Internet Protocol Version 6 (IPv6)

At a Glance

- IPv6 is the successor of IPv4.
- Main goal: solve IPv4 address exhaustion.
- Uses 128-bit addresses and a fixed 40-byte header.
- Introduces flow labeling and anycast.
- IPv4 → IPv6 transition is gradual.

1 Why IPv6 Was Introduced

Core Motivation

IPv4 uses **32-bit addresses**, which are insufficient for the modern Internet. IPv6 was designed in the early 1990s to support long-term Internet growth and improve IPv4 limitations.

- IPv4 address space:

$$2^{32} \approx 4.3 \text{ billion}$$

- Rapid growth of:
  - Internet users
  - Mobile devices
  - IoT and cloud systems
- In 2011, IANA allocated the last unassigned IPv4 address blocks.

Exam Tip

IPv6 was developed early because deploying a new network-layer protocol takes decades.

2 IPv6 Addressing

128-bit Address Space

IPv6 expands IP addresses to **128 bits**:

$$2^{128} \approx 3.4 \times 10^{38}$$

Address exhaustion is no longer a practical concern.

2.1 IPv6 Address Types

- **Unicast:** one-to-one

- **Multicast:** one-to-many
- **Anycast:** one-to-nearest (new in IPv6)

Anycast Example

Requests can be delivered to the nearest server among many replicas, reducing latency.

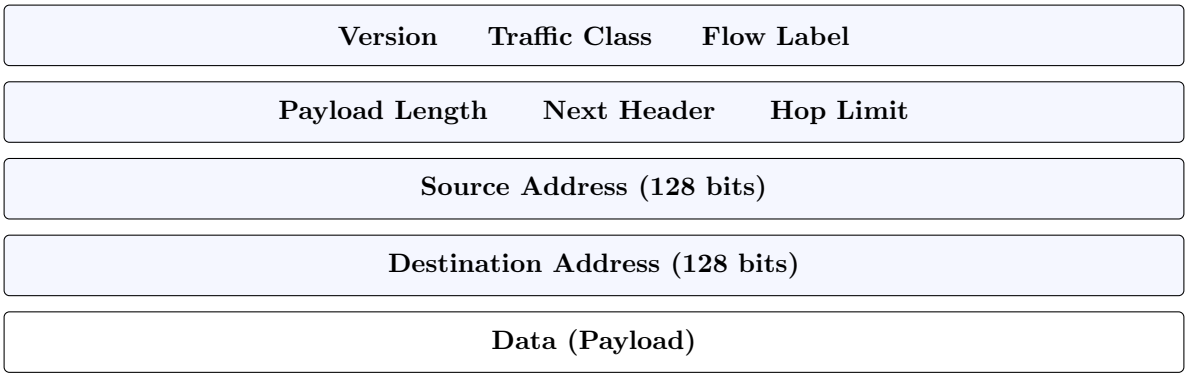
3 IPv6 Datagram Format (Base Header)

A Streamlined Fixed Header

IPv6 has a **fixed-length 40-byte base header**. Several IPv4 fields were removed or moved to extension headers, so routers can forward packets faster.

3.1 IPv6 Base Header Fields (Purpose)

- **Version (4 bits):** value is **6**.
- **Traffic Class (8 bits):** QoS/priority (similar idea to IPv4 TOS).
- **Flow Label (20 bits):** identifies packets belonging to a **flow** requiring special handling.
- **Payload Length (16 bits):** bytes after the 40-byte header.
- **Next Header (8 bits):** next protocol (TCP/UDP) or an extension header.
- **Hop Limit (8 bits):** decreases by 1 at each router; drop at 0.
- **Source & Destination Addresses (128 bits each).**
- **Data:** payload delivered to the upper-layer protocol.



4 Key Improvements Over IPv4

4.1 Performance-Oriented Design

- No router fragmentation
- No header checksum

- Fixed header size

Why This Matters

Routers forward packets faster because they do less per-packet processing.

4.2 Flow Labeling

Used to identify traffic flows needing special handling (e.g., real-time multimedia).

5 Fields Removed from IPv4

Important Design Change

IPv6 removes features that slowed IPv4 routers.

- **Fragmentation at routers** → done only by end hosts
- **Header checksum** → removed
- **Options field** → moved to extension headers

6 IPv4 to IPv6 Transition

Why Transition Is Hard

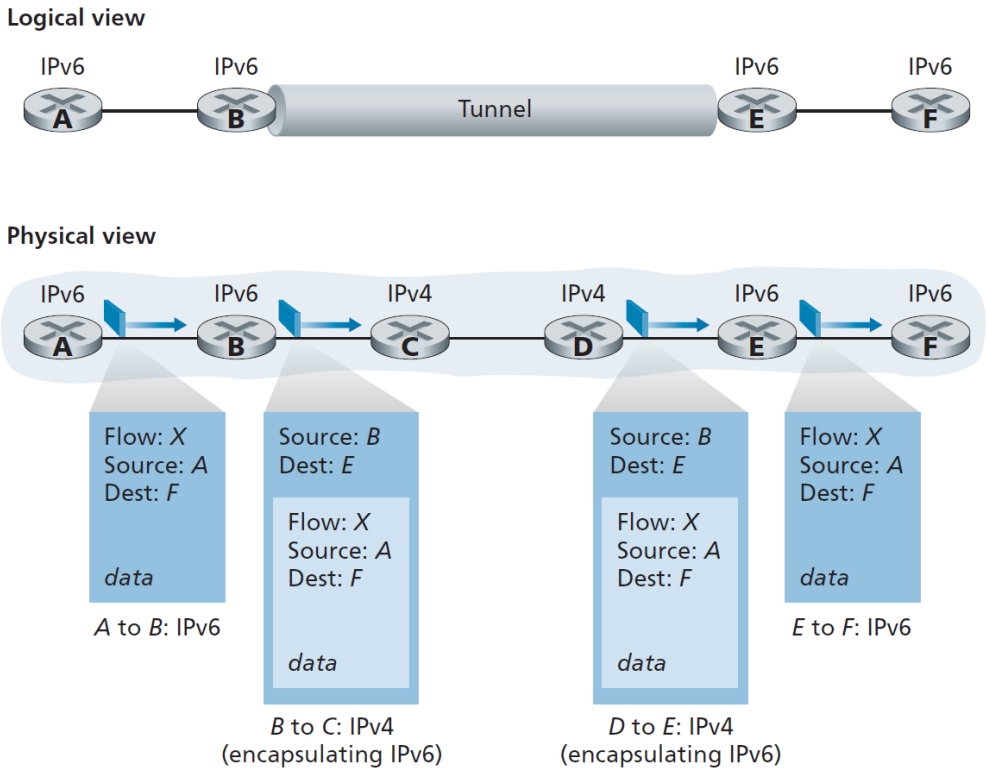
Billions of IPv4 devices cannot be upgraded instantly. A sudden "flag day" is impossible.

6.1 Tunneling

- IPv6 packet is encapsulated inside IPv4
- IPv4 routers forward it normally
- IPv6 is recovered at tunnel exit

Key Fact

IPv4 protocol number **41** indicates IPv6 encapsulation.



7 Summary

Exam-Ready Points

- IPv6 solves IPv4 address exhaustion.
- Uses 128-bit addresses and anycast.
- Fixed 40-byte header improves routing speed.
- Routers do not fragment packets.
- Transition is gradual using tunneling and coexistence.

IPv6 is essential for the long-term scalability of the Internet.