⇒ Huge business, early internet, govt. authority, ISP

  128 networks (16,777,216 IP each)

  1st octet network reserved, other 3 for Host / subnet
- **Class B** (128.0.0.0 to 191.255.255.255) ⇒ Medium size organisation

  16,384 networks (65,536 IP each)

  1st, 2nd octet for network, other 2 for Host

Class C (192.0.0.0 to 223.255.255.255) ⇒ small business, individuals

2,097,152 networks (256 IP each) 1st, 2nd, 3rd octet for network

Class D	**Class E**
multicast, streaming services, etc	Research Development

4. Subnetting Basics

Subnetting is a technique used to break down a large IP network into multiple smaller, manageable sub-networks called **subnets.** This **logical segmentation** enhances routing efficiency by limiting broadcast traffic to smaller domains, boosts network security through isolation, and allows for better control over data flow and access policies.

Moreover, subnetting optimizes IP address utilization by eliminating the waste associated with rigid class-based addressing, ensuring each subnet is allocated just the right number of addresses needed for its size and purpose.

Key Formulas:

- Number of Subnets = 2^n (where n = number of subnet bits used)
- Number of Hosts = 2^(h - 2) (where h = number of host bits left)

CIDR Notation:

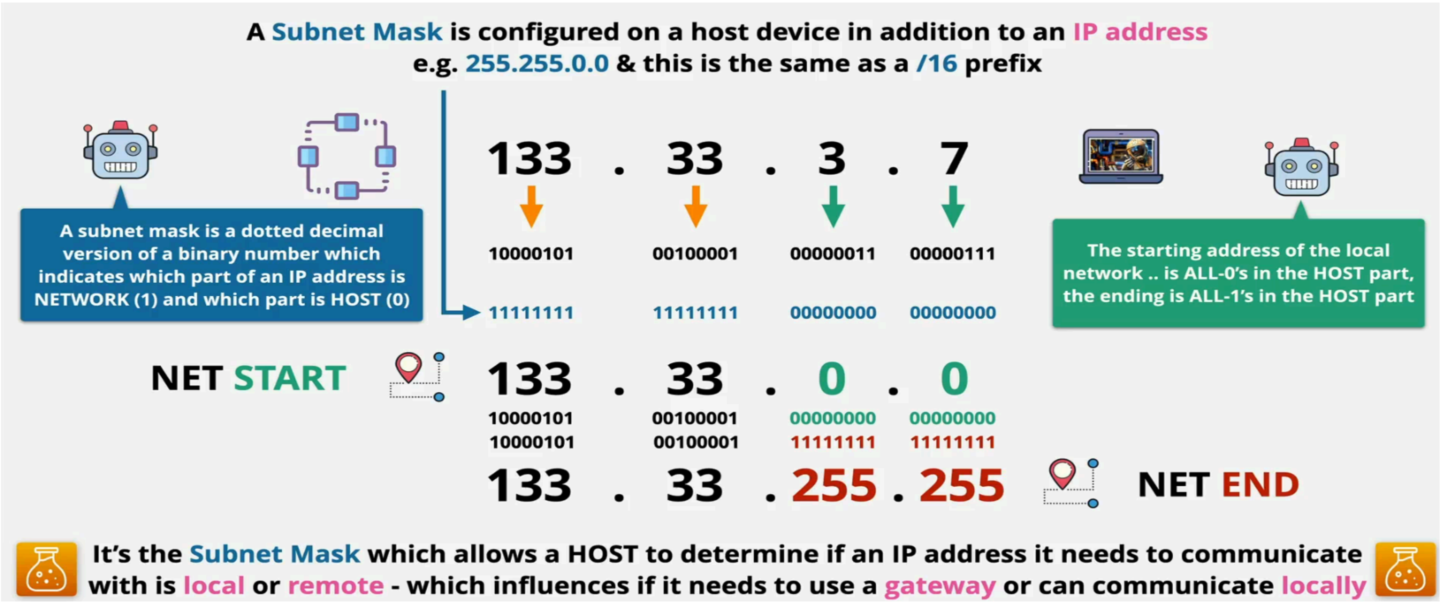
- Expresses IP with prefix length, e.g., 192.168.10.0/27

Example: For a Class C network 192.168.10.0 with subnet mask 255.255.255.224 (/27):

- Subnet Bits = 3 (borrowed from host bits)
- Subnets = 2^3 = 8
- Host Bits = 5 → Hosts per Subnet = 2^5 - 2 = 30

Subnet Ranges:

- 192.168.10.0 – 192.168.10.31
- 192.168.10.32 – 192.168.10.63
- ...
- 192.168.10.224 – 192.168.10.255



5. Subnetting Example

You are given the IP address: **192.168.10.0,**

You are asked to create **8 equal-sized subnets**.

Step 1 : Determine the Natural Mask

- The IP 192.168.10.0 belongs to Class C
- Natural mask ⇒ 255.255.255.0
- CIDR ⇒ /24
- Number of host bits ⇒ 8 bits (32 − 24 = 8)

Step 2 : Calculate Subnet Bits required

- we need 8 subnets , ($2^n \geq 8$ ∴ n = 3 subnet
- new subnet mask : 24 + 3 = /27

  Mask ⇒ 255.255.255.224
- CIDR ⇒ /27 for each of 8 subnets

Step 3 : Calculate total & Usable hosts per subnets

- Host bits left ⇒ 32 − 27 = 5
- Total hosts per subnet ⇒ $2^5 = 32$
- usable hosts per subnet ⇒ 32 − 2 = 30

  (reducing 2 , 1 for Network , 1 for broadcast

Step 4 : Addresses of these 8 subnets

1) 192.168.10.0/27
   - First Host ⇒ 192.168.10.1
   - Last Host ⇒ 192.168.10.30
   - Network Addⁿ ⇒ 192.168.10.0
   - Broadcast Addⁿ ⇒ 192.168.10.31
2) 192.168.10.32/27
3) 192.168.10.64/27
4) 192.168.10.96/27
5) 192.168.10.128/27
6) 192.168.10.160/27
7) 192.168.10.192/27
8) 192.168.10.224/27

Similarly for all Subnets

6. IPv6 Addressing and Subnetting

IPv6 simplifies and enhances subnetting:

- Typical subnet prefix: /64
- Network portion: first 64 bits
- Interface Identifier: last 64 bits (can be auto-generated)

Example:
IPv6 Address: 2001:0db8:abcd:0012::0/64

Subnetting in IPv6:

- Subnet size typically fixed at /64
- Subnetting done by varying bits beyond the initial prefix (e.g., /48 → /64 = 2^16 subnets)

Advantages over IPv4:

- Eliminates the need for NAT
- Larger address space
- Integrated security (IPsec)
- Simpler hierarchical routing

7. Reserved and Private IP Ranges (RFC 1918)

Private IP ranges are used for internal communication and are not routable over the public internet.

Class	Private IP Range	CIDR Notation
A	10.0.0.0 – 10.255.255.255	10.0.0.0/8
B	172.16.0.0 – 172.31.255.255	172.16.0.0/12
C	192.168.0.0 – 192.168.255.255	192.168.0.0/16

- Important IP's

AT & T : 12.0.0.0/8
IBM : 9.0.0.0/8
} Class A, require vast no. of hosts global operations.

Google : 8.8.8.8

: 127.0.0.0/8 ⇒ loopback (allow device to communicate with itself)

A Private : 10.0.0.0 to 10.255.255.255 (internal network)

Default : 0.0.0.0 → unspecified address of a device

Facebook : 31.13.71.36

Amazon : 72.21.206.80

B Private : 172.16.0.0 to 172.31.255.255 (often enterprise)

C Private : 192.168.0.0 to 192.168.255.255 (most home networks)