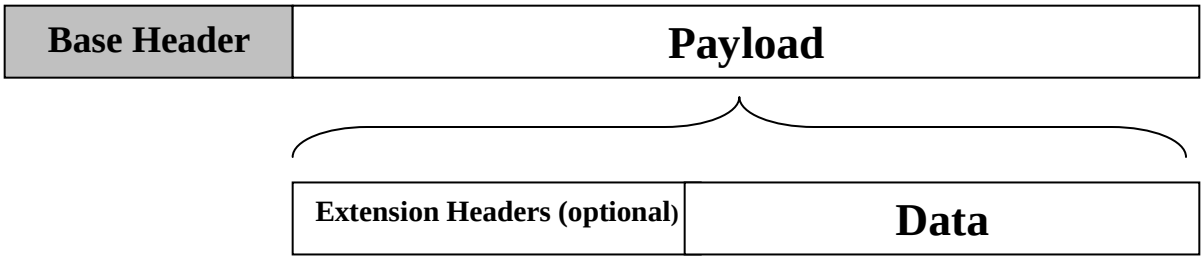
Internet Protocol version 6 (IPv6)

To overcome some drawbacks of IPv4. IPv6 -also known IPng (Internet Protocol next generation)- has been developed. IPv6 offers many features over IPv4 such as larger addressing space, supporting real time audio and video applications, and security.

IPv6 Datagram Format:

IPv6 datagram consists of two parts; Base header of 40B and a payload up to 65,536B. The payload may have optional extension headers plus the data.

IPv6 Datagram



❖ Base header format:-

The base header of IPv6 consists of the following fields:-

- **Ver. (4 bits):** This field specifies the version of the IP which is 6 for IPv6.
- **Priority (4 bits):** This field defines the priority of the datagram with respect to other datagrams of the same source. The highest value in this field yields the highest priority.
- **Flow label (3 byte):** The value of this field in combination with source address used to provide a special handling for a flow of data. The packets belongs to this flow have the same source, same destination, same priority and the same options. Flow label is important to support real time audio and video because it can speed up the processing of data by a router which

handles the entire flow in the same way. The datagram that doesn't belong to any flow has the all flow label bits set to zero

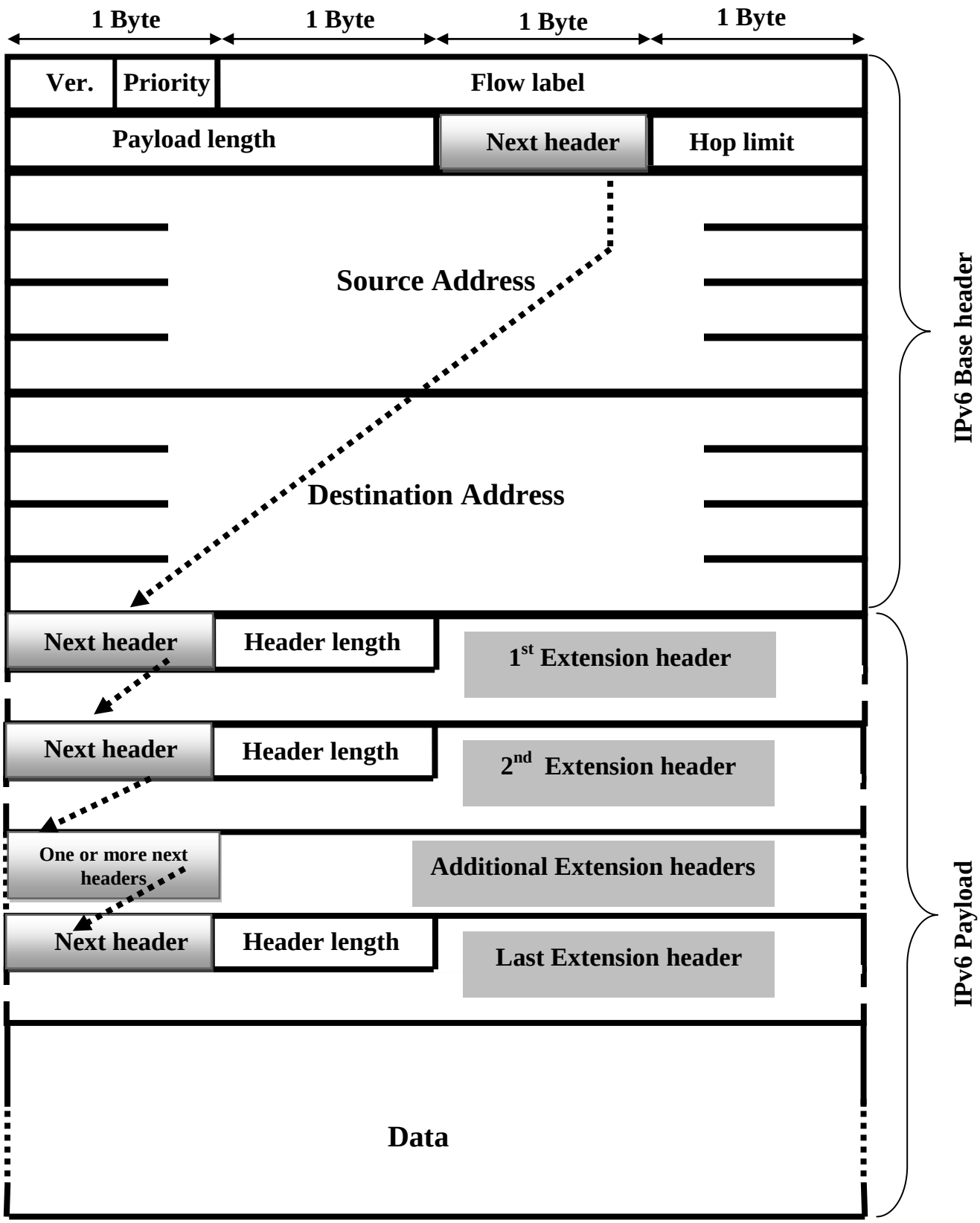
- **Payload Length (2 bytes):** This field specifies the length of the datagram in bytes excluding the length of the base header field.
- **Next header (1 bytes):** this field defines the header that immediately follows the base header which is either one of the optional extension headers used by IPv6 or a higher layer protocol header such as TCP or UDP. The followings are some examples of decimal codes used in this field

Code	Next header indication
06	TCP (higher layer protocol)
17	UDP (higher layer protocol)
43	Source Route (option)
44	Fragmentation (option)
59	Null header (No additional headers)

- **Hop limit (1 byte):** This field serves the same purpose of TTL field in IPv4.
- **Source address (16 bytes):** this field identifies the Internet Protocol address of the original source of the datagram.
- **Destination address (16 bytes):** This field specifies the Internet Protocol address of the final destination.

❖ Payload format:-

- **Next header (1 bytes):** this field is used as in the base header
- **Header length (1 bytes):** this field is used to specify the length of this extension header in bytes.
- **Data:** This field contains the data generated by the upper layer protocol.


1 Byte
1 Byte
1 Byte
1 Byte
Ver.
Priority
Flow label
Payload length
Next header
Hop limit
Source Address
Destination Address
IPv6 Base header
Next header
Header length
1st Extension header
Next header
Header length
2nd Extension header
One or more next headers
Additional Extension headers
Next header
Header length
Last Extension header
Data
IPv6 Payload

IPv6 Options

The base header of IPv6 can be followed by up to six extension headers. Each extension header can be the header of an upper layer protocol or an IPv6 option. Here are some of the options of IPv6:-

- **Source Routing:** this header combines the concepts of strict source route and loose source route options of IPv4.
- **Fragmentation:** the concept of fragmentation here is the same as in IPv4 except that IPv6 does fragmentation only on the original source using a technique known as "path MTU discovery" by which the source discovers the smallest MTU in the path and does fragmentation just once depending on this MTU value.
- **Authentication:** This header has a dual purpose; it validates message sender as well as ensuring data integrity.
- **Encryption Security Payload ESP**: this extension header provides confidentiality and guards against eavesdropping.

Comparison between IPv6 and IPv4:-

1. Larger address space in IPv6 (2^{128}) compared to (2^{32}) in IPv4.
2. Real time and security are supported by IPv6 extension fields.
3. *"Header length*" eliminated in IPv6 because header length is fixed to 40B.
4. *"Priority"* and *"Flow label"* fields takes over the function of "*Type of service"* field in IPv4.
5. *"Payload length*" field in IPv6 replaces IPv4 *"Total length"* field.
6. *"Hop limit*" field in IPv6 does the same work of *"TTL"* field in IPv4.
7. *"Next header*" field of IPv6 base header can perform the job of *"Protocol"* field of IPv4.
8. Fields regarded to fragmentation in IPv4 are eliminated in IPv6 base header and included in an optional extension header.
9. *"Checksum*" field is eliminated in IPv6 and left to the upper layer protocol.
10. Option fields are implemented as extension headers in IPv6.

IPv6 Addressing Format:-

IPv6 address consists of 128 b (16 B). To make addresses more readable, IPv6 addresses are specified in hexadecimal colon notation. In this notation the address is divided into eight sections each of four hexadecimal characters. An example on IPv6 address is given below:-

FDEC : 0074 : 0000 : 0000: 0000 : B0FF : 0000 : FFF1

❖ IPv6 Address Abbreviation:-

An IPv6 can be abbreviated as follows:-

- Consecutive sections consisting of zeros can be abbreviated and replaced by double double-colons. It should be mentioned here that this type of abbreviation is allowed once per address.
- Zeros at the most left digits of each section can be eliminated.

Example:-

IPV6 address 000F : A0B0 : 0000 : 0000 : 0010: FFEE : 0000 : D1C0

Can be abbreviated to F : A0B0 : :10: FFEE : 0 : D1C0

❖ IPv6 Address Re-Expansion :-

Abbreviated IPv6 address can be expanded to its original form by aligning the unabbreviated portions and inserting zeros then putting the missing double colons.

Example:-

The abbreviated address 133 : 15 : : 10 : FDE1 : 0

Can be re-expanded to 0133: 0015 : 0000 : 0000 : 0000 : 0010 : FDE1 : 0000

IPv6 Addresses Allocation:-

Each IPv6 address is divided into two parts. The first part is called the "type prefix". Type prefix is a variable length code that defines the purpose of the address. The second part of the address which as a result is also variable length code represents the remainder of the IPv6 address. The following table gives the type prefixes in IPv6 addresses.

Prefix	Type
0000 0000	Reserved
0000 0001	Reserved
0000 001	NSAP
0000 010	IPX
0000 011	Reserved
0000 100	Reserved
0000 101	Reserved
0000 110	Reserved
0000 111	Reserved
0001	Reserved
001	Reserved
010	Provider-based unicast address
011	Reserved
100	Geographica unicast address
101	Reserved
110	Reserved
1110	Reserved
1111 0	Reserved
1111 10	Reserved
1111 110	Reserved
1111 1110 0	Reserved
1111 1110 10	Link-local address
1111 1110 11	Site-local address
1111 1111	Multicast address

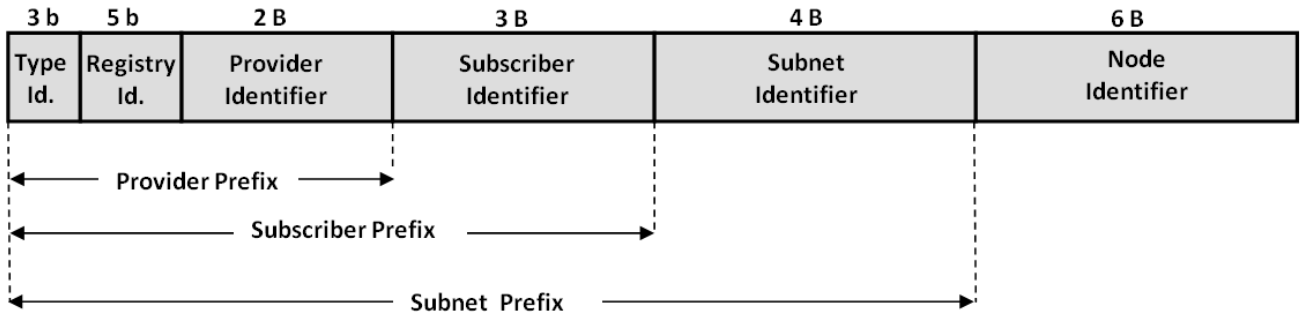
IPv6 Address Types:

IPv6 addresses are generally divided into three types; these are:

- Unicast.
- Anycast.
- Multicast

- **IPv6 Unicast Addresses:** Unicast address is unique as it defines a single interface. Unicast addresses can be used for a source or destination interfaces. There are several kinds of IPv6 unicast addresses; these include provider-based, special and local addresses.

❖ **Provider-based addresses:** These addresses are used for global communications over the internet. Provider-based address is composed of six fields as shown in the figure below



1- **Type Identifier:** **It identifies the address as provider-based address by the three bit code (010).**
2- **Registry Identifier:** **This field specifies the address of the internet agency that the address is registered with; examples of the currently available agencies are:**

   - **INTERNIC: The center of North America specified by the code (11000).**
   - **RIPNIC: The center of European registration specified by the code (01000).**
   - **APNIC: The center of Asia and Pacific countries specified by the code (10100).**

3- **Provider Identifier:** **this is usually a 16 bit code which represents the ID assigned by internet agency to each Internet Service Provider (ISP).**
4- **Subscriber Identifier:** **this field contains a code that is used by an ISP to uniquely identify each of its subscribers.**
5- **Subnet Identifier:** **it is used to define a subnetwork for a subscriber since the subscriber can have multiple subnets.**

6- **Node Identifier:** **node identifier field (also called interface identifier) specifies a single device interface within the subnet.**

IPv6 usually depends IEEE EUI-64 (EUI refers to Extended Unique Identifier) to derive the code in that defines the node. Here the node is identified by 64 bits (subnet prefix length is 64 bit and subnet identifier is 16 bits) where 48 bits are derived from the MAC address. The rest 16 bits are filled with the hexadecimal code (FFFE) which is inserted between the two halves of the MAC address.

Example:

What is the IPv6 address for an interface with the MAC address 02:17:95:AD:1A:10 if it is assigned manually the address 2001:8:85A3: : /64.

Answer:

- **In the IPv6 address written above, only the subnet prefix portion is given (2001:8:85A3) while the rest of the address (the 64-bit that identifies the node) are calculated according to the IEEE EUI-64 and derived from the MAC address**
- **The two parts of the MAC address (the OUI and the vendor assigned) are separated by the code FFFE ,thus it become 0217:95FF:FEAD:1A10**
- **The whole add is 2001:8:85A3::217:95FF:FEAD:1A10**

Provider-based address is hierarchical. It is comprised of several prefixes where each prefix defines a level of hierarchy. Type prefix defines the address type, registry prefix uniquely defines the registry agency for the address, provider prefix uniquely defines the ISP, subscriber prefix uniquely defines the subscriber and the subnet prefix uniquely defines the subnet.

- **Special addresses:** Special addresses are reserved addresses that starts by eight contiguous zeros (00000000). These include; loopback, unspecified, and IPv4 to IPv6 addresses.

i- **Loopback address:** **in IPv6 there is only one loopback address that is comprised of 127 0s followed by single 1 (it is represented in hexadecimal colon notation as " : : 1"). Loopback address is used by the device to test its own TCP/IP software. The datagram sent to a loopback address never leaves the device that originates it whether the device is connected or not connected to a network. The format of IPv6 loopback address is illustrated below.**

8 b	120 b
Type & Registry	Provider, Subscriber, Subnet, & Node Identifiers
00000000	000000000000000000 00000001

ii- **Unspecified addresses:** **it is comprised of 128 0s (represented as " : : "). It is used when a host sends an inquiry to learn its own IP address. The inquiry message contains the unspecified IPv6 address in the source address field. The format of IPv6 unspecified address is shown below.**

8 b	120 b
Type & Registry	Provider, Subscriber, Subnet, & Node Identifiers
00000000	000000000000000000 00000000

iii- **IPv4 over IPv6 addresses:** **During the transition from IPv4 to IPv6, a device can embed its IPv4 address within an IPv6 address. There are two mechanisms to achieve that:**

- **Compatible addresses:** **This mechanism is used when an IPv6 device sends a datagram to another IPv6 device and the datagram must pass through one or more IPv4 networks. Compatible address is compromised of 96 0s followed the 32-bit IPv4 address. The format of compatible IPv6 address is shown below.**

8 b	88 b	32 b
Type & Registry		IPv4 address
00000000	00000000000 00000000000	

- **Mapped addresses:** They are used when an IPv6 device sends a datagram to an IPv4 device and the datagram passes through one or more IPv6 networks. IPv6 mapped address is comprised of 80 0s, followed by 16 1s and ends by the 32-bit IPv4 address. The format of mapped IPv6 address is shown below.

8 b	72 b	16 b	32 b
Type & Registry 00000000	00000000 00000000	1111..... 1111	IPv4 address

Example:

Find the compatible and mapped IPv6 addresses for the IPv4 address (4.12.18.14).

Answer:

- **The compatible IPv6 address is (0::040C:120E)**
- **The mapped IPv6 address is (0::FFFF:040C:120E)**

- **Local addresses:** All IPV6 local addresses starts by the code (11111110) in the type and registry identifier fields. A local address is an address with only a local routability scope. IPv6 local addresses are divided into two types.

i. **Link-local addresses:** These addresses refer only to a particular physical link and are used for addressing on a single link for purposes such as automatic address configuration and neighbor discovery protocol. Link-local addresses can be used to reach the neighboring nodes attached to the same link. Site local addresses which starts by 1111111110 (FE80) can be compared APIPA (Automatic Private IP Addressing) IPv4 addresses. These addresses block 169.254.0.0/16 are assigned automatically whenever automatic IP configuration through DHCP fails

ii.

10 b	54 b	64 b
11111110 10	000000000000 0000000000000	Node address (16 b fill plus 48 b MAC address)

iii. **Site-local addresses:** **Site-local addresses are equivalent to private IP addresses in IPv4 (.0.0.0/8, 172.16.0.0/12, and 192.168.0.0/16). The address space reserved for these addresses, which are only routed within an organization and not on the public Internet, is 10.0.0.0/8, 172.16.0.0/12, and 192.168.0.0/16. In IPv6, the first 10 bits of a site-local address are set to 1111111011, which is why these addresses always begin with FEC0. The following 54 bits are the subnet ID, which you can use in your organization for hierarchical routing, and the last 64 bits are the interface ID.**

10 b	38 b	16 b	64 b
11111110 11	000000 000000	Subnet address	Node address (16 b fill plus 48 b MAC address)

- **IPv6 Anycast addresses:** An anycast address is an address that is assigned to a set of interfaces that typically belong to different nodes. A packet sent to an anycast address is delivered to the closest interface (as defined by the routing protocols in use) identified by the anycast address. Anycast addresses are syntactically indistinguishable from unicast addresses, because anycast addresses are allocated from the unicast address space. Assigning a unicast address to more than one interface makes a unicast address an anycast address
- **IPv6 Multicast addresses:** They specify a group of interfaces which do not necessarily share the same prefix. They are usually not in the same physical network. A datagram sent with a multicast address is delivered to all interfaces in the group.

Notes:

- **Anycast and multicast addresses are used only as destination addresses.**
- **There are no broadcast addresses in IPv6 , their function being superseded by multicast addresses**