IPv6: Internet Protocol Version 6

1. Introduction to IPv6

IPv6 (Internet Protocol version 6) is the most recent version of the Internet Protocol (IP), designed to overcome the limitations of **IPv4**. The primary reason for introducing IPv6 was the **exhaustion of IPv4 addresses**, which are 32 bits long and can support about 4.3 billion unique IP addresses.

IPv6 addresses are **128 bits** long, allowing for approximately **340 undecillion** (3.4×10^{38}) unique addresses, which is more than sufficient for future needs.

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2. Features of IPv6

- **Larger address space**: 128-bit address (compared to 32-bit in IPv4)
- **Simplified header format**
- **Built-in support for IPsec (security)**
- **No need for NAT (Network Address Translation)**
- **Auto-configuration (stateless and stateful)**
- **Better support for mobile devices**
- **Efficient routing and data flow**

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3. IPv6 Address Structure

IPv6 addresses are written as **eight groups of four hexadecimal digits**, separated by colons (:).

Example of Full IPv6 Address:

```
2001:0db8:0000:0000:0000:ff00:0042:8329
```

Each group represents **16 bits**, and the full address is **128 bits = 8 × 16 bits**.

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4. Hexadecimal System Recap

- IPv6 uses **hexadecimal** (base 16) format.
- Digits range from **0–9** and letters **A–F** (or **a–f**).
- One hexadecimal digit represents **4 bits** (a nibble).

Decimal	Hexadecimal
10	A
11	B
12	C
13	D
14	E
15	F

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5. Rules for Writing IPv6 Addresses

To simplify writing and reading IPv6 addresses, **several abbreviation rules** are used.

☑ Rule 1: Omit Leading Zeros

- In any 16-bit block, **leading zeros can be omitted**.
- Only leading zeros—not trailing ones—can be omitted.

Example:

```
Original: 2001:0db8:0000:0000:0000:ff00:0042:8329
Shortened: 2001:db8:0:0:0:ff00:42:8329
```

☑ Rule 2: Use Double Colon (`::`) to Represent Consecutive Zero Groups

- **Double colon** (`::`) can replace **one or more consecutive groups of zero blocks** (but only once in an address).
- Helps shorten the address significantly.

Example:

```
2001:db8:0:0:0:0:0:1  →  2001:db8::1
```

> ❗ Note: `::` can be used **only once** in a valid IPv6 address. Using it more than once creates ambiguity.

☑️ Rule 3: Don't Use `::` if Zero Groups Are Not Consecutive

Incorrect Example:

```
2001:db8:0:0:1:0:0:1 → 2001:db8::1::1 ❌ (Invalid)
```

Use:

```
2001:db8::1:0:0:1 ☑️
```

☑️ Rule 4: IPv6 Is Case-Insensitive

Hexadecimal letters (A–F) can be written in **uppercase or lowercase**.

```
2001:db8::ff00:42:8329 ☑️
2001:DB8::FF00:42:8329 ☑️
```

☑️ Rule 5: Embedded IPv4 Addresses

Sometimes IPv4 addresses are embedded in IPv6 (transition mechanisms).

Example:

```
::ffff:192.168.1.1
```

This represents an IPv4-mapped IPv6 address.

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6. Types of IPv6 Addresses

Type	Prefix	Description
Unicast	Varies	One-to-one communication
Multicast	`ff00::/8`	One-to-many communication
Anycast	Varies	One-to-nearest communication (routing decision-based)
Link-Local	`fe80::/10`	Used on local links, non-routable

Type	Prefix	Description
Unique Local	`fc00::/7`	Like private IPs in IPv4; for internal communication
Loopback	`::1`	Refers to the local host (same as 127.0.0.1 in IPv4)

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7. Examples of IPv6 Address Abbreviation

Example 1:

Full IPv6:

```
2001:0db8:0000:0000:0000:ff00:0042:8329
```

Steps:

- Remove leading zeros:

  ```
  2001:db8:0:0:0:ff00:42:8329
  ```

- Compress zeros:

  ```
  2001:db8::ff00:42:8329
  ```
  ✅

Example 2:

Full:

```
fe80:0000:0000:0000:0202:b3ff:fe1e:8329
```

Shortened:

```
fe80::202:b3ff:fe1e:8329
```
✅

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8. IPv6 Address Segmentation

Each IPv6 address consists of:

- **Network prefix** (first 64 bits)
- **Interface ID** (last 64 bits)

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9. IPv6 Address Allocation & Prefix Notation

Just like CIDR in IPv4 (`192.168.1.0/24`), IPv6 also uses prefix length.

Example:

```
2001:db8::/32
```

This means the **first 32 bits** are the network prefix, and the rest are available for subnetting.

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10. IPv6 Summary Table

Feature	IPv4	IPv6
Address Length	32 bits	128 bits
Notation	Decimal + Dots	Hexadecimal + Colons
Example	192.168.1.1	2001:db8::1
Number of Addresses	~4.3 billion	~340 undecillion
Broadcast	Yes	No (uses multicast)
NAT	Common	Not needed (globally unique IPs)
Security	Optional (IPSec)	Mandatory
Configuration	Manual/DHCP	Auto-config (SLAAC) or DHCPv6

☑️ Conclusion

IPv6 is the future of internet addressing, designed to handle the scale of modern and future networking needs. Understanding how to write, shorten, and interpret IPv6 addresses is critical for modern network professionals.