Prepared by: Nandini Goyal
Intern at Celebal Technologies
Department: Cloud Infra & Security
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R&D Document

IP Addressing and Subnetting(IPv4 & IPv6)

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1. Introduction

IP addressing and subnetting are fundamental to computer networking, enabling devices to communicate efficiently across networks. IP addresses uniquely identify devices, while subnetting divides large networks into smaller, manageable subnetworks to optimise resource allocation, security, and performance. This document provides a detailed exploration of IPv4 and IPv6 addressing, subnetting techniques, including natural masks, subnet masks, Classless Inter-Domain Routing (CIDR), and calculations for usable and total hosts. It includes practical examples, quick-reference tables, and real-world applications to aid network design and administration.

2. IPv4 Addressing

2.1 Structure

- Format: IPv4 addresses are 32-bit numbers, expressed in dotted-decimal notation (e.g., 192.168.1.1), consisting of four octets (8 bits each).
- Binary Representation: Each octet ranges from 0 to 255 (e.g., 192 = 11000000 in binary).
- Address Space: IPv4 supports 2^32 (~4.3 billion) unique addresses, which has led to address exhaustion, necessitating IPv6.

2.2 IPv4 Address Classes

- IPv4 addresses are categorised into five classes based on the first few bits of the address:

Class	Starting Bits	Range	Default Subnet Mask	Purpose
A	0xxx	1.0.0.0 - 126.255.255.255	255.0.0.0 (/8)	Large Networks
B	10xx	128.0.0.0 - 191.255.255.255	255.255.0.0 (/16)	Medium Networks
C	110x	192.0.0.0 - 223.255.255.255	255.255.255.0 (/24)	Small Networks
D	1110	224.0.0.0 - 239.255.255.255	N/A	Multicast
E	1111	240.0.0.0 - 255.255.255.255	N/A	Experimental/ Reserved

- Note: 127.0.0.0/8 is reserved for loopback addresses (e.g., 127.0.0.1).

2.3 Private and Special Addresses

- **Private Address Ranges (non-routable on the public internet):**
  - Class A: 10.0.0.0 – 10.255.255.255 (/8, 16.7M addresses)
  - Class B: 172.16.0.0 – 172.31.255.255 (/12, 1M addresses)
  - Class C: 192.168.0.0 – 192.168.255.255 (/16, 65K addresses)
- **Special Addresses:**
  - Loopback: 127.0.0.0/8 (used for testing).
  - APIPA: 169.254.0.0/16 (automatic private IP addressing for DHCP failures).
  - Default Gateway: Often the first usable address in a subnet (e.g., 192.168.1.1).

3. Subnetting in IPv4

Subnetting divides a network into smaller subnetworks, improving organisation, security, and address allocation efficiency. It involves borrowing bits from the host portion of an IP address to create additional subnets.

3.1 Key Concepts

- **Subnet Mask**: A 32-bit number that separates the network and host portions of an IP address (e.g., 255.255.255.0 or /24).
- **CIDR Notation**: Represents the subnet mask as a slash followed by the number of network bits (e.g., /24 indicates 24 bits for the network).
- **Network Address**: The first address in a subnet, reserved for identifying the subnet.
- **Broadcast Address**: The last address in a subnet, used for broadcasting to all devices in the subnet.
- **Usable Hosts**: Total addresses in a subnet minus the network and broadcast addresses (Total Hosts - 2).
- **Formulae**:
  - Total Addresses = 2^(32 - CIDR bits)
  - Usable Hosts = Total Addresses - 2
  - Number of Subnets = 2^(borrowed bits)

3.2 Subnetting Example (IPv4)

- **Scenario**: Subnet the network 192.168.10.0/24 into subnets with a /26 mask.
- **Subnet Mask**: /26 = 255.255.255.192 (binary: 11111111.11111111.11111111.11000000)

- **Total Addresses per Subnet**: 2^(32-26) = 2^6 = 64 addresses
- **Usable Hosts per Subnet**: 64 - 2 = 62 hosts
- **Number of Subnets**: Borrowed 2 bits (from /24 to /26), so 2^2 = 4 subnets
- **Subnet Ranges**:
  - 192.168.10.0 - 192.168.10.63 (Network: .0, Broadcast: .63)
  - 92.168.10.64 - 192.168.10.127 (Network: .64, Broadcast: .127)
  - 192.168.10.128 - 192.168.10.191 (Network: .128, Broadcast: .191)
  - 192.168.10.192 - 192.168.10.255 (Network: .192, Broadcast: .255)

3.3 Practical Application

Consider a company with three departments needing 50, 25, and 10 hosts, respectively. Using **Variable Length Subnet Masking (VLSM)**, assign subnets from 192.168.1.0/24:

- **Department A (50 hosts)**:
  - Needs 62 usable hosts → /26 (64 addresses, 62 usable).
  - Subnet: 192.168.1.0/26 (192.168.1.0 - 192.168.1.63).
- **Department B (25 hosts)**:
  - Needs 30 usable hosts → /27 (32 addresses, 30 usable).
  - Subnet: 192.168.1.64/27 (192.168.1.64 - 192.168.1.95).
- **Department C (10 hosts)**:
  - Needs 14 usable hosts → /28 (16 addresses, 14 usable).
  - Subnet: 192.168.1.96/28 (192.168.1.96 - 192.168.1.111).

This demonstrates efficient address allocation using VLSM, minimising waste.

4. CIDR and VLSM

4.1 Classless Inter-Domain Routing (CIDR)

CIDR eliminates traditional class-based addressing, allowing flexible subnet sizes. It uses a prefix length (/n) to define the network portion, enabling efficient address allocation.

- **Example**: 172.16.0.0/22
  - Subnet Mask: 255.255.252.0
  - Total Addresses: 2^(32-22) = 1024
  - Usable Hosts: 1024 - 2 = 1022
  - Range: 172.16.0.0 - 172.16.3.255

4.2 Variable Length Subnet Masking (VLSM)

VLSM allows subnets of different sizes within the same network, optimising address usage. It's commonly used in modern networks to accommodate varying host requirements.

- **Example**: From the VLSM example above, subnets /26, /27, and /28 were derived from a / 24 network, tailored to department needs.

5. IPv6 Addressing

5.1 Structure

- **Format**: IPv6 uses 128-bit addresses, written in hexadecimal with eight 16-bit blocks separated by colons (e.g., 2001:0db8:85a3:0000:0000:8a2e:0370:7334).
- **Shorthand Rules**:
  - Omit leading zeros in a block (e.g., 0db8 → db8).
  - Replace consecutive all-zero blocks with :: (once per address).
  - Example: 2001:0db8:0000:0000:0000:0000:0000:0001 → 2001:db8::1
- **Address Space**: 2^128 (~340 undecillion) addresses, eliminating the need for NAT.

5.2 Types of IPv6 Addresses

- **Unicast**: Identifies a single device (e.g., 2001:db8::1).
- **Multicast**: Sends data to multiple devices (e.g., FF00::/8).
- **Anycast**: Identifies a group where the nearest device responds.
- **Link-Local**: Auto-configured for local communication (FE80::/10).
- **No Broadcast**: IPv6 uses multicast instead of broadcast addresses.

5.3 Subnetting in IPv6

- **Standard Subnet**: /64 is the default for LANs, providing 2^64 addresses per subnet.
- **Subnetting Process**:

Typically, the first 48 bits are for the global routing prefix, the next 16 bits for subnetting, and the last 64 bits for host IDs.

- **Example:** Network 2001:db8:abcd::/48
  - **Subnet 1:** 2001:db8:abcd:0001::/64
  - **Subnet 2:** 2001:db8:abcd:0002::/64
  - Range for Subnet 1: 2001:db8:abcd:0001:: to 2001:db8:abcd:0001:ffff:ffff:ffff:ffff
- **Usable Hosts**: All addresses in an IPv6 subnet are usable (no network/broadcast reservation).

5.4 Practical Example

- **Scenario**: Subnet 2001:db8:1234::/48 for a company with four departments.
- **Allocation**: Assign /64 subnets:
  - Subnet 1: 2001:db8:1234:1::/64
  - Subnet 2: 2001:db8:1234:2::/64
  - Subnet 3: 2001:db8:1234:3::/64
  - Subnet 4: 2001:db8:1234:4::/64
- **Addresses per Subnet**: 2^64 (~18 quintillion), sufficient for any department size.

6. Quick Reference Tables

6.1 IPv4 CIDR to Subnet Mask

CIDR	Subnet Mask	Total Addresses	Usable Hosts	Increment
/24	255.255.255.0	256	254	1
/25	255.255.255.128	128	126	128
/26	255.255.255.192	64	62	64
/27	255.255.255.224	32	30	32
/28	255.255.255.240	16	14	16
/29	255.255.255.248	8	6	8
/30	255.255.255.252	4	2	4
/31	255.255.255.254	2	2 (point-to-point)	2
/32	255.255.255.255	1	1 (host)	N/A

6.2 IPv6 Common Prefixes

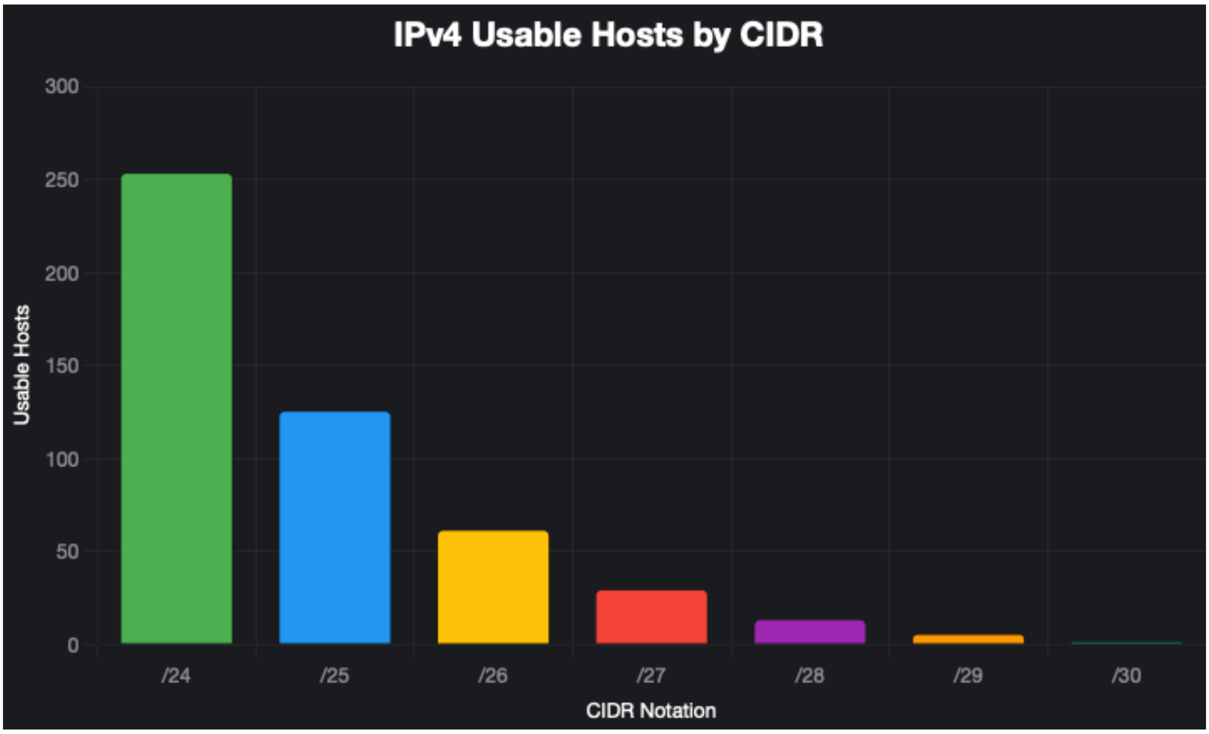
Prefix	Description	Typical Use Case
/32	ISP-level allocation	Large organizations
/48	Site-level subnetting	Enterprise networks
/56	Smaller sites	Small businesses
/64	Default for LANs	End-user devices
/128	Single host	Loopback or specific device

7. Special Cases

- **IPv4 /31 Subnets**: Used for point-to-point links, providing 2 usable addresses (no network/broadcast reservation, per RFC 3021).
- **IPv4 /32**: Represents a single host (e.g., 192.168.1.5/32).
- **IPv6 Multicast**: Replaces broadcast; addresses like FF02::1 target all nodes on a link.
- **IPv6 Link-Local Addresses**: Automatically assigned (FE80::/10) for local communication, requiring an interface identifier (e.g., %eth0).

8. Visualizing Subnet Sizes

To illustrate the relationship between CIDR notation and usable hosts in IPv4, the following chart compares subnet sizes. (If you want to include this in your document, confirm with your supervisor whether a visual chart is desired.)



This chart shows how the number of usable hosts decreases as the CIDR prefix length increases, highlighting the trade-off between subnet size and host availability.

9. Real-World Applications

- **Network Design**: Subnetting ensures efficient IP address allocation, reducing waste and improving routing efficiency. For example, VLSM allows a company to assign appropriately sized subnets to departments.
- **Security**: Subnets isolate network segments, limiting the scope of breaches. For instance, a DMZ subnet (e.g., 192.168.2.0/24) can separate public-facing servers from internal networks.
- **IPv6 Transition**: Organisations are adopting IPv6 to accommodate IoT devices and future growth. Subnetting in IPv6 (e.g., /64 per LAN) simplifies address management.
- **Cloud Networking**: Cloud providers use CIDR to allocate IP ranges to virtual private clouds (VPCs). For example, AWS VPCs often use /16 or /24 subnets.

10. Best Practices

- **Plan Subnets**: Use VLSM to allocate subnets based on actual host requirements, avoiding address waste.
- **Document Subnets**: Maintain a subnet allocation table to track network, broadcast, and usable IP ranges.
- **IPv6 Readiness**: Start integrating IPv6 subnets (e.g., /64) to prepare for future scalability.
- **Use Tools**: Leverage subnet calculators (e.g., SolarWinds, IpCalc) for accuracy in large-scale deployments.
- **Security Considerations**: Combine subnetting with VLANs and firewalls to enhance network security.

11. Conclusion

IP addressing and subnetting are critical skills for network administrators, enabling efficient, secure, and scalable network designs. IPv4 remains widely used but is limited by its address space, making IPv6 essential for future growth. Mastery of subnet masks, CIDR, VLSM, and IPv6 subnetting ensures robust network architectures. This document provides a foundation for creating and managing subnets, with practical examples and reference tables to support real-world applications.

12. References

- Cisco Networking Academy: IP Addressing and Subnetting

- Study-CCNA: OSI and TCP/IP Models
- Wikipedia: Subnetwork
- IETF RFC 1918: Address Allocation for Private Internets
- IETF RFC 4291: IPv6 Addressing Architecture
- ARIN IPv6 Guidelines: IPv6 Addressing Plans