A R&D report
on

IP Addressing and Subnetting

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By

Mr. Ganesh Ghadge

StudentId: CT_CSI_CI_6124

Objective

This document aims to provide a comprehensive understanding of IP Addressing and Subnetting, focusing on both IPv4 and IPv6 protocols. By explaining how IP addresses work, their allocation, and the process of subnetting, this document will help individuals understand how networks are structured and how IP addresses are assigned and managed in different contexts.

The document's objectives are as follows:

- Describe the concept of IP Addressing as well as the differences between IPv4 and IPv6, as well as their format, structure, and usage in networking environments.
- Understand Subnetting and how to divide networks into smaller, more manageable subnets, including how subnet masks, CIDR notation, and natural masks are used.
- Show how to find the number of usable and total hosts for a given IP address range, and how to create subnets in both IPv4 and IPv6.
- Show examples of subnetting with easy-to-follow, practical examples and describe how to design networks effectively.
- Show practical examples and use cases for IPv4 and IPv6 addressing and subnetting in today's modern networking environments.

Introduction

In the field of computer networking, IP Addressing and Subnetting are the foundation of how devices interact with each other over a network. Whether it is a small local area network (LAN) or the vast network commonly referred to as the internet, IP Addressing (this is how devices send and receive data) and Subnetting (this is how devices can share the IP Addressing space) will act as the primary method for managing the flow of data between devices.

An IP Address is a number that is meant to identify a device, whether it is a computer, printer, or router, to make sure that the data sent out to a network is directed towards the right device. The way an IP address is structured and how long it is, depends on the IP Address Format being used, either it is IPv4 (Internet Protocol version 4) or IPv6 (Internet Protocol version 6). IPv4 is the most commonly used format of IP addressing, and this consists of a 32-bit length of address length versus IPv6, which is 128-bit, to include more address options for the growing number of devices connected to the internet.

Subnetting is the process of breaking up a large network into smaller sub-networks (subnets) to improve organisation, to make it more secure, and to assist with the IP Addressing space that has been made available on the network. This allows network administrators to allocate IP addresses on a network to optimise network performance, organise the network, and minimise conflict on the network from duplicated IP Addresses.

IP Addressing (IPv4 & IPv6)

IP addressing is critical to ensuring that each device in a network is uniquely named, which permits data to be routed correctly between devices. Though IPv4 has been the main protocol for several years, it was clear that the address space limitations of IPv4 required the development of a new version of IP (IPv6) that greatly expanded the addressing space. Below, we'll examine both IPv4 and IPv6 addressing.

1. **IPv4 Addressing**

IPv4 (Internet Protocol version 4) uses a 32-bit addressing scheme that supports approximately 4.3 billion unique addresses (2^32). IPv4 addresses are written as a four-octet (or byte) decimal number, where each octet is expressed as a decimal number (between 0 and 255) and separated by a period.

IPv4 address: 192.168.1.1

IPv4 Address Classes

IPv4 addresses are organised into five classes (A, B, C, D, and E), though only Classes A, B, and C are used for general network allocation. The most common address types for network hosts are:

Class	Range	Number of Hosts per Network
A	0.0.0.0 to 127.255.255.255	16 million
B	128.0.0.0 to 191.255.255.255	65,000
C	192.0.0.0 to 223.255.255.255	254
D	224.0.0.0 to 239.255.255.255	Reserved for multicast
E	240.0.0.0 to 255.255.255.255	Reserved for experimental use

Special IPv4 Addresses:

Private Addresses: Ranges reserved for private networks:
- Class A: 10.0.0.0 - 10.255.255.255
- Class B: 172.16.0.0 - 172.31.255.255
- Class C: 192.168.0.0 - 192.168.255.255

Loopback Address: 127.0.0.1 is used to test local connections.

Broadcast Address: Used to send data to all devices within a network.

2. IPv6 Addressing

Internet Protocol version 6 (IPv6) was designed to overcome issues with Internet Protocol version 4 (IPv4), particularly the lack of address space. IPv6 is based on a 128-bit address scheme, enabling 340 undecillion (3.4×10^{38}) individual addresses (2^{128}). This enormous address space is necessary for overall Internet growth and systems for the Internet of Things (IoT).

IPv6 addresses are expressed in hexadecimal notation with colons separating each group. Each IPv6 address consists of eight 16-bit groups, where each group is represented by four hexadecimal digits.

IPv6 address: 2001:0db8:85a3:0000:0000:8a2e:0370:7334

To simplify the notation of an IPv6 address:

- Leading zeroes within each group of four hexadecimal characters can be omitted. For example, 0000 can be represented as 0.
- One or more contiguous groups of four hexadecimal characters with a value of 0 can be shortened to "::"; however, you can only use the "::" notation once per IP address.

IPv6 address: 2001:db8:85a3::8a2e:370:7334

Types of IPv6 addresses

Address Type	Range	Description
Global Unicast Address (GUA)	2000::/3	Publicly routable addresses, similar to IPv4 addresses.
Link-Local Address	fe80::/10	Used for communication within a local network segment.
Multicast Address	ff00::/8	Used to send data to multiple devices.
Anycast Address	N/A	Delivered to the nearest destination out of multiple destinations.

Difference between IPv4 & IPv6

Feature	IPv4	IPv6
Address Length	32 bits	128 bits
Address Format	Dotted decimal (e.g., 192.168.1.1)	Hexadecimal (e.g., 2001:0db8::1)
Total Addresses	4.3 billion	340 undecillion
Header Complexity	More complex	Simplified header
Private Address Ranges	Yes (Class A, B, C)	Yes (Unique Local Address ranges)
Broadcast Support	Yes	No
Auto-Configuration	No	Yes (Stateless address autoconfiguration)
Security	Optional (via IPSec)	Built-in (mandatory)

Subnetting (IPv4 & IPv6)

Subnetting is breaking a single network into smaller, manageable pieces (sub-networks or subnets). Subnetting achieves many benefits, such as better utilisation of IP address space, as well as increased security, improved performance, and better organisation of the network. How subnetting is executed differs between IPv4 and IPv6 because of their differing address formats and sizes.

1. **IPv4 Subnetting**

IPv4 Subnetting is done by dividing an IP address into two parts: the network portion and the host portion. The subnet mask determines where the division happens, and the process enables the network administrator to create subnets that are more efficient than using a single network.

Subnet Mask & CIDR Notation

- Subnet Mask: A 32-bit number that defines how many bits are used for the network portion of an address. A subnet mask looks like this: 255.255.255.0 (in decimal notation).
- CIDR Notation: Classless Inter-Domain Routing (CIDR) notation is a more compact form of subnet masking. It's written as the IP address followed by a forward slash (/) and the number of bits in the network portion.

Example: 192.168.1.0/24 means the first 24 bits are for the network address, and the remaining bits are for hosts.

Example of a Subnet Calculation:

Let's say we are working with the IP address 192.168.1.0 and a subnet mask of 255.255.255.0 (or /24 in CIDR notation).

- Network Portion: The first 24 bits are the network portion (as defined by the subnet mask).
- Host Portion: The remaining 8 bits are used for host addresses within this network.
- Total Number of Hosts: For a /24 subnet, the number of possible host addresses is 2^8 - 2 (subtract 2 because one address is reserved for the network address and one for the broadcast address).

Calculation:

$28-2=256-2=254$ usable hosts

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Usable IP Range: The usable IP addresses would be from 192.168.1.1 to 192.168.1.254, while the network address is 192.168.1.0 and the broadcast address is 192.168.1.255.

Subnetting with Different Masks:

When subnetting, you might use different subnet masks based on your requirements. Here are a few common ones:

Subnet Mask	CIDR Notation	Usable Hosts	Example Subnet
255.255.255.0	/24	254	192.168.1.0/24
255.255.255.192	/26	62	192.168.1.0/26
255.255.255.128	/25	126	192.168.1.0/25
255.255.255.224	/27	30	192.168.1.0/27

2. **IPv6 Subnetting**

Subnetting in IPv6 is conceptually similar to IPv4 but operates in a much larger address space. Since IPv6 addresses are 128 bits long, the number of subnets you can create is vast compared to IPv4. In IPv6, subnetting is often used to manage large address spaces in enterprise networks or data centres.

IPv6 Prefix and Subnetting

IPv6 addresses are divided into two parts: the **network** portion (prefix) and the **host** portion. The prefix is denoted using **CIDR notation**, similar to IPv4, but the prefix length is typically much longer. For example, a standard IPv6 network might use a /64 prefix, leaving 64 bits for the host portion.

Example:

Let's say you are given an IPv6 network **2001:0db8::/32** and want to create subnets.

Network Portion: The first 32 bits represent the network portion.
Host Portion: The remaining 96 bits are available for hosts.

If you create subnets with a /64 prefix, you are essentially taking the first 64 bits for the network, leaving 64 bits for the host portion. This is common in IPv6 subnetting.

Example Subnet Calculation:

If the network is **2001:0db8::/32**, and you want to create subnets with /64 prefixes, you would have:

Prefix: 2001:0db8::/64 (network portion is 64 bits)

Subnets: With 64 bits for the host portion, you can create a virtually limitless number of subnets.

The actual subnetting calculations for IPv6 are simpler than IPv4 due to the larger address space. Most networks will use /64 as the standard subnet size, and each subnet will have over 18 quintillion addresses, far more than any network could realistically use.

IPv6 Subnetting Examples:

IPv6 Network	CIDR Notation	Number of Subnets	Usable Hosts per Subnet
2001:0db8::/32	/64	2^32 (about 4.3 billion)	2^64 (more than enough for each subnet)
2001:0db8:abcd::/48	/64	2^16	2^64
2001:0db8:abcd:ef01::/64	/64	1 (single subnet)	2^64

References

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