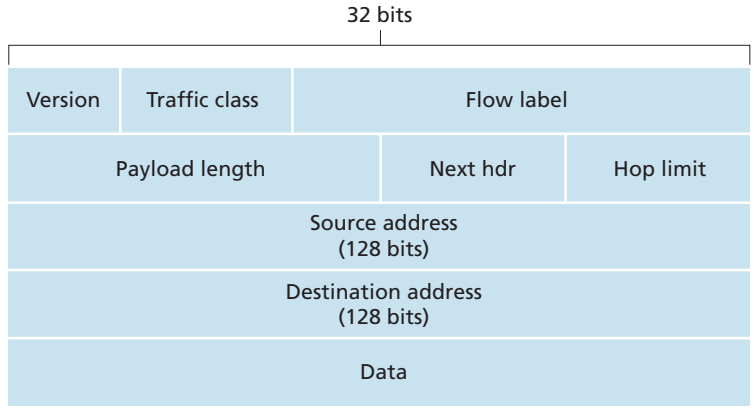


Figure 4.24 ♦ IPv6 datagram format

for faster processing of the IP datagram. A new encoding of options allows for more flexible options processing.

- *Flow labeling and priority.* IPv6 has an elusive definition of a **flow**. RFC 1752 and RFC 2460 state that this allows "labeling of packets belonging to particular flows for which the sender requests special handling, such as a nondefault quality of service or real-time service." For example, audio and video transmission might likely be treated as a flow. On the other hand, the more traditional applications, such as file transfer and e-mail, might not be treated as flows. It is possible that the traffic carried by a high-priority user (for example, someone paying for better service for their traffic) might also be treated as a flow. What is clear, however, is that the designers of IPv6 foresee the eventual need to be able to differentiate among the flows, even if the exact meaning of a flow has not yet been determined. The IPv6 header also has an 8-bit traffic class field. This field, like the TOS field in IPv4, can be used to give priority to certain datagrams within a flow, or it can be used to give priority to datagrams from certain applications (for example, ICMP) over datagrams from other applications (for example, network news).

As noted above, a comparison of Figure 4.24 with Figure 4.13 reveals the simpler, more streamlined structure of the IPv6 datagram. The following fields are defined in IPv6:

- *Version.* This 4-bit field identifies the IP version number. Not surprisingly, IPv6 carries a value of 6 in this field. Note that putting a 4 in this field does not create a valid IPv4 datagram. (If it did, life would be a lot simpler—see the discussion below regarding the transition from IPv4 to IPv6.)

- *Traffic class.* This 8-bit field is similar in spirit to the TOS field we saw in IPv4.
- *Flow label.* As discussed above, this 20-bit field is used to identify a flow of datagrams.
- *Payload length.* This 16-bit value is treated as an unsigned integer giving the number of bytes in the IPv6 datagram following the fixed-length, 40-byte datagram header.
- *Next header.* This field identifies the protocol to which the contents (data field) of this datagram will be delivered (for example, to TCP or UDP). The field uses the same values as the protocol field in the IPv4 header.
- *Hop limit.* The contents of this field are decremented by one by each router that forwards the datagram. If the hop limit count reaches zero, the datagram is discarded.
- *Source and destination addresses.* The various formats of the IPv6 128-bit address are described in RFC 4291.
- *Data.* This is the payload portion of the IPv6 datagram. When the datagram reaches its destination, the payload will be removed from the IP datagram and passed on to the protocol specified in the next header field.

The discussion above identified the purpose of the fields that are included in the IPv6 datagram. Comparing the IPv6 datagram format in Figure 4.24 with the IPv4 datagram format that we saw in Figure 4.13, we notice that several fields appearing in the IPv4 datagram are no longer present in the IPv6 datagram:

- *Fragmentation/Reassembly.* IPv6 does not allow for fragmentation and reassembly at intermediate routers; these operations can be performed only by the source and destination. If an IPv6 datagram received by a router is too large to be forwarded over the outgoing link, the router simply drops the datagram and sends a "Packet Too Big" ICMP error message (see below) back to the sender. The sender can then resend the data, using a smaller IP datagram size. Fragmentation and reassembly is a time-consuming operation; removing this functionality from the routers and placing it squarely in the end systems considerably speeds up IP forwarding within the network.
- *Header checksum.* Because the transport-layer (for example, TCP and UDP) and link-layer (for example, Ethernet) protocols in the Internet layers perform checksumming, the designers of IP probably felt that this functionality was sufficiently redundant in the network layer that it could be removed. Once again, fast processing of IP packets was a central concern. Recall from our discussion of IPv4 in Section 4.4.1 that since the IPv4 header contains a TTL field (similar to the hop limit field in IPv6), the IPv4 header checksum needed to be recomputed at every router. As with fragmentation and reassembly, this too was a costly operation in IPv4.

- *Options.* An options field is no longer a part of the standard IP header. However, it has not gone away. Instead, the options field is one of the possible next headers pointed to from within the IPv6 header. That is, just as TCP or UDP protocol headers can be the next header within an IP packet, so too can an options field. The removal of the options field results in a fixed-length, 40-byte IP header.

Recall from our discussion in Section 4.4.3 that the ICMP protocol is used by IP nodes to report error conditions and provide limited information (for example, the echo reply to a ping message) to an end system. A new version of ICMP has been defined for IPv6 in RFC 4443. In addition to reorganizing the existing ICMP type and code definitions, ICMPv6 also added new types and codes required by the new IPv6 functionality. These include the "Packet Too Big" type, and an "unrecognized IPv6 options" error code. In addition, ICMPv6 subsumes the functionality of the Internet Group Management Protocol (IGMP) that we'll study in Section 4.7. IGMP, which is used to manage a host's joining and leaving of multicast groups, was previously a separate protocol from ICMP in IPv4.

Transitioning from IPv4 to IPv6

Now that we have seen the technical details of IPv6, let us consider a very practical matter: How will the public Internet, which is based on IPv4, be transitioned to IPv6? The problem is that while new IPv6-capable systems can be made backward-compatible, that is, can send, route, and receive IPv4 datagrams, already deployed IPv4-capable systems are not capable of handling IPv6 datagrams. Several options are possible [Huston 2011b].

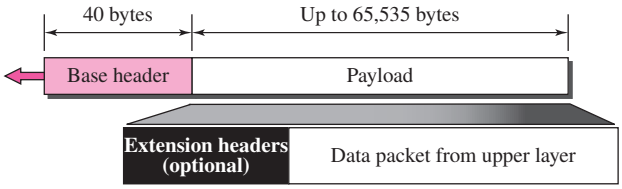
One option would be to declare a flag day—a given time and date when all Internet machines would be turned off and upgraded from IPv4 to IPv6. The last major technology transition (from using NCP to using TCP for reliable transport service) occurred almost 25 years ago. Even back then [RFC 801], when the Internet was tiny and still being administered by a small number of "wizards," it was realized that such a flag day was not possible. A flag day involving hundreds of millions of machines and millions of network administrators and users is even more unthinkable today. RFC 4213 describes two approaches (which can be used either alone or together) for gradually integrating IPv6 hosts and routers into an IPv4 world (with the long-term goal, of course, of having all IPv4 nodes eventually transition to IPv6).

Probably the most straightforward way to introduce IPv6-capable nodes is a **dual-stack** approach, where IPv6 nodes also have a complete IPv4 implementation. Such a node, referred to as an IPv6/IPv4 node in RFC 4213, has the ability to send and receive both IPv4 and IPv6 datagrams. When interoperating with an IPv4 node, an IPv6/IPv4 node can use IPv4 datagrams; when interoperating with an IPv6 node, it can speak IPv6. IPv6/IPv4 nodes must have both IPv6 and IPv4 addresses. They

27.2 PACKET FORMAT

The IPv6 packet is shown in Figure 27.1. Each packet is composed of a mandatory base header followed by the payload. The payload consists of two parts: optional extension headers and data from an upper layer. The base header occupies 40 bytes, whereas the extension headers and data from the upper layer contain up to 65,535 bytes of information.

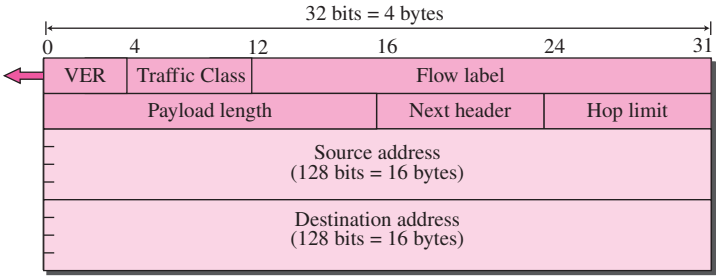
Figure 27.1 *IPv6 datagram*



Base Header

Figure 27.2 shows the **base header** with its eight fields.

Figure 27.2 *Format of the base header*



These fields are as follows:

- **Version.** This 4-bit field defines the version number of the IP. For IPv6, the value is 6.
- **Traffic Class.** This 8-bit field is used to distinguish different payloads with different delivery requirements. It replaces the service class field in IPv4.
- **Flow label.** The **flow label** is a 20-bit field that is designed to provide special handling for a particular flow of data. We will discuss this field later.
- **Payload length.** The 2-byte payload length field defines the length of the IP datagram excluding the base header.

- **Next header.** The **next header** is an 8-bit field defining the header that follows the base header in the datagram. The next header is either one of the optional extension headers used by IP or the header of an encapsulated packet such as UDP or TCP. Each extension header also contains this field. Table 27.1 shows the values of next headers. Note that this field in version 4 is called the *protocol*.

Table 27.1 *Next Header Codes*

Code	*Next Header*	*Code*	*Next Header*
0	Hop-by-hop option	44	Fragmentation
2	ICMP	50	Encrypted security payload
6	TCP	51	Authentication
17	UDP	59	Null (No next header)
43	Source routing	60	Destination option

- **Hop limit.** This 8-bit **hop limit** field serves the same purpose as the TTL field in IPv4.
- **Source address.** The source address field is a 16-byte (128-bit) Internet address that identifies the original source of the datagram.
- **Destination address.** The destination address field is a 16-byte (128-bit) Internet address that usually identifies the final destination of the datagram. However, if source routing is used, this field contains the address of the next router.

Flow Label

The IP protocol was originally designed as a connectionless protocol. However, as we discussed in Chapters 4 and 6, the tendency is to use the IP protocol as a connection-oriented protocol. The MPLS technology described in Chapter 6 allows us to encapsulate an IPv4 packet in an MPLS header using a label field. In version 6, the *flow label* has been directly added to the format of the IPv6 datagram to allow us to use IPv6 as as connection-oriented protocol.

To a router, a flow is a sequence of packets that share the same characteristics, such as traveling the same path, using the same resources, having the same kind of security, and so on. A router that supports the handling of flow labels has a flow label table. The table has an entry for each active flow label; each entry defines the services required by the corresponding flow label. When the router receives a packet, it consults its flow label table to find the corresponding entry for the flow label value defined in the packet. It then provides the packet with the services mentioned in the entry. However, note that the flow label itself does not provide the information for the entries of the flow label table; the information is provided by other means such as the hop-by-hop options or other protocols.

In its simplest form, a flow label can be used to speed up the processing of a packet by a router. When a router receives a packet, instead of consulting the routing table and going through a routing algorithm to define the address of the next hop, it can easily look in a flow label table for the next hop.

In its more sophisticated form, a flow label can be used to support the transmission of real-time audio and video. Real-time audio or video, particularly in digital form,

requires resources such as high bandwidth, large buffers, long processing time, and so on. A process can make a reservation for these resources beforehand to guarantee that real-time data will not be delayed due to a lack of resources. The use of real-time data and the reservation of these resources require other protocols such as Real-Time Protocol (RTP) and Resource Reservation Protocol (RSVP) in addition to IPv6 (see Chapter 25).

To allow the effective use of flow labels, three rules have been defined:

1. The flow label is assigned to a packet by the source host. The label is a random number between 1 and $2^{24} - 1$. A source must not reuse a flow label for a new flow while the existing flow is still alive.
2. If a host does not support the flow label, it sets this field to zero. If a router does not support the flow label, it simply ignores it.
3. All packets belonging to the same flow have the same source, same destination, same priority, and same options.

Comparison between IPv4 and IPv6 Headers

The following shows the comparison between IPv4 and IPv6 headers.

- The header length field is eliminated in IPv6 because the length of the header is fixed in this version.
- The service type field is eliminated in IPv6. The traffic class and flow label fields together take over the function of the service type field.
- The total length field is eliminated in IPv6 and replaced by the payload length field.
- The identification, flag, and offset fields are eliminated from the base header in IPv6. They are included in the fragmentation extension header.
- The TTL field is called hop limit in IPv6.
- The protocol field is replaced by the next header field.
- The header checksum is eliminated because the checksum is provided by upper layer protocols; it is therefore not needed at this level.
- The option fields in IPv4 are implemented as extension headers in IPv6.

Extension Headers

The length of the base header is fixed at 40 bytes. However, to give more functionality to the IP datagram, the base header can be followed by up to six **extension headers.** Many of these headers are options in IPv4. Figure 27.3 shows the extension header format.

Six types of extension headers have been defined. These are hop-by-hop option, source routing, fragmentation, authentication, encrypted security payload, and destination option (see Figure 27.4).

Hop-by-Hop Option

The **hop-by-hop option** is used when the source needs to pass information to all routers visited by the datagram. For example, perhaps routers must be informed about

Figure 27.3 *Extension header format*

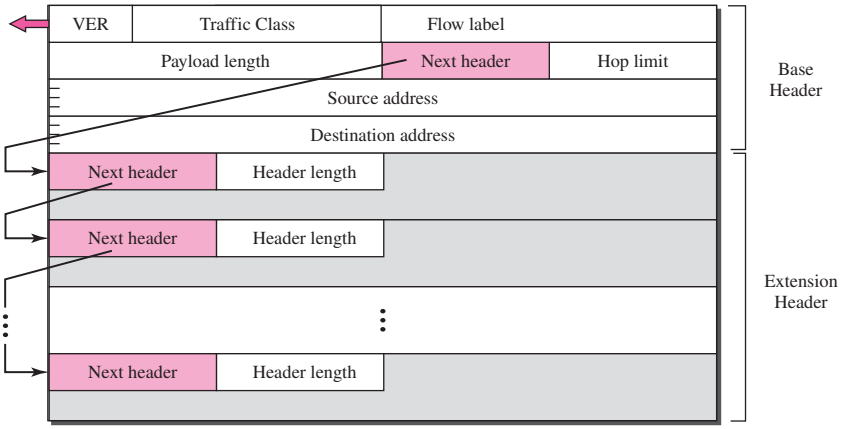
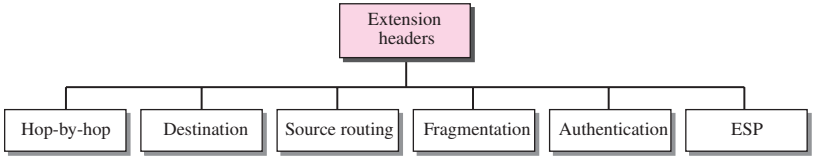
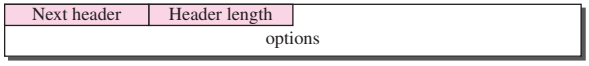


Figure 27.4 *Extension header types*



certain management, debugging, or control functions. Or, if the length of the datagram is more than the usual 65,535 bytes, routers must have this information. Figure 27.5 shows the format of the hop-by-hop option header. The first field defines the next header in the chain of headers. The header length defines the number of bytes in the header (including the next header field). The rest of the header contains different options.

Figure 27.5 *Hop-by-hop option header format*



So far, only three hop-by-hop options have been defined: **Pad1, PadN,** and **jumbo payload.** Figure 27.6 shows the general format of the option.

- **Pad1.** This option is 1 byte long and is designed for alignment purposes. Some options need to start at a specific bit of the 32-bit word (see the jumbo payload description to come). If an option falls short of this requirement by exactly one