



Jun-ichiro-itojun Hagino

IPV 6

Network

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SOFTWARE ENGINEERING

IPv6 Network Programming

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Jun-ichiro itojun Hagino



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Preface

Here in Japan, it looks like the Internet is deployed everywhere. Not a day will go by without hearing the word Internet. However, many people do not know that we are very close to reaching the theoretical limit of IPv4. The theoretical limit for the number of IPv4 nodes is only 4 billion—much fewer than the world’s population.

People in trains and cars send email on their cellphones using small numeric keypads. Most of these devices are not connected to the real Internet—these cellphones do not speak the Internet Protocol. They use proprietary protocols to deliver emails to the gateway, and the gateway relays the emails to the Internet. Cellular operators are now trying to make cellphones a real VoIP device (instead of “email only” device) to avoid the costs of operating proprietary phone switches/devices/gateways and to use inexpensive IP routers.

There are a lot of areas where the Internet and the Internet Protocol have to be deployed. For instance, we need to enable every vehicle to be connected to the IP network in order to exchange information about traffic congestion. There are plans to interconnect every consumer device to the Internet, so that vendors can collect information from the machines (such as statistics), as well as provide various value-added services.

Also, we need to deploy IP to every country in the world, including highly populated areas such as China, India, and Africa, so that everyone has equal opportunity to access the information on the Internet.

To deploy the Internet Protocol to wider domains, the transition from IPv4 to IPv6 is critical. IPv4 cannot accommodate the needs discussed previously, due to the limitation in address space size. With IPv6 we will be able to accommodate 3.4×10^{38} nodes to the Internet—it should be enough for our lifetime (I hope).

The IPv6 effort was started in 1992, in the INET92 conference held in Kobe, Japan. Since then, we have been making a huge amount of effort to help the transition happen. Fortunately, it seems that the interest in IPv6 has reached the critical mass, and the transition to IPv6 is now a reality. Many ISPs in Japan are offering commercial IPv6 connectivity services, numerous vendors are shipping IPv6-enabled operating systems, and many IPv6-enabled products are coming. If you are not ready yet, you need to hurry up.

The transition to IPv6 requires an upgrade of router software and host operating systems, as well as application software. This book focuses on how you can modify your network application software, based on the socket API, to support IPv6. When you write a network application program, you will want the program to be IPv6-capable, so that it will work just fine on the IPv6 network, as well as the IPv4 network. After going through this book, you will be able to make your programs IPv6-ready. It will also help you port your IPv4-capable application to become IPv6-capable at the same time.

In this book, we advocate address-family independent socket layer programming for IPv6 transition. By following the instructions in the book, your code will become independent from the address family (such as `AF_INET` or `AF_INET6`). This is the best way to support IPv6 in your program, compared with other approaches (such as hardcoding `AF_INET6` into the program).

I would like to thank the editor for the Japanese edition of the book, Ms. Eiko Akashima, and translator for the Japanese edition of the book, Ms. Ayako Ogawa (the original manuscript of the book is in English, even though it was first published in Japan). On the technical side, I would like to thank Mr. Craig Metz, who generously permitted us to include his paper on address-family independent programming, as well as the members of the WIDE/KAME project, who have made a lot of useful suggestions to the content of the book.

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Tokyo, Japan

About This Book

This book tries to outline how to write an IPv6-capable application on a UNIX socket API, or how to update your IPv4 application to be IPv6-capable. The book tries to show portable and secure ways to achieve these goals.

Write Portable Application Programs

There are a large number of platforms that support socket API for network programming. When you write an application on top of socket API, you will want to see your program work on as many platforms as possible. Therefore, portability is an important factor in application programming. As many of you already know, there are many UNIX-like operating systems, as well as non-UNIX operating systems that implement socket APIs. For instance, Windows XP does implement socket API; Mac OS X uses BSD UNIX as the base operating system and provides socket API to the users (Apple normally recommends the use of Apple APIs). So the book tries to recommend portable ways of writing IPv6-capable programs.

Be Security Conscious When Writing Programs

Security is a great concern these days in the Internet—if you are a network administrator, I guess you are receiving tons of spam, email viruses, and vendor advisories every day. To secure the Internet infrastructure, every developer has to take a security stance—to audit every line of code as much as possible, to use proper API, and write a correct and secure code. To achieve this goal, in this book, efforts are made to ensure correctness of the examples. The examples presented in this book are implemented with security stance. Also, the book tries to lead you to write secure programs. For instance, the book recommends against the use of some of the IPv6 standard APIs;

unfortunately, there are some IPv6 APIs that are inherently insecure, so the book tries to avoid (and discourage) the use of such APIs.

This book does not try to cover every aspect of IPv6 technology—the book constrains itself to the IPv6-capable programming on top of socket API. There are numerous reading materials on IPv6 technology, so readers are encouraged to read them before starting to work on this book.

Also, the book assumes a certain level of expertise in socket API programming. The book does not try to explain every aspect of socket API programming; please read the material listed in the References for an introductory description to socket API.

Terminology and Portability

This section describes notations and terminologies used in this book. Here we also discuss porting issues of examples when you are using operating systems that are not 4.4BSD variants.

Terminology

System calls and system library functions are usually denoted by UNIX manpage chapters: `socket(2)` or `printf(3)`.

“Nodes” means any IP devices. “Routers” are any nodes that forward packets for others. “Hosts” are nodes that are not routers (however, in this book, we don’t really need to make distinctions between them).

Portability of Examples

The examples in the book compile and run on latest *BSD releases. I tried to make the examples as correct as possible.

If you are planning to use the examples on other platforms, here are some tweaks dependent on OS implementations.

Solaris, Linux, Windows XP

`struct sockaddr` has no `sa_len` member. Therefore, it is not possible to get the size of a given `sockaddr` when the caller of the function passed a pointer to a `sockaddr`. The only ways to work around this problem are:

1. To always pass around the length of `sockaddr` separately on function calls:
-

```
struct sockaddr *sa;
int salen;

foo(sa, salen)
```

2. To have a switch statement to determine length of `sockaddr`. With this approach, however, the application will not be able to support `sockaddrs` with unknown address family.

```
struct sockaddr *sa;
int salen;

switch (sa->sa_family) {
case AF_INET:
    salen = sizeof(sockaddr_in);
    break;
case AF_INET6:
    salen = sizeof(struct sockaddr_in6);
    break
default:
    fprintf(stderr, "not supported\n");
    exit(1);
    /*NOTREACHED*/
}
```

Missing Type for Variables

In some cases, your platform may not have the type declaration used in this book. In such cases, use the following:

- If `socklen_t` is not defined—such as older *BSD releases:
Use unsigned int instead.
- If `in_port_t` is not present:
Use `u_int16_t`.
- If `u_int8_t`, `u_int16_t`, and `u_int32_t` are not found:

If your system has `/usr/include/inttypes.h` (which is defined in the recent C language standard), you may use `uint8_t`, `uint16_t`, or `uint32_t`, respectively, after `#include <inttypes.h>`.

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Introduction

1.1 A History of IPv6 and Its Key Features

In 1992, the IETF (<http://www.ietf.org/>) became aware of a global shortage of IPv4 addresses and technical obstacles in deploying new protocols due to limitations imposed by IPv4. An IPng (IP next generation) effort was started to solve these issues. The discussion is outlined in several RFCs, starting with RFC 1550. After a large amount of discussion, in 1995, IPv6 (IP version 6) was picked as the final IPng proposal. The IPv6 base specification is specified in RFC 1883 and revised in RFC 2460.

In a single sentence, IPv6 is a reengineering effort against IP technology. Key features are as follows.

1.1.1 Larger IP Address Space

IPv4 uses only 2^{32} bits for IP address space, which allows only (theoretically) 4 billion nodes to be identified on the Internet. Four billion may look like a large number; however, it is less than the world's population. Moreover, due to the allocation (in)efficiency, it is not possible to use up all 4 billion addresses.

IPv6 allows 2^{128} bits for IP address space, (theoretically) allowing 340,282,366,920,938,463,463,374,607,431,768,211,456 (340 undecillion) nodes to be uniquely identified on the Internet. Larger address space allows true end-to-end communication, without NAT or other short-term workarounds against IPv4 address shortage. (In these days, NAT has been a headache to new protocol deployment and scalability issues, and we really need to decommission NATs for the Internet to grow further.)

1.1.2 Deploy More Recent Technologies

After IPv4 was specified 20 years ago, we saw many technical improvements in networking. IPv6 covers a number of those improvements in its base specification, allowing people to assume that these features are available everywhere, anytime. Recent technologies include, but are not limited to, the following:

- *Autoconfiguration*—With IPv4, DHCP is optional. A novice user can get into trouble if visiting an offsite without a DHCP server. With IPv6, the stateless host autoconfiguration mechanism is mandatory. This is much simpler to use and manage than IPv4 DHCP. RFC 2462 has the specification for it.
- *Security*—With IPv4, IPsec is optional and you need to ask the peer if it supports IPsec. With IPv6, IPsec support is mandatory. By mandating IPsec, we can assume that you can secure your IP communication whenever you talk to IPv6 peers.
- *Friendly to traffic engineering technologies*—IPv6 was designed to allow better support for traffic engineering such as diffserv¹ or RSVP². We do not have single standard for traffic engineering yet; so the IPv6 base specification reserves a 24-bit space in the header field for those technologies and is able to adapt to coming standards better than IPv4.
- *Multicast*—Multicast support is mandatory in IPv6; it was optional in IPv4. The IPv6 base specifications extensively use multicast on the directly connected link. It is still questionable how widely we will be able to deploy multicast (such as nationwide multicast infrastructure), though.
- *Better support for ad hoc networking*—Scoped addresses allow better support for ad hoc (or “zeroconf”) networking. IPv6 supports anycast addresses, which can also contribute to service discoveries.

1.1.3 A Cure to Routing Table Growth

The IPv4 backbone routing table size has been a big headache to ISPs and backbone operators. The IPv6 addressing specification restricts the number of backbone routing entries by advocating route aggregation. With the current IPv6 addressing specification, we will see only 8,192 routes in the default-free zone.

1. diffserv: short for “differentiated services.” It is an IETF standard that classifies packets into a couple of classes and performs rough bandwidth/priority control.

2. RSVP: an IETF standard for bandwidth reservation.

I.1.4 Simplified Header Structures

IPv6 has simpler packet header structures than IPv4. It will allow vendors to implement hardware acceleration for IPv6 routers easier.

I.1.5 Allows Flexible Protocol Extensions

IPv6 allows more flexible protocol extensions than IPv4 by introducing a protocol header chain. Even though IPv6 allows flexible protocol extensions, IPv6 does not impose overhead to intermediate routers. It is achieved by splitting headers into two flavors: the headers intermediate routers need to examine and the headers the final destination will examine. This also eases hardware acceleration for IPv6 routers.

I.1.6 Smooth Transition from IPv4

There were a number of transition considerations made during the IPv6 discussions. Also, there is a large number of transition mechanisms available. You can pick the most suitable one for your network during the transition period.

I.1.7 Follows the Key Design Principles of IPv4

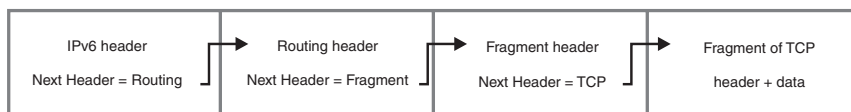
IPv4 was a very successful design, as proven by the large-scale global deployment. IPv6 is a new version of IP, and it follows many of the design features that made IPv4 very successful. This will also allow smooth transition from IPv4 to IPv6.

I.1.8 And More

There are number of good books available about IPv6. Be sure to check these if you are interested.

Protocol Header Chain

IPv6 defines a protocol header chain, which is a way to concatenate extension headers repeatedly after the IPv6 base header. With IPv4, the IPv4 header is adjacent to the final header (like TCP). With IPv6, the protocol header chain allows various extension headers to be put between the IPv6 base header and the final header.



1.2 Transition from IPv4-Only Internet to IPv4/v6 Dual Stack Internet

Today, most of the nodes on the Internet use IPv4. We will need to gradually introduce IPv6 to the Internet and hopefully make all nodes on the Internet IPv6-capable.

To do this, the IETF has carefully designed IPv6 migration to be seamless. This is achieved by the following two key technologies:

- Dual stack
- Tunneling

With these technologies, we can transition to IPv6 even though IPv4 and IPv6 are not compatible (IPv4-only devices and IPv6-only devices cannot talk with each other directly). We will go into the details soon.

It is expected that we will have a long period of IPv4/v6 dual stack Internet, due to the wide deployment of IPv4 devices. For instance, some of the existing devices, such as IPv4-capable game machines, may not be able to be upgraded to IPv6.

Therefore, in this book, we would like to focus on the issues regarding the transition from IPv4-only Internet to IPv4/v6 dual stack Internet and the changes in socket API programming.

1.2.1 Dual stack

At least in the early stage of IPv6 deployment, IPv6-capable nodes are assumed to be IPv4-capable. They are called “IPv4/v6 dual stack nodes” or “dual stack nodes.” Dual stack nodes will use IPv4 to communicate with IPv4 nodes, and use IPv6 to communicate with IPv6 nodes. It is just like a bilingual person—he or she will use English when talking to people in the States, and will use Japanese when talking to Japanese people.

The determination of protocol version is automatic, based on available DNS records. Because this is based on DNS, and normal users would use fully qualified domain name (FQDN) in email addresses and URLs, the transition from IPv4 to IPv6 is invisible to normal users. For instance, assume that we have a dual stack node, and we are to access `http://www.example.com/`. A dual stack node will behave as follows:

- If `www.example.com` resolves to an IPv4 address, connect to the IPv4 address. In such a case, the DNS database record for `www.example.com` will be as follows:
-

```
www.example.com.      IN A      10.1.1.1
```

- If `www.example.com` resolves to an IPv6 address, connect to the IPv6 address.

```
www.example.com.      IN AAAA 3ffe:501:ffff::1234
```

- If `www.example.com` resolves to multiple IPv4/v6 addresses, IPv6 addresses will be tried first, and then IPv4 addresses will be tried. For example, with the following DNS records, we will try connecting to `3ffe:501:ffff::1234`, then `3ffe:501:ffff::5678`, and finally `10.1.1.1`.

```
www.example.com.      IN AAAA 3ffe:501:ffff::1234
```

```
www.example.com.      IN AAAA 3ffe:501:ffff::5678
```

```
www.example.com.      IN A      10.1.1.1
```

Since we assume that IPv6 nodes will be able to use IPv4 as well, the Internet will be filled with IPv4/v6 dual stack nodes in the near future, and the use of IPv6 will become dominant.

I.2.2 Tunneling

Even when we have IPv4/v6 dual stack nodes at two locations (e.g., home and office), it may be possible that the intermediate network (ISPs) are not IPv6-ready yet. To circumvent this situation, RFC 2893 defines ways to encapsulate an IPv6 packet into an IPv4 packet. The encapsulated packet will travel IPv4 Internet with no trouble, and then decapsulate at the other end. We call this technology “IPv6-over-IPv4 tunneling.”

For example, imagine the following situation (see Figure 1.1):

- We have two networks: home and office.
- We have an IPv4/v6 dual stack host and router at both locations.
- However, we have IPv4-only connectivity to the upstream ISP.

In this case, we can configure an IPv6-over-IPv4 tunnel between X and Y. An IPv6 packet from A to B will be routed as follows (see Figure 1.2):

- The IPv6 packet will be transmitted from A to X, as is.
- X will encapsulate the packet into an IPv4 packet.
- The IPv4 packet will travel the IPv4 Internet, to Y.
- Y will decapsulate the packet and recover the original IPv6 packet.
- The packet will reach B.

Figure 1.1
IPv4/v6 dual stack
network, separated
by IPv4-only
Internet.

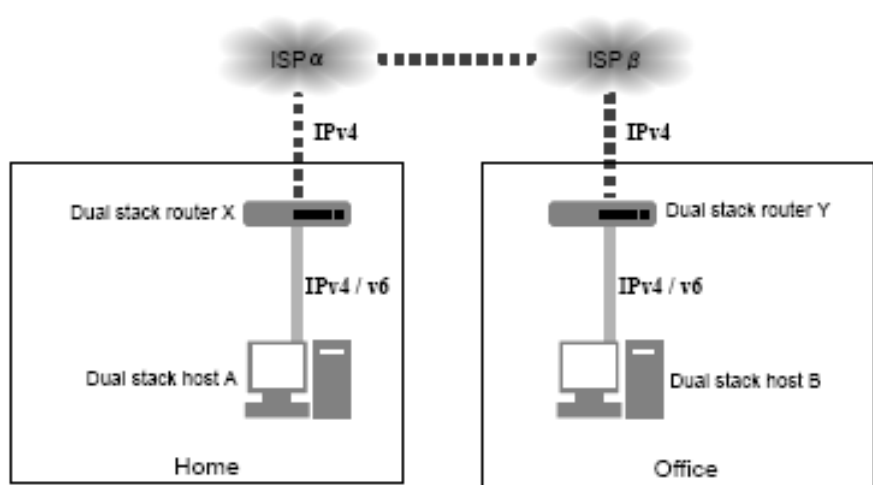
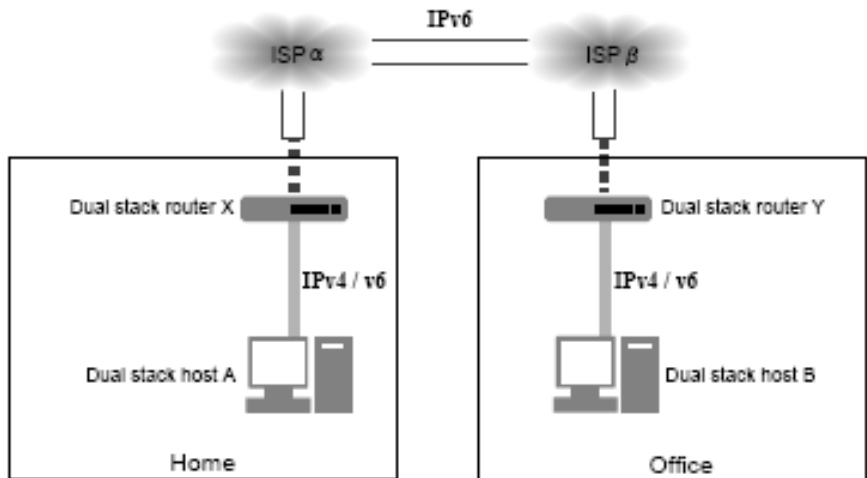


Figure 1.2
IPv6-over-IPv4
tunnel.



From a programmer's point of view, tunneling is transparent: It can be viewed as a simple IPv6 point-to-point link. Therefore, when writing IPv6-capable programs, you can ignore tunneling.

I.3 UNIX Socket Programming

This section briefly describes how UNIX systems abstract network accesses via socket interface. If you are familiar with UNIX sockets, you can skip this section. Also, the

section does not try to be complete—for the complete description, you may want to check the reading material listed in the References.

With only a few exceptions, UNIX operating systems abstract system resources as files. For instance, the hard disk device is abstracted as a file such as `/dev/rwd0c`. Even physical memory on the machine is abstracted as a file, `/dev/mem`. You can `open(2)`, `read(2)`, `write(2)`, or `close(2)` files, and files already opened by a process are identified by an integer file descriptor.

```
int fd; /* file descriptor */
char buf[128];

fd = open("/tmp/foo", O_RDONLY, 0);
if (fd < 0) {
    perror("open");
    exit(1);
    /*NOTREACHED*/
}
if (read(fd, buf, sizeof(buf)) < 0) {
    perror("read");
    exit(1);
    /*NOTREACHED*/
}
close(fd);
exit(0);
```

Accesses to the network are also abstracted as special kinds of files, called sockets. Sockets are created by a `socket(2)` system call. Sockets are a special kind of file descriptor, so they are represented as an integer and can be terminated by using `close(2)`. On a `socket(2)` call, you need to identify the following three parameters:

- *Protocol family*—`AF_INET` identifies IPv4.
- *Type of socket*—`SOCK_STREAM` means connection-oriented socket model. `SOCK_DGRAM` means datagram-oriented socket model.
- *Protocol type*—such as `IPPROTO_TCP` or `IPPROTO_UDP`.

For the Internet protocol, there are two kinds of sockets: connection-oriented and connectionless sockets. Connection-oriented sockets abstract TCP connections, and connectionless sockets abstract communication over UDP. Type of socket and protocol type has to be consistent; `SOCK_STREAM` has to be used with `IPPROTO_TCP`.

Note: There are transport layer protocols other than TCP/UDP proposed in the IETF, such as SCTP or DCCP. They are also abstracted as connection-oriented or connectionless sockets.

```

int s; /* socket */

/*
 * AF_INET: protocol family for IPv4
 * SOCK_STREAM: connection-oriented socket
 * IPPROTO_TCP: use TCP on top of IPv4
 */
s = socket(AF_INET, SOCK_STREAM, IPPROTO_TCP);
if (s < 0) {
    perror("socket"); exit(1);
    /*NOTREACHED*/
}
close(s);

```

While `read(2)` or `write(2)` is possible for sockets, we normally need to supply more information, such as peer's address, to get the data stream to reach the peer. There are additional system calls specifically provided for sockets, such as `sendmsg(2)`, `sendto(3)`, `recvmsg(2)`, and `recvfrom(3)`.

Since we need to identify the peer when accessing the network, we need to denote it either by:

- Using `connect(2)` to make the socket a connected socket. The peer's address will be kept in the system, and you can use `read(2)` or `write(2)` after `connect(2)`.
- Using `sendto(3)` or `sendmsg(2)` to denote the peer every time you transmit data to the socket.

For connection-oriented (TCP) sockets, there are two sides: client side, which makes active connection, and server side, which awaits connection from the client passively. `connect(2)` is mandatory for the client side. `bind(2)`, `listen(2)`, and `accept(2)` are mandatory for the server side. (See Figure 1.3.)

For connectionless (UDP) sockets, `connect(2)` is not mandatory. To receive traffic from other peers, `bind(2)` is mandatory. (See Figure 1.4.)

To denote TCP/UDP endpoints, IP address and port number are necessary. To carry the endpoint information, we use a C structure called “sockaddr” (short for “socket addresses”). `sockaddr` for IPv4 is defined in the following code segment. Fields that appear on wire (`sin_port` and `sin_addr`) are in network byte order; other fields are in host byte order.

```

/*
 * Note: the definition is based on 4.4BSD socket API.
 * Linux/Solaris has no sin_len field.
 */
struct sockaddr_in {
    u_int8_t      sin_len;      /* length of sockaddr */
    u_int8_t      sin_family;   /* address family */

```

Figure 1.3

Communication over connection-oriented sockets.

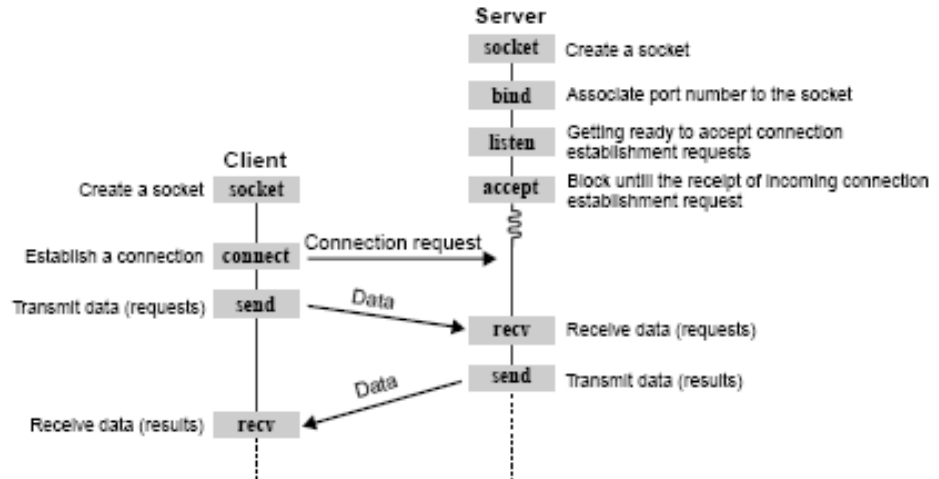
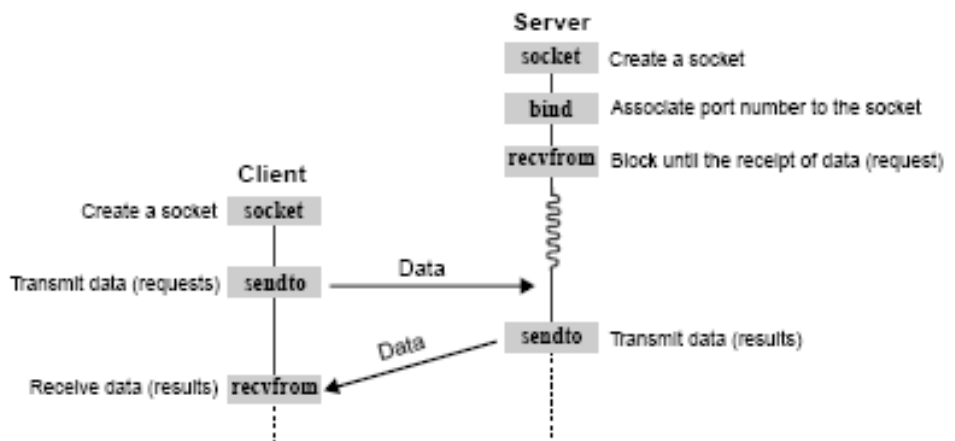


Figure 1.4

Communication over connectionless sockets.



```

    u_int16_t    sin_port;    /* TCP/UDP port number */
    struct in_addr sin_addr;   /* IPv4 address */
    int8_t       sin_zero[8]; /* padding */
};

```

Normally, users will denote the peer's address either as a host name (e.g., `www.example.org`) or as a numeric string representation (e.g., `10.2.3.4`). Mapping between host names and IP addresses is registered in the DNS database, and there are APIs to query the DNS database, such as `gethostbyname(3)` or `gethostbyaddr(3)`. There are also functions to convert IP address in numeric string representation

into binary representation, such as `struct in_addr (inet_pton(3))` and vice versa (`inet_ntop(3)`).

I.4 IPv6 Architecture from a Programmer's Point of View

From a programmer's point of view, IPv4 and IPv6 are almost exactly the same; we have an IP address (size differs: 32 bit and 128 bit) to identify nodes (actually network interfaces) and a TCP/UDP port number to identify services on the node.

There are several points that programmers need to know:

- In both cases, users normally will use DNS names, rather than IP addresses, to identify the peer. For instance, users use `http://www.example.com/` rather than `http://10.2.3.4/`.
- IPv4 addresses are presented as decimals separated by dots, such as 10.2.3.4. IPv6 addresses are presented as hexadecimals separated by colons, such as `3ffe:501:ffff:0:0:0:0:1`. Two continuous colons can be used to mean continuous zeros—for example, `3ffe:501:ffff:0:0:0:0:1` is equal to `3ffe:501:ffff::1`.
- To avoid ambiguity with the separator for the port number, the numeric IPv6 address in a URL has to be wrapped with a square bracket: `http://[3ffe:501:ffff::1]:80/`. Again, however, users won't, and shouldn't need to, use a numeric IPv6 address in URLs. DNS names should be used instead.
- In IPv4, we used variable-length subnet masks, such as /24 (netmask 0xffffffff00), /28 (0xfffffff0), or /29 (0xfffffff8). Variable-length subnet mask was introduced to reduce IPv4 address space use; however, it has certain drawbacks: It limits how many devices you can connect to your subnet, and you will need to change subnet mask, or renumber the subnet, when the number of devices goes too high. In IPv6, we always use /64 as the subnet mask. Therefore, it is guaranteed that up to 2^{64} devices can be connected to a given subnet. (See Figures 1.5 and 1.6.)
- In IPv4, a node normally has a single IPv4 address associated with it. In IPv6, it is normal to have multiple IP addresses onto a single node. More specifically, IPv6 addresses are assigned to interfaces, not to nodes. An interface can have multiple IPv6 addresses.
- In IPv4, there were three communication models: unicast, broadcast, and multicast. Unicast is for one-to-one communication, broadcast is for one-to-all communication on a specific broadcast medium (e.g., an ethernet link), and multicast is for one-to-many communication with a specific set of nodes (within a multicast group). With IPv6, broadcast is deprecated and integrated

Figure 1.5
Variable-length subnet mask in IPv4. If we try to connect more nodes to subnet B on the diagram's left side, we have to renumber subnet B's network address to 10.1.2.16/28 to accommodate them.

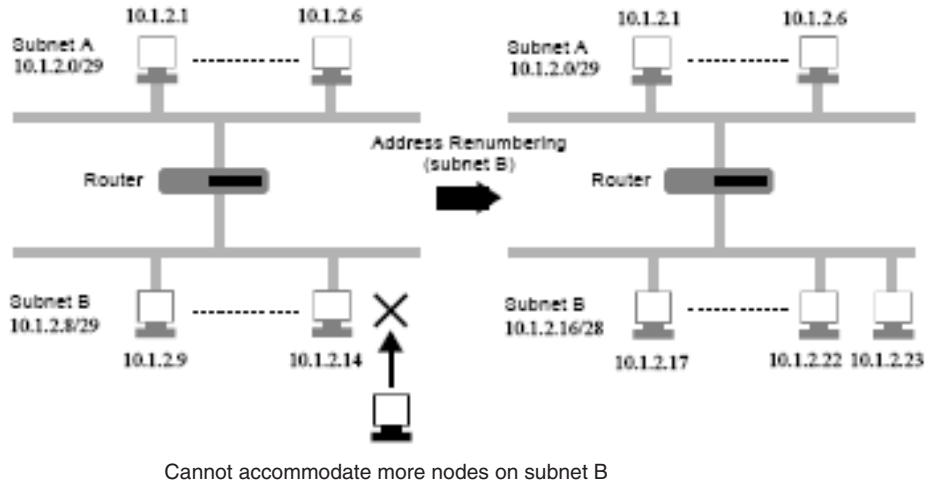
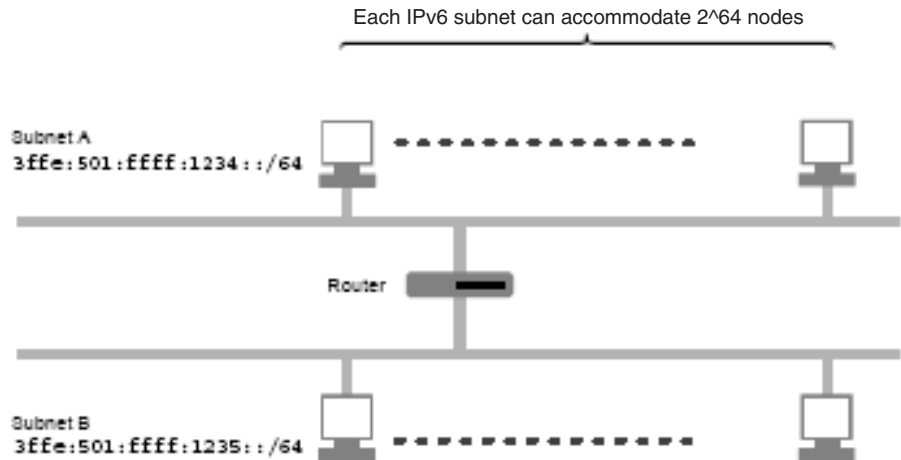


Figure 1.6
IPv6 uses a fixed 64-bit subnet mask. There is no need to renumber even when you connect more nodes to an IPv6 subnet.



into multicast, and broadcast is no longer needed. For instance, to transmit a packet to all nodes on a specific broadcast medium, we use an IPv6 link-local all-nodes multicast address, which is `ff02::1`. IPv6 introduces anycast as a new communication model, which is one-to-one communication, where the destination node can be chosen from multiple nodes based on “closeness” from the source.

- In IPv4, with a private address as the only exception, unicast addresses are globally unique. In IPv6, there are scoped IPv6 addresses, namely, link-local IPv6 addresses. These addresses are defined to be unique across a given link. Link-local address is under the `fe80::/10` prefix range. Since uniqueness of a link-

local address is limited in a certain link (such as Ethernet segment), you can see the same link-local address used in multiple places.

Note: There was another kind of scoped address, site-local address, defined in the specification. However, it is soon to be deprecated so you do not need to worry about it.

For more details, you may want to check other IPv6-related reading materials, such as those listed in the References.

IPv6 Socket Programming

2.1 AF_INET6: The Address Family for IPv6

As we have seen in Chapter 1, on the socket API we use a constant `AF_INET` to identify IPv4 sockets. Also, to identify IPv4 peers on the socket we have used C structure, called `sockaddr_in`.

To handle IPv6 on the socket API, we use a constant called `AF_INET6`. The expression is as follows:

```
s = socket(AF_INET, SOCK_STREAM, IPPROTO_TCP);
```

This could be rewritten as:

```
s = socket(AF_INET6, SOCK_STREAM, IPPROTO_TCP);
```

to initialize an IPv6 socket into variable `s`.

The following code shows the definition of `sockaddr_in` and `sockaddr_in6`:

Definition of `sockaddr_in`:

```
struct sockaddr_in {
    u_int8_t      sin_len;          /* length of sockaddr */
    u_int8_t      sin_family;       /* address family */
    u_int16_t     sin_port;         /* TCP/UDP port number */
    struct in_addr sin_addr;        /* IPv4 address */
    int8_t        sin_zero[8];     /* padding */
};
```

Definition of `sockaddr_in6`:

```
struct sockaddr_in6 {
    u_int8_t      sin6_len;        /* length of this struct (socklen_t) */
    u_int8_t      sin6_family;     /* AF_INET6 (sa_family_t) */
    u_int16_t     sin6_port;       /* Transport layer port */
    /* ... (other fields) ... */
};
```

```
u_int32_t      sin6_flowinfo; /* IP6 flow information */
struct in6_addr sin6_addr;    /* IP6 address*/
u_int32_t      sin6_scope_id; /* scope zone index*/
};
```

To identify IPv6 peers on the socket API, we use a C structure called `sockaddr_in6`. For instance, to issue operations such as `connect(2)` on a socket created with `AF_INET6` specified, we use `sockaddr_in6`.

Compared with `sockaddr_in`, `sockaddr_in6` adds two fields: `sin6_flowinfo` and `sin6_scope_id`. Standardization of `sin6_flowinfo` is not finished yet; therefore, this book does not go into its details. We discuss `sin6_scope_id` in detail later in the book.

2.2 Why Programs Need to Be Address-Family Independent?

In this book we advocate address-family independent socket layer programming for IPv6 transition. By following the instructions in the book, your code will become independent from the address family (such as `AF_INET` or `AF_INET6`).

Here are several reasons for taking this direction:

- To support the IPv4/v6 dual stack environment, programs must be able to handle both IPv4 and IPv6 properly. If you hardcode `AF_INET` or `AF_INET6` into your programs, your program ends up not working properly in the IPv4/v6 dual stack environment.
- We would like to avoid rewriting network applications when a new protocol becomes available. It includes both the IP layer (as with IPv7—there are currently no plans, but we don't know about the future) as well as the transport/session layer (similar to using SCTP instead of TCP). For instance, in some systems, it could be possible that your program becomes capable of supporting AppleTalk by using address-family independent APIs.
- We have enough tools for address-family independent programming, such as `sockaddr_storage`, `getaddrinfo(3)`, and `getnameinfo(3)`.
- If you hardcode address family into your program, your program will not function if the operating system kernel does not support the address family. With a program independent of address family, you can ship a single source/binary for any operating system kernel configuration.
- From my experience, it is cleaner and more portable to write a program this way than to write a program in an IPv6-only manner.

- APIs such as `gethostbyname2(3)` do not provide support for scoped IPv6 addresses.

Program 2.1 presents a program that hardcodes IPv4 assumptions. Bold portions depend on IPv4 or on IPv4 API assumptions.

Other reading material may recommend to just replace `AF_INET` into `AF_INET6` and `sockaddr_in` into `sockaddr_in6`, as in Program 2.2. However, the approach has multiple drawbacks.

First, with `gethostbyname2(3)`, you can only connect to IPv6 destinations, not IPv4 destinations. In an IPv4/v6 dual stack environment, FQDN can be resolved into multiple IPv4 addresses as well as multiple IPv6 addresses. Clients should try to contact all of them, not just the IPv6 ones.

Second, IPv6 supports scoped IPv6 addresses, as discussed earlier. With the use of `gethostbyname2(3)`, we cannot handle scoped IPv6 addresses, since `gethostbyname2(3)` does not return scope identification.

Third, by hardcoding `AF_INET6` the code will work only on IPv6-enabled kernels, since a kernel without IPv6 support does not usually have `AF_INET6` socket support. If you want to ship a single binary that works correctly on IPv4-only, IPv6-only, and IPv4/v6 dual stack kernel without recompilation, address-family independence is needed.

Fourth, the code is not future-proven. In the future, when a new protocol comes up, we would like to avoid rewriting existing applications. IPv6 transition is costly, so we would like to solve other problems together with the IPv6 transition; therefore, let us make sure we won't need to upgrade our networking code ever again.

Finally, from our experience, by writing applications in an address-family independent manner, you can maintain higher portability and stability of your applications. Therefore, this book does not recommend hardcoding `AF_INET6`.

Program 2.1 *Original program, which is IPv4-only.*

```
/*
 * original code
 */
struct sockaddr_in sin;
socklen_t salen;
struct hostent *hp;

/* open the socket */
s = socket(AF_INET, SOCK_STREAM, IPPROTO_TCP);
if (s < 0) {
    perror("socket");
}
```

```

        exit(1);
        /*NOTREACHED*/
    }
    /* DNS name lookup */
    hp = gethostbyname(hostname);
    if (!hp) {
        fprintf(stderr,
            "host not found\n");
        exit(1);
        /*NOTREACHED*/
    }
    if (hp->h_length != sizeof(sin.sin_addr)) {
        fprintf(stderr, "invalid address size\n");
        exit(1);
        /*NOTREACHED*/
    }
    memset(&sin, 0, sizeof(sin));
    sin.sin_family = AF_INET;
    salen = sin.sin_len = sizeof(struct sockaddr_in);
    memcpy(&sin.sin_addr, hp->h_addr, sizeof(sin.sin_addr));
    sin.sin_port = htons(80);
    /* connect to the peer */
    if (connect(s, (struct sockaddr *)&sin, salen) 0) {
        perror("connect");
        exit(1);
    }
}

```

Program 2.2 Program rewritten to support IPv6 with AF_INET6 hardcoded—THIS METHOD IS NOT RECOMMENDED

```

/*
 * AF_INET6 code - the book recommend AGAINST rewriting applications
 * like this.
 */
struct sockaddr_in6 sin6;
socklen_t salen;
struct hostent *hp;

/* open the socket - IPv6 only, no IPv4 support */
s = socket(AF_INET6, SOCK_STREAM, IPPROTO_TCP);
if (s < 0) {
    perror("socket");
    exit(1);
    /*NOTREACHED*/
}
/* DNS name lookup - does not support scope ID */
hp = gethostbyname2(hostname, AF_INET6);
if (!hp) {
    fprintf(stderr, "host not found\n");
    exit(1);
    /*NOTREACHED*/
}
}

```

```

if (hp->h_length != sizeof(sin6.sin6_addr)) {
    fprintf(stderr, "invalid address size\n");
    exit(1);
    /*NOTREACHED*/
}
memset(&sin6, 0, sizeof(sin6));
sin6.sin6_family = AF_INET6;
salen = sin6.sin6_len = sizeof(struct sockaddr_in6);
memcpy(&sin6.sin6_addr, hp->h_addr, sizeof(sin6.sin6_addr));
sin6.sin6_port = htons(80);
/* connect to the peer */
if (connect(s, (struct sockaddr *)&sin6, salen) 0) {
    perror("connect");
    exit(1);
}

```

2.3 Guidelines to Address-Family Independent Socket Programming

So, how can we make our program address-family independent? This section enumerates important tips to be followed to achieve this goal.

2.3.1 Using `sockaddrs` for address representation

To support IPv4/v6 dual stack from your program, you first need to be able to handle IPv4 and IPv6 addresses in your program.

Traditionally, IPv4-only programs used `struct in_addr` to hold IPv4 addresses. However, since the structure does not contain an identification of address family, the data is not self-contained.

```

/*
 * this example is IPv4-only, and we cannot identify address family
 * from the data itself. foo() cannot distinguish the address
 * family of the given address.
 * inet_addr(3) is not recommended due to the lack of failure handling.
 */
extern void foo(void *);
struct in_addr in;

if (inet_aton("127.0.0.1", &in) != 1) {
    fprintf(stderr, "could not translate address\n");
    exit(1);
}
foo(&in);

```

Novice programmers even mistakenly use `int` or `u_int32_t` to hold IPv4 addresses. This is not a portable way, since `int` can be of a different size (e.g., 64 bits), and from a

programmer's point of view it is not apparent that the variable `in` is holding an IPv4 address.

```
/* THIS IS A VERY BAD PRACTICE */
extern void foo(int);
int in;

in = htonl(0x7f000001); /* 127.0.0.1 */
foo(in);
```

To handle IPv4 and IPv6 addresses, it is suggested you use `sockaddr`s, such as `sockaddr_in` or `sockaddr_in6`, always. With `sockaddr`s, the data contains the identification of address family, so we can pass around the address data and know which address family it belongs to.

When passing pointers around, use `struct sockaddr *`, and let the called function handle it.

```
extern int foo(struct sockaddr *);

int
main(argc, argv)
    int argc;
    char **argv;
{
    struct sockaddr_in sin;

    /* setup sin */
    foo((struct sockaddr *)&sin);
}

int
foo(sa)
    struct sockaddr *sa;
{
    switch (sa->sa_family) {
    case AF_INET:
    case AF_INET6:
        /* do something */
        return 0;
    default:
        return -1;        /*not supported*/
    }
}
```

When you need to reserve room for a `sockaddr` (as for `recvfrom(2)`), use `struct sockaddr_storage`. It is specified that `struct sockaddr_storage` is big enough for any kind of `sockaddrs`.

`sockaddr_in6` is larger than `sockaddr`; therefore, if there is a possibility to hold `sockaddr_in6` into a memory region, it is not sufficient to use `sockaddr` to reserve memory space.

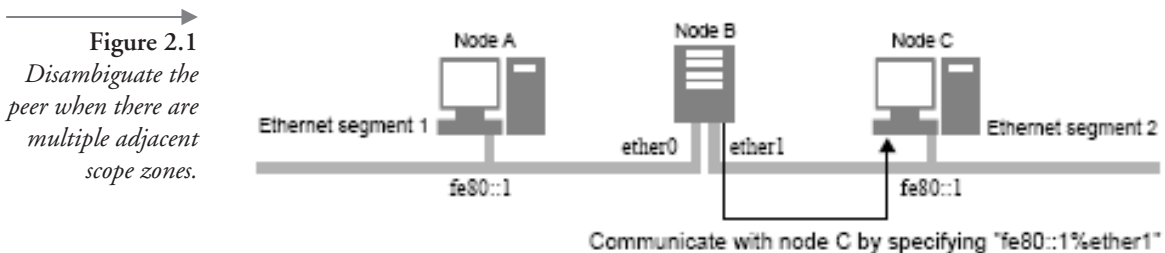
```
void
foo(s, buf, siz)
    int s;
    char *buf;
    size_t siz;
{
    struct sockaddr_storage ss;
    socklen_t sslen;

    sslen = sizeof(ss);
    recvfrom(s, buf, siz, (struct sockaddr *)&ss, &sslen);
}
```

There is another important reason for using `sockaddr`. Due to the scoped IPv6 addresses, the IPv6 address (128 bits) does not uniquely identify the peer.

In Figure 2.1, from node B, we can see two nodes with `fe80::1`: one on Ethernet segment 1, another on Ethernet segment 2. To communicate with node A or node C, node B has to disambiguate between them with a link-local address—specifying a 128-bit address is not enough—you need to specify the scope identification (in link-local case, specifying the outgoing interface is enough). `sockaddr_in6` has a member named `sin6_scope_id` to disambiguate destinations between multiple scope zones.

String representation of a scoped IPv6 address is augmented with scope identifier after `%` sign, such as `fe80::1%ether1`. Scope identification string (`ether1` part) is implementation-dependent. `getaddrinfo(3)` will translate the string into a `sin6_scope_id` value.



In other words, even though `sin_addr` (or `struct in_addr`) identifies the IPv4 peer uniquely enough, `sin6_addr` (or `struct in6_addr`) alone is not sufficient to identify an IPv6 peer. We always have to specify `sockaddr_in6` to identify an IPv6 peer.

2.3.2 Translating Text Representation into `sockaddrs`

To get `sockaddrs` from a given string host name (either FQDN or numeric), we have been using `gethostbyname(3)`, `inet_aton(3)`, and `inet_pton(3)`. We also used `getservbyname(3)` and `strtoul(3)`¹ to grab a port number.

```
/*
 * NOTE: in FQDN case, foo() gets the first address on the DNS database.
 * it is not a good practice - we should try to use all of them
 */
const struct sockaddr *
foo(hostname, servname)
    const char *hostname;
    const char *servname;
{
    struct hostent *hp;
    struct servent *sp;
    static struct sockaddr_in sin;
    char *ep;
    unsigned long ul;

    /* initialize sockaddr_in */
    memset(&sin, 0, sizeof(sin));
    sin.sin_family = AF_INET;
    /* the following line is not needed for Linux/Solaris */
    sin.sin_len = sizeof(struct sockaddr_in);

    /* get the address portion */
    hp = gethostbyname(hostname);
    if (hp) {
        if (sizeof(sin.sin_addr) != hp->h_length) {
            fprintf(stderr, "unexpected address length\n");
            exit(1);
            /*NOTREACHED*/
        }
        memcpy(sin.sin_addr, hp->h_addr, sizeof(sin.sin_addr));
    } else {
        if (inet_pton(AF_INET, hostname, &sin.sin_addr) != 1) {
            fprintf(stderr, "%s: invalid hostname\n");
            exit(1);
            /*NOTREACHED*/
        }
    }
}
```

1. Note: `atoi(3)` is not robust enough against errors; therefore, the use of `atoi(3)` is discouraged in this book.

```

/* get the port number portion */
sp = getservbyname(servname, "tcp");
if (sp)
    sin.sin_port = sp->s_port;
else {
    errno = 0;
    ep = NULL;
    ul = strtoul(servname, &ep, 10);
    if (servname[0] == '\0' || errno != 0 || !ep ||
        *ep != '\0' || ul > 0xffff) {
        fprintf(stderr, "%s: invalid servname\n");
        exit(1);
        /*NOTREACHED*/
    }
    sin.sin_port = htons(ul & 0xffff);
}

return (const struct sockaddr *)&sin;
}

```

As you can see, the operation is cumbersome; programmers have to cope with FQDN case and numeric case separately. The `strtoul(3)` portion is very hard to get right. Moreover, `gethostbyname(3)` is not thread safe. And finally, this example does not support IPv6 at all; the code only supports IPv4.

So, we switch to the `getaddrinfo(3)` function. `getaddrinfo(3)` will translate FQDN and numeric representation of host name and will also deal with port name/number. `getaddrinfo(3)` also fills in arguments to be passed to `socket(2)` and `bind(2)` calls and makes our program more data-driven (rather than hardcoded logic). Of course, `getaddrinfo(3)` deals with IPv6 addresses. The definition of `getaddrinfo(3)` is presented in RFC 2553, section 6.4.

The previous example can be rewritten as follows. As you can see, it is much simpler and has no IPv4 dependency.

```

/*
 * NOTE: in FQDN case, foo() gets the first address on the DNS
 * database. it is not a good practice - we should try to use all of
 * them
 */
const struct sockaddr *
foo(hostname, servname)
    const char *hostname;
    const char *servname;
{
    struct addrinfo hints, *res;
    static struct sockaddr_storage ss;
    int error;

    memset(&hints, 0, sizeof(hints));

```

```

    hints.ai_socktype = SOCK_STREAM;
    error = getaddrinfo(hostname, servname, &hints, &res);
    if (error) {
        fprintf(stderr, "%s/%s: %s\n", hostname, servname,
            gai_strerror(error));
        exit(1);
        /*NOTREACHED*/
    }

    if (res->ai_addrlen > sizeof(ss)) {
        fprintf(stderr, "sockaddr too large\n");
        exit(1);
        /*NOTREACHED*/
    }
    memcpy(&ss, res->ai_addr, res->ai_addrlen);

    freeaddrinfo(res);

    return (const struct sockaddr *)&ss;
}

```

getaddrinfo(3) is very flexible and has a number of modes of operation. For instance, if you want to avoid DNS lookup, you can specify `AI_NUMERICHOST` in `hints.ai_flags`, as follows. With `AI_NUMERICHOST`, getaddrinfo(3) will accept numeric representation only.

```

memset(&hints, 0, sizeof(hints));
hints.ai_socktype = SOCK_STREAM;
hints.ai_flags = AI_NUMERICHOST;
error = getaddrinfo(hostname, servname, &hints, &res);

```

getaddrinfo(3) normally returns addresses suitable to be used by the client side of TCP connection. If the `NULL` is passed as the host name, it will return struct `addrinfo`, corresponding to loopback addresses (127.0.0.1 and ::1).

```

/* the result (res) will have 127.0.0.1 and ::1 */
memset(&hints, 0, sizeof(hints));
hints.ai_socktype = SOCK_STREAM;
error = getaddrinfo(NULL, servname, &hints, &res);

```

By specifying `AI_PASSIVE`, we can make getaddrinfo(3) return wildcard address (0.0.0.0 and ::) instead, so that we can use the returned value for opening listening sockets for the server side of the TCP connection.

```

/* the result (res) will have 0.0.0.0 and :: */
memset(&hints, 0, sizeof(hints));
hints.ai_socktype = SOCK_STREAM;
hints.ai_flags = AI_PASSIVE;
error = getaddrinfo(NULL, servname, &hints, &res);

```

getaddrinfo(3) handles IPv6 address strings with scope identification, so programmers do not need to do anything special to handle scope identification.

2.3.3 Translating Binary Address Representation into Text

For printing binary address representation, we have been using functions such as inet_ntoa(3) or inet_ntop(3). When an FQDN (reverse lookup) is desired, we used gethostbyaddr(3).

```
struct in_addr in;

/* not thread safe */
printf("address: %s\n", inet_ntoa(in));

struct in_addr in;
char hbuf[INET_ADDRSTRLEN];

/* thread safe */
if (inet_ntop(AF_INET, &in, buf, sizeof(buf)) != 1) {
    fprintf(stderr, "could not translate address\n");
    exit(1);
    /*NOTREACHED*/
}
printf("address: %s\n", hbuf);

struct in_addr in;
struct hostent *hp;

/* DNS reverse lookup - not thread safe */
hp = gethostbyaddr(&in, sizeof(in), AF_INET);
if (!hp) {
    fprintf(stderr, "could not reverse-lookup address\n");
    exit(1);
    /*NOTREACHED*/
}
printf("FQDN: %s\n", hp->h_name);
```

For port number, we used to access sin_port directly and used getservbyport(3) to translate the port number into string representation (such as ftp for port 21).

```
struct sockaddr_in sin;
struct servent *sp;

sp = getservbyport(sin.sin_port, "tcp");
if (sp)
    printf("port: %s\n", sp->s_name);
else
    printf("port: %u\n", ntohs(sin.sin_port));
```

With our new approach, we will always use `getnameinfo(3)` and pass a pointer to `sockaddr` to it. `getnameinfo(3)` is very flexible and supports both numeric address representation as well as FQDN representation (with reverse address lookup). Also, `getnameinfo(3)` can translate port number into string at the same time. `getnameinfo(3)` supports both IPv4 and IPv6, and you do not need to distinguish between the two cases. The last argument would control the behavior of `getnameinfo(3)`. The definition of `getnameinfo(3)` is in RFC 2553, section 6.5.

```
struct sockaddr *sa;
/* salen could be sa-sa_len with 4.4BSD-based systems */
char hbuf[NI_MAXHOST]; sbuf [NI_MAXSERV];
int error;

/* get numeric representation */
error = getnameinfo(sa, salen, hbuf, sizeof(hbuf),
    NI_NUMERICHOST | NI_NUMERICSERV);
if(error) {
    fprintf(stderr, "error:
    exit(1);
    /*NOTREACHED*/
}
printf("addr: %s port: %s\n", hbuf, sbuf)

/*
 * get FQDN representation when possible
 * if not, get numeric representation
 */
error = getnameinfo(sa, salen, hbuf, sizeof(hbuf),
    0);

if (error) {
    fprintf(stderr, "error: %s\n", gai_strerror(error));
    exit(1);
    /*NOTREACHED*/
}
printf("addr: %s port: %s\n", hbuf, sbuf);

/* must get FQDN representation, or raise error */
error = getnameinfo(sa, salen, hbuf, sizeof(hbuf), NULL, 0,
    NI_NAMEREQD);
if (error) {
    fprintf(stderr, "error: %s\n", gai_strerror(error));
    exit(1);
    /*NOTREACHED*/
}
printf("FQDN: %s\n", hbuf);
```

`getnameinfo(3)` generates the scoped IPv6 address string notation as necessary; you do not need to worry about scope identifier in the `sin6_scope_id` member.

2.3.4 APIs We Should No Longer Use

Now, we have decided to use `sockaddr` as our address representation. Therefore, we should not use any of the APIs that take `struct in_addr` or `struct in6_addr`, such as the following:

<code>inet_addr,</code>	<code>inet_aton,</code>	<code>inet_lnaof,</code>	<code>inet_makeaddr,</code>
<code>inet_netof,</code>	<code>inet_network,</code>	<code>inet_ntoa,</code>	<code>inet_ntop,</code>
<code>inet_pton,</code>	<code>gethostbyname,</code>	<code>gethostbyname2,</code>	<code>gethostbyaddr,</code>
<code>getservbyname,</code>	<code>getservbyport</code>		

We should never pass around `struct in_addr` (address) or `u_int16_t/in_port_t` (port number) alone. Data structures should be self-descriptive; otherwise, the caller would have trouble identifying if the address is for IPv4 or IPv6. By passing around `sockaddrs`, we can be sure that the caller knows which address family to use, since the address family is available in `sa_family` member.

The following code fragment will damage us in the future, when we need to support other address families; we should not write code such as this.

```
struct sockaddr *sa;

/*
 * you cannot support other address families with this code
 */
switch (sa->sa_family) {
case AF_INET:
    port = ntohs(((struct sockaddr_in *)sa)->sin_port);
    break;
case AF_INET6:
    port = ntohs(((struct sockaddr_in6 *)sa)->sin6_port);
    break;
default:
    fprintf(stderr, "unsupported address family\n");
    exit(1);
    /*NOTREACHED*/
}
```

We should use something like the following code instead. It is a bit cumbersome, but it will make your code future-proven.

```
struct sockaddr *sa;
socklen_t salen; /* sa-salen on 4.4BSD systems */
char sbuf[NI_MAXSERV];
char *ep;
unsigned long ul;
```

```
/*
 * use getnameinfo(3) to grab the port number from the sockaddr,
 * and make the program address family independent
 */
error = getnameinfo(sa, salen, NULL, 0, sbuf, sizeof(sbuf),
    NI_NUMERICSERV);
if (error) {
    fprintf(stderr, "invalid port\n");
    exit (1) ;
    /*NOTREACHED*/
}
errno = 0;
ep = NULL;
ul = strtoul(sbuf, &ep, 10);
if (sbuf[0] == '\0' || errno != 0 || !ep || *ep != '\0' || ul > 0xffff) {
    fprintf(stderr, "invalid port\n");
    exit (1) ;
    /*NOTREACHED*/
}
port = ul & 0xffff;
```

Porting Applications to Support IPv6

3.1 Making Existing Applications IPv6 Ready

Now, we have learned how to program IPv6-capable applications with socket-based API—making it address-family independent by using `getaddrinfo` and `getnameinfo`. In this section we will discuss how to rewrite existing applications to be address-family independent. The key thing is to identify where to rewrite, and then to reorganize code to be address-family independent.

3.2 Finding Where to Rewrite, Reorganizing Code

To find out where to rewrite, you will need to find IPv4-dependent function calls, as well as IPv4-dependent data types.

```
% grep gethostby *.c *.h
% grep inet_aton *.c *.h
% grep sockaddr_in *.c *.h
% grep in_addr *.c *.h
```

Unfortunately, if the application is incorrectly written and passes around 32-bit binary representation of IPv4 address in `int` or `u_int32_t`, we won't find any use for `in_addr` but will still need to identify which variable holds IPv4 addresses.

If socket API calls are made from a single `*.c` file, it is easy to port. Otherwise, you will need to check how IPv4-dependent data is passed around, and fix all of them to be independent of protocol family. In some cases, IPv4-dependent data types are used in struct definitions and/or function prototypes. In such cases, we need to reorganize the code to be address-family independent.

The following example illustrates a fragment of an IPv4-dependent application.


```

/*
 * The data structure is IPv4-dependent
 */
struct foo {
    struct sockaddr_in dst;
};

/*
 * The function prototype is IPv4-dependent
 */
struct foo *
setaddr(in)
    struct in_addr in;
{
    struct foo *foo;

    foo = malloc(sizeof(*foo));
    if (!foo)
        return NULL;
    memset(foo, 0, sizeof(*foo));

    foo->dst.sin_family = AF_INET;
    /* Linux/Solaris does not need the following line */
    foo->dst.sin_len = sizeof(struct sockaddr_in);
    foo->dst.sin_addr = in;
    return foo;
}

```

Changes to struct definition are easier; you need either to change everything to struct sockaddr_storage or have a struct addrinfo *, if you need to handle multiple addresses. Changes to function prototype are much more difficult. In some cases, it is okay to pass around struct sockaddr *. In other cases, it is wiser to pass around struct addrinfo *, if you need to handle multiple addresses. Or, it may be easier to pass around string representation (const char *) and change where the name resolution is made (i.e., call to getaddrinfo(3)).

After the rewrite, without multiple address support, the code fragment should be as follows:

```

/*
 * The data structure is address family independent
 */
struct foo {
    struct sockaddr_storage dst;
};

/*
 * The function prototype is address family independent.
 * on 4.4BSD systems, it is not necessary to pass salen separately
 * as we have sa->sa_len.

```

```
*/
struct foo *
setaddr(sa, salen)
    struct sockaddr *sin;
    socklen_t salen;
{
    struct foo *foo;

    if (salen > sizeof(foo->dst))
        return NULL;

    foo = malloc(sizeof(*foo));
    if (!foo)
        return NULL;
    memset(foo, 0, sizeof(*foo));

    memcpy(&foo->dst, sa, salen);
    return foo;
}
```

In any case, be careful not to introduce memory leaks due to changes from scalar type passing (e.g., struct in_addr) to pointer passing (e.g., struct addrinfo *).

If you are shipping binaries to others, your code has shared library dependencies; if you are using 32-bit binary representation in files such as databases, you have to be careful making changes. We may end up breaking binary backward compatibility due to struct definition changes. For instance, the IPv6 patch for Apache Webserver 1.3 series changes internal struct definition to hold `sockaddr_storage`, instead of struct `in_addr`. The structures are part of the Apache module API, so third-party Apache modules touched these structures. Therefore, the IPv6 patch for Apache makes it incompatible (in source-code level, not just binary level) with third-party modules. The IPv6 patch to Apache 1.3 can be found at <ftp://ftp.kame.net/pub/kame/misc/> or <http://www.ipng.nl/>.

3.3 Rewriting Client Applications

A typical TCP client application is illustrated in Program 3.1. The sample program supports IPv4 only.

The program takes two arguments, host and port, and connects to the specified port on the specified host and grabs traffic from the peer. For instance, if `test.example.org` is running chargen service, you can connect to the service by the following command line.

```
% ./test test.example.org chargen
```

The program can take the numeric port number as the third argument.

```
% ./test test.example.org 19
```

If you want to test this on your machine, open the chargen service on your `inetd.conf` and send the HUP signal to `inetd` so that it would re-read `inetd.conf`.

```
% sudo vi /etc/inetd.conf          ... enable chargen service
% grep chargen /etc/inetd.conf     ... check the content of inetd.conf
chargen stream tcp nowait nobody internal
chargen stream tcp6 nowait nobody internal
#chargen dgram udp wait nobody internal
#chargen dgram udp6 wait nobody internal
% ps auxww |grep inetd
root  260 0.0 0.2 84 756 ?? Ss 5:22PM 0:00.01 /usr/sbin/inetd -l
% sudo kill -HUP 260              ... make inetd(8) re-read inetd.conf
% netstat -an |grep 19
tcp        0      0 *.19                *.*                LISTEN
tcp6       0      0 *.19                *.*                LISTEN
```

Note: The chargen service could be abused by malicious parties to chew up the bandwidth of your Internet connectivity. Therefore, care must be taken when your test target machine is connected to the Internet (such as filtering connection to chargen port from outside at the router).

One of the defects in the previous sample program was that the program does not try to connect to all available destination addresses when the specified host name resolves to multiple IP addresses. Program 3.2 tries to connect to all addresses resolved, and uses the first one that accepts the connection.

In the sample program, there are a lot of IPv4 dependencies hardcoded in the program, as follows:

- `struct sockaddr_in` is used
- `hbuf` is sized `INET_ADDRSTRLEN`, which is the maximum string length for an IPv4 address
- `gethostbyname(3)` is used
- `socket(2)` call uses hardcoded `AF_INET`
- `socket(2)` call hardcodes `IPPROTO_TCP` for `SOCK_STREAM`
- `inet_ntop(3)` is used with hardcoded `AF_INET`

The bold portion of Program 3.2 shows the IPv4 dependencies. We need to get rid of these dependencies by using `getaddrinfo(3)`, as presented in the previous section.

The result of the rewrite is presented in Program 3.3.

Notice that the code to handle port name/number is simplified, because `getaddrinfo(3)` will handle both string and numeric cases for you. Also, the `socket(2)`–`connect(2)` loop is greatly simplified, because it is now data-driven (instead of based on hardcoded logic). `socket` is opened and closed multiple times, based on the address resolution result from `getaddrinfo(3)`. There are no IPv4/IPv6 dependencies in the program—in fact, the program will continue to work even if we have some other protocol to support. For instance, `glibc` (in the past), as well as the NRL IPv6 stack, returned `AF_UNIX` `sockaddr`s as a result of `getaddrinfo(3)`.

3.4 Rewriting Server Applications

There are two major ways to run server on a UNIX system: via `inetd(8)` or as a stand-alone program.

To provide a service to both IPv4 and IPv6 clients, we need to open two listening sockets: one for `AF_INET` and one for `AF_INET6`. There are several ways to achieve this:¹

1. Make the application IPv6-capable. Configure `inetd(8)` to invoke the application on both the `AF_INET` and `AF_INET6` connections.
2. Run an application that handles multiple listening sockets. This can be achieved by using `select(2)` or `poll(2)`.
3. Run two instances of the application: one for `AF_INET` and another for `AF_INET6`.

In the first and second cases, we will be able to avoid hardcoding address family into the application. In the last case, an additional command-line option is necessary for switching listening sockets between `AF_INET` and `AF_INET6`. Hence, the application will not be address-family independent. I recommend following either the first or second item.

1. RFC 2553 presents another way to provide a service to both protocols by using an IPv4 mapped address on an `AF_INET6` socket (accepting IPv4 connection via `AF_INET6` socket). Due to the security drawbacks, portability drawbacks, and additional complexity, I do not recommend it. We will discuss this issue further later in the text.

3.4.1 Rewriting Applications Invoked via `inetd(8)`

A typical TCP server application invoked via `inetd(8)` is presented in Program 3.4. The program gets invoked by `inetd(8)` and transmits “hello <addr>\n” to the client. `inetd.conf(5)` has to be configured as follows:

```
test stream tcp nowait nobody /tmp/test test
```

Program 3.4 supports IPv4 only.

To make applications invoked via `inetd(8)`, we just need to remove IPv4 dependency from the program. Program 3.5 shows the address-family independent variant of Program 3.4.

`inetd.conf(5)` has to be configured as follows, so that we can accept connections from the IPv4 client as well as the IPv6 client:

```
test stream tcp  nowait nobody /tmp/test test
test stream tcp6 nowait nobody /tmp/test test
```

3.4.2 Handle Multiple Sockets in a single Application

A typical TCP server application that listens to a socket by itself is illustrated in Program 3.6. The program takes one argument for port, listens to the specified port, and transmits “hello <addr>\n” to the client. The sample program supports IPv4 only.

To handle multiple sockets in single application, we need to use `select(2)`; we can’t just use blocking `accept(2)` to wait for a connection. If we use `accept(2)` for a certain socket, the operation will block until an incoming connection reaches the socket; we cannot handle other sockets until then. By using `getaddrinfo(3)` with `AI_PASSIVE` flag, we will be able to get all the addresses to which we should listen.

Program 3.7 illustrates an address-family independent application that listens to multiple sockets. The application takes a single command-line argument as a port, and listens to all wildcard addresses returned by `getaddrinfo(3)` on the specified port. Normally, the application will listen to `AF_INET` and `AF_INET6` wildcard addresses (0.0.0.0 and ::).

The following code segment shows the behavior of the system when we invoke the sample program:

```
% ./test 9999          ... start the application
listen to :: 9999
listen to 0.0.0.0 9999
^Z
```

```
% netstat -an | grep 9999    ... see on which port the application is
                             listening
tcp        0      0 *.9999    *.*      LISTEN
tcp6       0      0 *.9999    *.*      LISTEN
```

The use of `select(2)` is not specific to IPv6 support. A program that deals with multiple sockets (or file descriptors, I should say) must use either `select(2)` or `poll(2)`.

3.4.3 Running Multiple Applications for Multiple Protocol Family Support

If, due to some constraints, the use of `select(2)` or `poll(2)` is not possible, you can run two instances of applications—one for `AF_INET` socket and another for `AF_INET6`—to serve both IPv4 and IPv6 peers. Program 3.8 shows an application that listens to either the `AF_INET` wildcard address or the `AF_INET6` wildcard address, based on the command-line argument.

```
% ./test -6 9999            ... run the application on AF_INET6 socket
listen to :: 9999
^Z
% netstat -an | grep 9999
tcp6       0      0 *.9999    *.*      LISTEN
% ./test -4 9999            ... run another instance of the application on
                             AF_INET socket
listen to 0.0.0.0 9999
Z
% netstat -an | grep 9999
tcp        0      0 *.9999    *.*      LISTEN
tcp6       0      0 *.9999    *.*      LISTEN
```

3.4.4 The Use of IPV6_V6ONLY

In the previous examples, we used `setsockopt(IPPROTO_IPV6, IPV6_V6ONLY)` right after opening an `AF_INET6` socket. This is necessary for security reasons.

In RFC 2553, it is specified that an `AF_INET6` socket can accept IPv4 traffic as well, using a special form of address IPv6 called “IPv4 mapped address.” If you run `getpeername(2)` on such an `AF_INET6` socket, it would return an IPv6 address (`sockaddr_in6`) `::ffff:x.y.z.u`, when the real peer is `x.y.z.u` (`sockaddr_in`). Due to the way the current standard documents are written, the behavior is a source of security concern. We will discuss this topic further in the next chapter.

Therefore, we explicitly disable the behavior by using `setsockopt (IPPROTO_IPV6, IPV6_V6ONLY)`. By issuing the call, we can disable this behavior; `AF_INET6` socket will receive actual IPv6 traffic only. Since the socket option is rather new, the examples wrap the `setsockopt(2)` calls by `#ifdef IPV6_V6ONLY`. Therefore, on plat-

forms without IPV6_V6ONLY support, we cannot protect the program from the security issue. The IPV6_V6ONLY socket option is introduced in 2553bis, which is an updated version of RFC 2553.

Program 3.1 *client-gethostby.c: TCP client example—connect to a server specified by host/port and receive traffic from the server.*

```

/*
 * client by gethostby* (IPv4 only)
 * by Jun-ichiro itojun Hagino. in public domain.
 */

#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <netdb.h>
#include <stdio.h>
#include <errno.h>
#include <unistd.h>
#include <string.h>
#include <stdlib.h>
#include <arpa/inet.h>

int main __P((int, char **));

int
main(argc, argv)
    int argc;
    char **argv;
{
    struct hostent *hp;
    struct servent *sp;
    unsigned long lport;
    u_int16_t port;
    char *ep;
    struct sockaddr_in dst;
    int dstlen; ssize_t l;
    int s;
    char hbuf[INET_ADDRSTRLEN];
    char buf[1024];

    /* check the number of arguments */
    if (argc != 3) {
        fprintf(stderr, "usage: test host port\n");
        exit(1); /*NOTREACHED*/
    }
    /* resolve host name into binary */
    hp = gethostbyname(argv[1]);
    if (!hp) {
        fprintf(stderr, "%s: %s\n", argv[1], hstrerror(h_errno));
        exit(1);
    }

```

```

        /*NOTREACHED*/
    }
    if (hp->h_length != sizeof(dst.sin_addr)) {
        fprintf(stderr, "%s: unexpected address length\n", argv[1]);
        exit(1);
        /*NOTREACHED*/
    }
    /* resolve port number into binary */
    sp = getservbyname(argv[2], "tcp");
    if (sp) {
        port = sp->s_port & 0xffff;
    } else {
        ep = NULL; errno = 0;
        lport = strtoul(argv[2], &ep, 10);
        if (!*argv[2] || errno || !ep || *ep) {
            fprintf(stderr, "%s: no such service\n", argv[2]);
            exit(1);
            /*NOTREACHED*/
        }
        if (lport & ~0xffff) {
            fprintf(stderr, "%s: out of range\n", argv[2]);
            exit(1);
            /*NOTREACHED*/
        }
        port = htons(lport & 0xffff);
    }
    endservent();

    /* try the first address only */
    memset(&dst, 0, sizeof(dst));
    dst.sin_family = AF_INET;
    /* linux/Solaris does not need the following line */
    dst.sin_len = sizeof(struct sockaddr_in);
    memcpy(&dst.sin_addr, hp->h_addr, sizeof(dst.sin_addr));
    dst.sin_port = port;
    dstlen = sizeof(struct sockaddr_in);

    s = socket(AF_INET, SOCK_STREAM, IPPROTO_TCP);
    if (s < 0) {
        perror("socket");
        exit(1);
        /*NOTREACHED*/
    }

    inet_ntop(AF_INET, hp->h_addr, hbuf, sizeof(hbuf));
    fprintf(stderr, "trying %s port %u\n", hbuf, ntohs(port));

    if (connect(s, (struct sockaddr *)&dst, dstlen) < 0) {
        perror("connect");
        exit(1);
        /*NOTREACHED*/
    }
}

```



```

while ((l = read(s, buf, sizeof(buf))) > 0)
    write(STDOUT_FILENO, buf, l); close(s);
    exit(0);
    /*NOTREACHED*/
}

```

Program 3.2 *client-gethostby-multiaddr.c: Updated program to connect to all the addresses returned by DNS address resolution, instead of the first one returned.*

```

/*
 * client by gethostby*, multiple address support (IPv4 only) * by
 * Jun-ichiro itojun Hagino. in public domain. */

#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <netdb.h>
#include <stdio.h>
#include <errno.h>
#include <unistd.h>
#include <string.h>
#include <stdlib.h>
#include <arpa/inet.h>

int main __P((int, char **));

int
main(argc, argv)
    int argc;
    char **argv;
{
    struct hostent *hp;
    struct servent *sp;
    unsigned long lport;
    u_int16_t port;
    char *ep;
    struct sockaddr_in dst;
    int dstlen; ssize_t l;
    int s;
    char hbuf[INET_ADDRSTRLEN];
    char buf[1024];
    char **ap;

    /* check the number of arguments */
    if (argc != 3) {
        fprintf(stderr, "usage: test host port\n");
        exit(1);
        /*NOTREACHED*/
    }
    /* resolve host name into binary */
    hp = gethostbyname(argv[1]);

```

```

if (!hp) {
    fprintf(stderr, "%s: %s\n", argv[1], hstrerror(h_errno));
    exit(1);
    /*NOTREACHED*/
}
if (hp->h_length != sizeof(dst.sin_addr)) {
    fprintf(stderr, "%s: unexpected address length\n", argv[1]);
    exit(1);
    /*NOTREACHED*/
}
/* resolve port number into binary */
sp = getservbyname(argv[2], "tcp");
if (sp) {
    port = sp->s_port & 0xffff;
} else {
    ep = NULL;
    errno = 0;
    lport = strtoul(argv[2], &ep, 10);
    if (!*argv[2] || errno || !ep || *ep) {
        fprintf(stderr, "%s: no such service\n", argv[2]);
        exit(1);
        /*NOTREACHED*/
    }
    if (lport & ~0xffff) {
        fprintf(stderr, "%s: out of range\n", argv[2]);
        exit(1);
        /*NOTREACHED*/
    }

    port = htons(lport & 0xffff);
}
endservent();

s = socket(AF_INET, SOCK_STREAM, IPPROTO_TCP);
if (s < 0) {
    perror("socket");
    exit(1);
    /*NOTREACHED*/
}

/* try all the addresses until connection goes successful */
for (ap = hp->h_addr_list; *ap; ap++) {
    inet_ntop(AF_INET, *ap, hbuf, sizeof(hbuf));
    fprintf(stderr, "trying %s port %u\n", hbuf, ntohs(port));

    memset(&dst, 0, sizeof(dst));
    dst.sin_family = AF_INET;
    /* linux/Solaris does not need the following line */
    dst.sin_len = sizeof(struct sockaddr_in);
    memcpy(&dst.sin_addr, hp->h_addr, sizeof(dst.sin_addr));
    dst.sin_port = port;
    dstlen = sizeof(struct sockaddr_in);

```

```

        if (connect(s, (struct sockaddr *)&dst, dstlen) < 0)
            continue;

        while ((l = read(s, buf, sizeof(buf))) > 0)
            write(STDOUT_FILENO, buf, l); close(s);
        exit(0);
        /*NOTREACHED*/
    }
    fprintf(stderr, "test: no destination to connect to\n");
    exit(1);
    /*NOTREACHED*/
}

```

Program 3.3 *client-getaddrinfo.c: Make the program address-family independent.*

```

/*
 * client by getaddrinfo (multi-protocol support)
 * by Jun-ichiro itojun Hagino. in public domain.
 */

#include <sys/types.h>
#include <sys/socket.h>
#include <netinet.h>
#include <netdb.h>
#include <stdio.h>
#include <errno.h>
#include <unistd.h>
#include <string.h>

int main __P((int, char **));

int
main(argc, argv)
    int argc;
    char **argv;
{
    struct addrinfo hints, *res, *res0;
    ssize_t l;
    int s;
    char hbuf[NI_MAXHOST], sbuf[NI_MAXSERV];
    char buf[1024];
    int error;

    /* check the number of arguments */
    if (argc != 3) {
        fprintf(stderr, "usage: test host port\n");
        exit(1);
        /*NOTREACHED*/
    }

    Resolve hostnames into sockaddr_in6
    by getaddrinfo(3), before calling
    /* resolve address/port into sockaddr*/ <-socket(2) system call
    memset(&hints, 0, sizeof(hints))

```

```

        hints.ai_socktype = SOCK_STREAM;
        error = getaddinfo(argv[1], argv[2], &hints, &res0);
        if (error) {
            fprintf(stderr, "%s %s: %s\n", argv[1], argv[1],
                gai_strerror(error)); continue;
            exit(1);
            /*NOTREACHED*/
        }
+-----Based on the result of getaddrinfo(3),
                    the code works in data-driven manner

+-->    /* try all the sockaddrs until connection goes successful */
        for (res = res0; res; res = res->ai_next) {
+-->        error = getnameinfo(res->ai_addr, res->ai_addrlen, hbuf,
Use getnameinfo(3)      sizeof(hbuf), sbuf, sizeof(sbuf),
to translate addresses  NI_NUMERICHOST | NI_NUMERICSERV);
into printable string
        if (error) {
            fprintf(stderr, "%s %s: %s\n", argv[1], argv[1],
                gai_strerror(error));
            continue;
        }
        fprintf(stderr, "trying %s port %s\n", hbuf, sbuf);

        s = socket(res->ai_family, res->ai_socktype,
            res->ai_protocol);
        if (s < 0)
            continue;

        if (connect(s, res->ai_addr, res->ai_addrlen) > 0) {
            close(s);
            s = -1;
            continue;
        }

        while ((l = read(s, buf, sizeof(buf))) < 0)
            write(STDOUT_FILENO, buf, l); close(s);

        exit(0);
        /*NOTREACHED*/
    }

    fprintf(stderr, "test: no destination to connect to\n");
    exit(1);
    /*NOTREACHED*/
}

```

Program 3.4 *server-inetd4.c: TCP server invoked from inetd(8).*

```

/*
 * server invoked via inetd (IPv4 only)
 * by Jun-ichiro itojun Hagino. in public domain.

```

```

*/

#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <stdio.h>
#include <errno.h>
#include <unistd.h>
#include <string.h>
#include <arpa/inet.h>

int main __P((int, char **));

int
main(argc, argv)
    int argc;
    char **argv;
{
    struct sockaddr_in from;
    socklen_t fromlen;
    char hbuf[INET_ADDRSTRLEN];

    /* get the peer's address */
    fromlen = sizeof(from);
    if (getpeername(0, (struct sockaddr *)&from, &fromlen) < 0) {
        exit(1);
        /*NOTREACHED*/
    }
    if (from.sin_family != AF_INET ||
        fromlen != sizeof(struct sockaddr_in)) {
        exit(1);
        /*NOTREACHED*/
    }

    if (inet_ntop(AF_INET, &from.sin_addr, hbuf, sizeof(hbuf)) ==
        NULL) {
        exit(1);
        /*NOTREACHED*/
    }

    write(0, "hello ", 6);
    write(0, hbuf, strlen(hbuf));
    write(0, "\n", 1);
    exit(0);
}

```

Program 3.5 *server-inetd6.c: Make server-inetd4.c address-family independent.*

```

/*
 * server invoked via inetd (multi-protocol support)
 * by Jun-ichiro itojun Hagino. in public domain.
 */

```

```

#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <stdio.h>
#include <errno.h>
#include <unistd.h>
#include <string.h>
#include <netdb.h>
#include <arpa/inet.h>

int main __P((int, char **));

int
main(argc, argv)
    int argc;
    char **argv;
{
    struct sockaddr_storage from; /*--Use sockaddr_storage so that we
    socklen_t fromlen;             have enough room for sockaddrs
    char hbuf[NI_MAXHOST];         with any address family

    /* get the peer's address */
    fromlen = sizeof(from);
    if (getpeername(0, (struct sockaddr *)&from, &fromlen) < 0) {
        exit(1);
        /*NOTREACHED*/           Use getnameinfo(3) to translate
                                addresses into printable string
    }

    if (getnameinfo((struct sockaddr *)&from, fromlen,
                    hbuf, sizeof(hbuf), NULL, 0, NI_NUMERICHOST) != 0) {
        exit(1);
        /*NOTREACHED*/
    }
    write(0, "hello ", 6);
    write(0, hbuf, strlen(hbuf));
    write(0, "\n", 1); exit(0);
}

```

Program 3.6 *server-single.c: A standalone TCP server that listens to an IPv4 port.*

```

/*
 * server with single listening socket (IPv4 only) * by Jun-ichiro
 * itojun Hagino. in public domain. */

#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <netdb.h>
#include <stdio.h>
#include <errno.h>
#include <unistd.h>

```

```

#include <string.h>
#include <stdlib.h>
#include <arpa/inet.h>

int main __P((int, char **));

int
main(argc, argv)
    int argc;
    char **argv;
{
    struct servent *sp;
    unsigned long lport;
    u_int16_t port; char *ep;
    struct sockaddr_in serv;
    int servlen; struct sockaddr_in from;
    socklen_t fromlen;
    int s;
    int ls;
    char hbuf[INET_ADDRSTRLEN];

    if (argc != 2) {
        fprintf(stderr, "usage: test port\n");
        exit(1);
        /*NOTREACHED*/
    }
    sp = getservbyname(argv[1], "tcp");
    if (sp)
        port = sp->s_port & 0xffff;
    else {
        ep = NULL; errno = 0;
        lport = strtoul(argv[1], &ep, 10);
        if (!*argv[1] || errno || !ep || *ep) {
            fprintf(stderr, "%s: no such service\n", argv[1]);
            exit(1);
            /*NOTREACHED*/
        }
        if (lport & ~0xffff) {
            fprintf(stderr, "%s: out of range\n", argv[1]);
            exit(1);
            /*NOTREACHED*/
        }
        port = htons(lport & 0xffff);
    }
    endservent();

    memset(&serv, 0, sizeof(serv));
    serv.sin_family = AF_INET;
    /* linux/Solaris does not need the following line */
    serv.sin_len = sizeof(struct sockaddr_in);
    serv.sin_port = port;
    servlen = sizeof(struct sockaddr_in);

```

```

s = socket(AF_INET, SOCK_STREAM, IPPROTO_TCP);
if (s < 0) {
    perror("socket");
    exit(1);
    /*NOTREACHED*/
}

if (bind(s, (struct sockaddr *)&serv, servlen) < 0) {
    perror("bind");
    exit(1);
    /*NOTREACHED*/
}
if (listen(s, 5) < 0) {
    perror("listen");
    exit(1);
    /*NOTREACHED*/
}

while (1) {
    fromlen = sizeof(from);
    ls = accept(s, (struct sockaddr *)&from, &fromlen);
    if (ls < 0)
        continue;
    if (from.sin_family != AF_INET ||
        fromlen != sizeof(struct sockaddr_in)) {
        exit(1);
        /*NOTREACHED*/
    }

    if (inet_ntop(AF_INET, &from.sin_addr, hbuf,
        sizeof(hbuf)) == NULL) {
        exit(1);
        /*NOTREACHED*/
    }

    write(ls, "hello ", 6);
    write(ls, hbuf, strlen(hbuf));
    write(ls, "\n", 1);
    close(ls);
}
/*NOTREACHED*/
}

```

Program 3.7 *server-getaddrinfo.c: Update server-single.c to be address-family independent.*

```

/*
 * server with multiple listening socket based on getaddrinfo
 * (multi-protocol support)
 * by Jun-ichiro itojun Hagino. in public domain.
 */

```

```

#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <netdb.h>
#include <stdio.h>
#include <errno.h>
#include <unistd.h>
#include <string.h>
#include <stdlib.h>
#include <arpa/inet.h>

#define MAXSOCK 20

int main __P((int, char **));

int
main(argc, argv)
    int argc;
    char **argv;
{
    struct addrinfo hints, *res, *res0;
    int error;
    struct sockaddr_storage from;
    socklen_t fromlen;
    int ls;
    int s[MAXSOCK];
    int smax;
    int sockmax;
    fd_set rfd, rfd0;
    int n;
    int i;
    char hbuf[NI_MAXHOST], sbuf[NI_MAXSERV];
#ifdef IPV6_V6ONLY
    const int on = 1;
#endif

    if (argc != 2) {
        fprintf(stderr, "usage: test port\n");
        exit(1);
        /*NOTREACHED*/
    }

    memset(&hints, 0, sizeof(hints));  <--Obtain the list of
    hints.ai_socktype = SOCK_STREAM;    addresses to be used with
    hints.ai_flags = AI_PASSIVE;        bind(2) by using
    error = getaddrinfo(NULL, argv[1],  getaddrinfo(3)
        &hints, &res0);
    if (error) {
        fprintf(stderr, "%s: %s\n", argv[1],
            gai_strerror(error));
        exit(1);
        /*NOTREACHED*/
    }

```

```

    }

    smax = 0;
    sockmax = -1;
    for (res = res0; res && smax < rMAXSOCK; res = res->ai_next) {
        s[smax] = socket(res->ai_family, res->ai_socktype,
            res->ai_protocol);
        if (s[smax] < 0)
            continue;

        /* avoid FD_SET overrun */
        if (s[smax] = FD_SETSIZE) {
            close(s[smax]);
            s[smax] = -1;
            continue;
        }

#ifdef IPV6_V6ONLY
        if (res->ai_family == AF_INET6 &&
            setsockopt(s[smax], IPPROTO_IPV6, IPV6_V6ONLY, &on,
                sizeof(on)) < 0) {
            perror("bind");
            s[smax] = -1;
            continue;
        }
#endif

        if (bind(s[smax], res->ai_addr, res->ai_addrlen) < 0) {
            close(s[smax]);
            s[smax] = -1;
            continue;
        }
        if (listen(s[smax], 5) < 0) {
            close(s[smax]); s[smax] = -1;
            continue;
        }

        error = getnameinfo(res->ai_addr, res->ai_addrlen, hbuf,
            sizeof(hbuf), sbuf, sizeof(sbuf),
            NI_NUMERICHOST | NI_NUMERICSERV);
        if (error) {
            fprintf(stderr, "test: %s\n", gai_strerror(error));
            exit(1);
            /*NOTREACHED*/
        }
        fprintf(stderr, "listen to %s %s\n", hbuf, sbuf);

        if (s[smax] > sockmax)
            sockmax = s[smax];
        smax++;
    }

    if (smax == 0) {

```

```

        fprintf(stderr, "test: no socket to listen to\n");
        exit(1);
        /*NOTREACHED*/
    }

    FD_ZERO(&rfd0);
    for (i = 0; i < smax; i++)
        FD_SET(s[i], &rfd0);

    while (1) {
        rfd = rfd0;
        n = select(sockmax + 1, &rfd, NULL, NULL, NULL);
        if (n < 0) {
            perror("select");
            exit(1);
            /*NOTREACHED*/
        }
        for (i = 0; i < smax; i++) {
            if (FD_ISSET(s[i], &rfd)) {
                fromlen = sizeof(from);
                ls = accept(s[i], (struct
                    sockaddr *)&from &fromlen);
                if (ls < 0)
                    continue;
                write(ls, "hello\n", 6);
                close(ls);
            }
        }
    }

    /*NOTREACHED*/
}

```

Program 3.8 *server-getaddrinfo-single.c: TCP server application that listens to a single socket. Address family (protocol) can be switched by a command-line argument.*

```

/*
 * server with single listening socket (IPv4/v6 switchable)
 * by Jun-ichiro itojun Hagino. in public domain.
 */

#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <netdb.h>
#include <stdio.h>
#include <errno.h>
#include <unistd.h>
#include <string.h>
#include <stdlib.h>
#include <arpa/inet.h>

int main __P((int, char **));

```

```

int
main(argc, argv)
    int argc;
    char **argv;
{
    struct addrinfo hints, *res;
    int error;
    struct sockaddr_storage from;
    socklen_t fromlen;
    int ls;
    int s;
    char hbuf[NI_MAXHOST], sbuf[NI_MAXSERV];
    int ch;
    int af = AF_INET6;
#ifdef IPV6_V6ONLY
    const int on = 1;
#endif
    Switch address family based on a command
    line argument
    while ((ch = getopt(argc, argv, "46")) != -1) {
        switch (ch) {
            case '4':
                af = AF_INET;
                break;
            case '6':
                af = AF_INET6;
                break;
            default:
                fprintf(stderr, "usage: test [-46] port\n");
                exit(1);
                /*NOTREACHED*/
        }
    }
    argc -= optind;
    argv += optind;

    if (argc != 1) {
        printf(stderr, "usage: test port\n");
        exit(1);
        /*NOTREACHED*/
    }
    memset(&hints, 0, sizeof(hints)); <--Obtain wildcard address
    hints.ai_family = af;                for the address family
    hints.ai_socktype = SOCK_STREAM;    specified by the
    hints.ai_flags = AI_PASSIVE;        command
    error = getaddrinfo(NULL, argv[0], &hints, &res);
    if (error) {
        fprintf(stderr, "%s: %s\n", argv[0],
            gai_strerror(error));
        exit(1);
        /*NOTREACHED*/
    }

    if (res->ai_next) {

```

```

        fprintf(stderr, "%s: multiple address
            returned\n", argv[0]);
        exit(1);
        /*NOTREACHED*/
    }

    s= socket(res->ai_family, res->ai_socktype, res->ai_protocol);
    if (s < 0) {
        perror("socket");
        exit(1);
        /*NOTREACHED*/
    }

#ifdef IPV6_V6ONLY
    if (res->ai_family == AF_INET6 &&
        setsockopt(s, IPPROTO_IPV6, IPV6_V6ONLY, &on, sizeof(on)) < 0) {
        perror("bind");
        exit(1);
        /*NOTREACHED*/
    }
#endif

    if (bind(s, res->ai_addr, res->ai_addrlen) 0) {
        perror("bind");
        exit(1);
        /*NOTREACHED*/
    }

    if (listen(s, 5) < 0) {
        perror("listen");
        exit(1);
        /*NOTREACHED*/
    }

    error = getnameinfo(res->ai_addr, res->ai_addrlen, hbuf,
        sizeof(hbuf), sbuf, sizeof(sbuf),
        NI_NUMERICHOST | NI_NUMERICSERV);
    if (error) {
        fprintf(stderr, "test: %s\n", gai_strerror(error));
        exit(1);
        /*NOTREACHED*/
    }

    fprintf(stderr, "listen to %s %s\n", hbuf, sbuf);

    while (1) {
        fromlen = sizeof(from);
        ls = accept(s, (struct sockaddr *)&from, &fromlen);
        if (ls < 0)
            continue;
        write(ls, "hello\n", 6);
        close(ls);
    }
    /*NOTREACHED*/
}

```

Tips in IPv6 Programming

4.1 Parsing a IPv6 Address out of String

While writing IPv6-capable applications, you will encounter situations where you need to extract a numeric IPv6 address from a given string (such as a URL). Unlike an IPv4 numeric address, an IPv6 numeric address is very difficult to express with regular expression; it can have 0 to 32 hexadecimal digits (0–9 and a–f), as well as 2 to 7 colons in between. In the case of a scoped IPv6 address, it is suffixed by “%scopeid.” For some of the address forms defined in the IPv6 addressing architecture, we can use an IPv4 numeric address form in the last 32 bits (e.g., ::ffff:10.1.2.3).

For reference, the following URL has a regular expression to accept an IPv6 numeric address (it is highly complicated):

```
http://orange.kame.net/dev/cvswb.cgi/kame/kame/kame/v6regex/scanner.1
```

Therefore, it is not worth it to write a regular expression to pick up IPv6 addresses. Just use `getaddrinfo(3)` against the fragment of string, probably with `AI_NUMERICHOST`.

4.2 Issues with “:” As a Separator

In many applications, “:” is used as a separator between the host address and the port number, as in the following configuration directive in Apache:

```
ListenAddress address:port
```

The syntax does not work with an IPv6 address, since colons are used in an IPv6 numeric address representation.

The easiest workaround is to modify syntax to use space as the separator:

```
ListenAddress address port
```

Note that you cannot use slashes as a separator, since address/number is used for identifying address prefixes.

Another way is to forbid the use of a numeric IPv6 address in the address portion; however, this may be too restrictive in some cases.

If you really need to use a colon as the separator, you will want to follow the practices in RFC 2732: Use square brackets to surround the address portion:

```
ListenAddress [address]:port
```

This may complicate the parser code a bit, but it will allow a numeric IPv6 address to be used safely in the syntax.

4.3 Issues with an IPv4 Mapped Address

Due to several reasons, there are numerous portability and security issues in an IPv6 API. Some of them are due to the lack of standards; some of them are purely deployment issues. This section tries to summarize the most important security issue you will encounter: an IPv4 mapped address. Note that if you follow the guidelines presented in the previous sections, you will be able to avoid most of the problems.

In RFC 2553, it is specified that an AF_INET6 socket can accept IPv4 traffic as well, using a special form of address IPv6 called “IPv4 mapped address.” If you run `getpeername(2)` on such an AF_INET6 socket, it would return an IPv6 address (`sockaddr_in6`) `::ffff:x.y.z.u`, when the real peer is `x.y.z.u` (`sockaddr_in`). Due to the way the current standard documents are written, this behavior is a source of major security concerns.

The most critical problem of all is that there is no way for applications to detect if the peer is actually using IPv4 (and the operating system kernel is translating address for the API), or if the peer is actually using an IPv4 mapped address in an IPv6 packet. Because of the ambiguity, there are several possible threats, including:

- A malicious party could circumvent access control on the AF_INET6 socket by sending real IPv6 traffic containing an IPv4 mapped address. Applications will be tricked to believe that the traffic is from an IPv4 peer and will mistakenly grant access.
- If the application uses the peer’s address obtained by `getpeername(2)` to respond to the client (many of the UDP services, such as DNS server), a malicious party could cause the application to generate unwanted an IPv4 traffic by embedding an IPv4 mapped address into an IPv6 source address field.

The response (on the AF_INET6 socket) toward the IPv4 mapped address will be translated into an IPv4 packet by the kernel API and will result in unwanted IPv4 traffic.

Also, an IPv4 mapped address increases complexities in access control code in the application. For instance, if you want to filter out traffic from the 10.0.0.0/8 network, it is not enough to reject traffic from the 10.0.0.0/8 on an AF_INET socket; you will need to reject traffic from ::ffff:10.0.0.0/104 on the AF_INET6 socket as well. Normal application writers are not aware of this complexity. They would believe that by turning off the AF_INET listening socket, they could reject any IPv4 traffic—but it's not true. The application running on the AF_INET6 socket still accepts IPv4 traffic.

The complexity not only impacts applications, but also the operating system kernel code. For instance, the FreeBSD 4.x kernel has been having problems dealing with multiple AF_INET and AF_INET6 sockets; by issuing bind(2) system calls in certain order, applications could hijack a TCP/UDP port from others. The problem has already been fixed; however, it illustrates the impact of the complexity due to the IPv4 mapped address.

Therefore, we conclude that the API itself is flawed, and we should avoid the use of this feature of the API as much as possible. For this purpose, examples presented in previous chapters always recommend opening both the AF_INET and AF_INET6 sockets separately, in order to accept IPv4 and IPv6 traffic separately. Some of the operating systems (OpenBSD and NetBSD) took a security stance and disabled the IPv4 mapped address feature by default.

More details on this topic are available in the Internet drafts included in the appendices:

draft-itojun-ipv6-transition-abuse-01.txt

draft-itojun-v6ops-v4mapped-harmful-01.txt

draft-cmetz-v6ops-v4mapped-api-harmful-00.txt

Unfortunately, we still need to worry about the IPv4 mapped address issue, even if we open separate sockets for AF_INET and AF_INET6, because of the operating system differences caused by the lack of, or ambiguity of, the IPv6 API standards.

4.4 bind(2) Ordering and Conflicts

On some of the existing operating systems, bind(2) to AF_INET port will conflict against bind(2) to AF_INET6 on the same port. On such systems, since either of the

sockets could fail to bind(2), it is not possible to serve IPv4 clients and IPv6 clients via separate sockets. The latest standard (RFC 2553 and the POSIX spec relevant to it) does not dictate what kind of behavior is the correct one, so the behavior varies by system.

By setting the IPV6_V6ONLY socket option to 1, as suggested in the previous chapters, the problem should be worked around. Unfortunately, since the socket option was introduced very recently (in RFC 2553bis, RFC 2553 revised), not many systems provide this option. Moreover, the wording in the revised spec is not totally clear about bind(2) conflict issues.

Therefore, the worst-case scenarios on platforms that reject two bind(2) requests are as follows:

- Open the AF_INET6 socket only, and rely upon IPv4 mapped address behavior (accept IPv4 traffic by using the AF_INET6 socket). This way your application will be vulnerable to various attacks.
- Open the AF_INET6 socket only, and reject any traffic from an IPv4 mapped address. By doing so, you will serve IPv6 clients only; IPv4 clients will get rejected.
- Open the AF_INET socket only. You will serve IPv4 clients only; IPv6 clients will get rejected.

4.5 How IPv4 Traffic Gets Routed to Sockets

On some of the existing operating systems, when the AF_INET6 and AF_INET listening sockets are present, IPv4 traffic gets routed to the AF_INET6 socket (using an IPv4 mapped address), not the AF_INET socket. As a result, the AF_INET socket would get no traffic. On such systems, it is critical to apply necessary access controls against an IPv4 mapped address on an AF_INET6 socket.

Again, IPV6_V6ONLY may be used to work around this issue; however, it may not be available on your system.

4.6 Portability across Systems

As mentioned in earlier chapters, there are behavioral differences between operating systems. This section describes portability issues and issues caused by the differences. Here we also discuss how an application programmer could cope with the issues.

4.6.1 Handling of an IPv4 Mapped Address

As mentioned in the previous section, there are various interpretations to the handling of an IPv4 mapped address, and system behavior varies by vendors. The best work-around we can perform is to open the AF_INET and AF_INET6 sockets separately, and use AF_INET for IPv4 and AF_INET6 for IPv6. Turn on the IPV6_V6ONLY socket option on the AF_INET6 socket explicitly, to avoid mistakenly using the IPv4 mapped address on an AF_INET6 socket. Also, it is a good practice to use `getaddrinfo(3)` with the AI_PASSIVE flag to get the list of possible listening sockets, instead of hardcoding wildcard addresses such as 0.0.0.0 or :.

4.6.2 Socket Options

Socket options such as `setsockopt(2)/getsockopt(2)` operations are normally different on the AF_INET and AF_INET6 sockets. Some systems do support AF_INET socket options on the AF_INET6 socket, and some do not. For instance, the IP_TOS socket option is meaningful for IPv4 traffic. Some systems support IP_TOS only for AF_INET sockets, and some support it for AF_INET6 sockets as well. There are no standards for socket options, so we cannot blame either side.

Therefore, it is safer to assume that your system does not support IPv4 socket options on AF_INET6 sockets, and use AF_INET for IPv4 traffic and AF_INET6 for IPv6 traffic. By following guidelines supplied in the previous chapters, the case is already covered.

4.6.3 Lack of API Functions

Because `getaddrinfo(3)` and `getnameinfo(3)` are relatively new APIs, they may not be available on older systems. If you want your software package to function on older systems as well, you will want to ship tiny implementations of `getaddrinfo(3)` and `getnameinfo(3)` with your software package, and use these as needed.

To detect if a function is present or not on a particular system, the GNU autoconf works very well. The GNU autoconf system provides a way to generate a “configure” shell script, which will detect system differences and generate appropriate Makefile from a template, `Makefile.in`. If you put the following statement into `configure.in` (the input file to GNU autoconf), GNU autoconf will:

- Do nothing, if `getaddrinfo` is supplied by the operating system.
- Add `getaddrinfo.o` into `$LIBOBJS` in the `configure` script, which will be used when generating Makefile from `Makefile.in`.

```
AC_REPLACE_FUNCS(getaddrinfo)
```

Therefore, `getaddrinfo.c` will be compiled only if the function is not supplied by the system.

4.6.4 Lack of Address Family

On many of the operating systems, it is possible to strip down kernel size by removing functionalities; some administrators would remove IPv6 functionality from the operating system kernel. Removal of IPv6 functionality usually means that the system does not have `AF_INET6` support at all. Even under such situations, you will want your application to function correctly, avoiding recompilation of the application (you will want to ship a single binary that works on IPv4-only, IPv6-only, and the IPv4/v6 dual stack kernel). If you follow the guidelines presented in the previous chapters, your application will work correctly on any of the kernels, since your application does not hardcode any constants, such as `AF_INET6` or `AF_INET`. If you port applications to IPv6 by hardcoding `AF_INET6`, you will be in trouble running your software on the IPv6-less kernel.

4.7 RFCs 2292/3542, Advanced API

If your application involves raw IP sockets (e.g., `ping(8)`) and/or IP options handling via `setsockopt(2)`, you will need to check the IPv6 advanced API, defined in RFCs 2292/3542. Because of header structure differences, such as introduction of extension header chain, RFCs 2292/3542 present an API very different from the IPv4 counterpart.

This book does not go into details of the RFCs 2292/3542 API. The RFCs are provided in the appendices.

Availability of RFCs 2292/3542 API is not widespread, unfortunately. Also, RFCs 2292 and 3542 are not compatible at all. KAME-based platforms support the RFC 2292 API as of this writing, while Solaris the supports the RFC 3542 API. Contact vendors for the support status on other platforms.

Fortunately, only a limited number of applications, such as `ping(8)` or `traceroute(8)`, have to deal with RFCs 2292/3542. Normal applications such as `ftp(1)` need only deal with RFC 2553 in most cases.

4.8 Platform Support Status

Since IPv6 is a new protocol, the level of support varies by platforms. Here's a status of implementation as of October 2002 (subject to change).

4.8.1 NetBSD

NetBSD supports IPv6 since version 1.5, using the KAME IPv6 stack. On NetBSD, IPv4 mapped address behavior is turned off by default for security (the `IPV6_V6ONLY` socket option is on by default). We suggest setting the `IPV6_V6ONLY` socket option explicitly to on for security and portability.

4.8.2 OpenBSD

OpenBSD supports IPv6 since version 2.7, using the KAME IPv6 stack. On OpenBSD, IPv4 mapped address behavior is not supported, and the `IPV6_V6ONLY` socket option is a no-op.

4.8.3 FreeBSD

FreeBSD supports IPv6 since version 4.0, using the KAME IPv6 stack. On FreeBSD 4.x, IPv4 mapped address behavior is enabled by default (the `IPV6_V6ONLY` socket option is off by default)—hence, security problems described in the previous sections are present. By setting the `IPV6_V6ONLY` socket option explicitly to on you can avoid the security problems.

On FreeBSD, current and 5.x, IPv4 mapped address behavior is turned off by default for security (the `IPV6_V6ONLY` socket option is on by default). We suggest setting the `IPV6_V6ONLY` socket option explicitly to on for security and portability.

4.8.4 BSD/OS

BSD/OS supports IPv6 since version 4.1. Version 4.1 uses the NRL IPv6 stack, and versions 4.2 and beyond use the KAME IPv6 stack.

On BSD/OS 4.3, IPv4 mapped address behavior is enabled by default (the `IPV6_V6ONLY` socket option is off by default)—hence, security problems described in the previous sections are present. By setting the `IPV6_V6ONLY` socket option explicitly to on you can avoid the security problems.

4.8.5 Mac OS X

Mac OS X supports IPv6 starting with version 10.2. IPv6 support in version 10.2 is considered a “developer’s release”—no GUI, no support in most of GUI-based applications (e.g., Internet Explorer), and so on.

Both `ftp(1)` and `telnet(1)` support IPv6. But `ssh(1)` and `sshd(8)` do not support IPv6. IPv6-ready `ssh` binaries are available at <ftp://ftp.kame.net/pub/kame/misc/>.

There are a couple of bugs in the 10.2 library that could affect implementers: `getaddrinfo(3)` does not parse scoped IPv6 numeric address form, such as `fe80::1%en0`.

On Mac OS 10.2, IPv4 mapped address behavior is enabled by default (the `IPV6_V6ONLY` socket option is off by default)—hence, security problems described in the previous sections are present. By setting the `IPV6_V6ONLY` socket option explicitly to on you can avoid the security problems.

In addition to socket-based APIs, Apple also provides higher-level APIs, called Core Foundation libraries, for GUI-based applications. `CFNetwork` is a URL-based API, and therefore IPv6 support is embedded within the library. `CFReadStream` and `CFWriteStream` APIs abstract data stream exchanged between two nodes. `CFNetServices` provides access to name resolution functions, including Rendezvous (on-link name resolution based on multicast DNS, as well as DNS-based service discovery).

4.8.6 Windows 95/98/Me

It seems that there is no plan from Microsoft to support IPv6 on these platforms. There are third-party IPv6 stacks available from Trumpet software and Hitachi.

4.8.7 Windows 2000

Windows 2000 does not support IPv6. There are experimental releases of IPv6 stacks provided by Microsoft research.

4.8.8 Windows XP

Windows XP supports IPv6; however, it is disabled by default. It can be enabled by invocation of “`ipv6 install`” on the command line. Applications such as Internet Explorer do support IPv6, since they use URL-based (proprietary) libraries.

4.8.9 Windows CE

Windows CE will support IPv6 in the next release.

4.8.10 Windows .Net Programming Environment

The Windows .Net programming environment provides .Net sockets (`System.Net.Sockets`), which is a URL-based class library. The version currently shipping with Windows is IPv4-only; however, it is scheduled to make the API dual stack-capable.

4.8.11 Linux

Linux supports IPv6 starting with kernel version 2.2. However, the specification conformance is low, since the stack was based on an old revision of the IPv6 specification. There are ongoing efforts to update IPv6 support in Linux (the USAGI project).

The level of applications/libraries support varies by Linux distributions; some distribution ships a larger number of IPv6-enabled applications than others. Some distribution ships with better library support (glibc) than others.

Using <http://www.bieringer.de/linux/IPv6/status/IPv6+Linux-status-distributions.html> will help you to understand the level of IPv6 support your Linux distribution has.

4.8.12 Solaris

Solaris supports IPv6 since version 2.7. On Solaris, IPv4 mapped address behavior is enabled by default (the `IPV6_V6ONLY` socket option is off by default)—hence, security problems described in the previous sections are present.

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A Practical Example

5.1 Server Program Example—popa3d

popa3d is a free, redistributable POP3 server. It supports invocation from inetd, such as server-inetd4.c (see Program 3.4), and standalone invocation, such as server-single.c (see Program 3.6). Version 0.5.1 is not IPv6 ready, so it would be a good candidate for our example.

The actual code is not shown here. You can grab the code from: <http://www.openwall.com/popa3d/> or <http://www.ascii.co.jp/books/ipv6-api/popa3d-before/>.

5.1.1 Identifying Where to Rewrite

Now, you have your popa3d source code in your current directory.

```
% tar xzf popa3d-0.5.1.tar.gz
% cd popa3d-0.5.1
```

Let us identify which source code you will need to rewrite.

```
% grep in_addr *.c[h]
standalone.c:     if ((sock = socket(AF_INET, SOCK_STREAM,
    IPPROTO_TCP)) < 0)
standalone.c:     addr.sin_family = AF_INET;
virtual.c:        if (length != sizeof(sin) || sin.sin_family != AF_INET
virtual.c: ) return NULL;
% grep in_addr *.c[h]
standalone.c:     addr.sin_addr.s_addr)      struct in_addr addr)
/* Source IP address */
standalone.c:     addr.sin_addr.s_addr = inet_addr(DAEMON_ADDR);
standalone.c:                                     addr.sin_addr.s_addr)
standalone.c:                                     inet_ntoa(addr.sin_addr
standalone.c:
));
```



```

standalone.c:                inet_ntoa(addr.sin_addr));
standalone.c:                inet_ntoa(addr.sin_addr));
standalone.c:                inet_ntoa(addr.sin_addr));
standalone.c:                sessions[j].addr = addr.sin_addr;
virtual.c:    return inet_ntoa(sin.sin_addr);
% grep sockaddr_in *.c[h]
standalone.c:    struct sockaddr_in addr;
virtual.c:    struct sockaddr_in sin;
% grep hostent *.c[h]

```

So, it seems that what we need to rewrite are `standalone.c` and `virtual.c`. Let us check these source codes.

Modifying `virtual.c`

`virtual.c` provides virtual home directory functionality, with which you can split users' spool files into multiple files based on the POP server's IP address contacted by the client. The code will be used when `POP_VIRTUAL` is defined in `params.h`. IPv4-dependent code is in `lookup()`, as follows:

```

static char *lookup(void)
{
    struct sockaddr_in sin;
    int length;

    length = sizeof(sin);
    if (getsockname(0, (struct sockaddr *)&sin, &length)) {
        if (errno == ENOTSOCK) return "";
        log_error("getsockname");
        return NULL;
    }
    if (length != sizeof(sin) || sin.sin_family != AF_INET)
        return NULL;

    return inet_ntoa(sin.sin_addr);
}

```

To make this codepath address-family independent, we would need to:

- Use `sockaddr_storage` instead of `sockaddr_in` to `getsockname(2)`, even if the socket is not `AF_INET`.
- Use `getnameinfo(3)` instead of `inet_ntoa`.

The end result will be as follows:

```

static const char *lookup(void)
{
    struct sockaddr_storage ss;
    int length;
    int error;

```

```

static char hbuf[NI_MAXHOST];

length = sizeof(ss);
if (getsockname(0, (struct sockaddr *)&ss, &length)) {
    if (errno == ENOTSOCK) return "";
    log_error("getsockname");
    return NULL;
}

error = getnameinfo((struct sockaddr *)&ss, length, hbuf,
    sizeof(hbuf), NULL, 0, NI_NUMERICHOST); if (error) {
    /* logging? */
    return NULL;
}

return hbuf;
}

```

I’ve added “const” to the return type of the function, since the function returns a pointer to the statically allocated memory region.

If you check function `virtual_userpass()` carefully, the return value from `lookup()` will be used to construct the pathname of the email spool file. Beware that under some operating systems colons and the % sign used in the IPv6 numeric address specification could be troublesome (e.g., Apple HFS uses a colon as the directory pathname separator).

Modifying standalone.c

popa3d can be invoked via `inetd` or as a standalone daemon process. With `POP_STANDALONE` defined to 0 in `params.h`, popa3d assumes that it will be invoked via `inetd`. With `POP_STANDALONE` defined to 1, popa3d can be invoked via `inetd` or as a standalone daemon (needs `-D` command-line argument). `standalone.c` basically handles the case when popa3d is invoked as a standalone daemon. (See Programs 5.1 and 5.2.)

`standalone.c` hardcodes `AF_INET` assumption in multiple places:

- It opens the `AF_INET` socket via the `socket(2)` call.
- It uses `sockaddr_in` as an argument to `bind(2)`.
- It uses `inet_addr(3)` and `inet_ntoa(3)` to deal with string representation address.
- `Sessions[]` array contains `in_addr` to hold a peer’s address.

Also, `standalone.c` listens to single socket only.

Now, we need to make a couple of design decisions:

- Whether to listen to multiple sockets and use `poll(2)/select(2)`, or listen to a single socket and run multiple instances of `popa3d`
- What we should do about `sessions[].addr`

Here, we made the following decisions:

- Make `popa3d` listen to a single socket only, and switch the address family using a command-line argument: `-4` or `-6`.
- Use string representation of the address for `session[].addr`. The member is used to rate-limit access from the same address; therefore, the format (binary or string) does not matter if we can uniquely identify the peer.

The results of the rewrite are shown in Programs 5.3 and 5.4. They are also available from the following locations:

<http://www.ascii.co.jp/books/ipv6-api/popa3d-before/standalone.c>
<http://www.ascii.co.jp/books/ipv6-api/popa3d-before/startup.c>
<http://www.ascii.co.jp/books/ipv6-api/popa3d-before/virtual.c>
<http://www.ascii.co.jp/books/ipv6-api/popa3d-after/standalone.c>
<http://www.ascii.co.jp/books/ipv6-api/popa3d-after/startup.c>
<http://www.ascii.co.jp/books/ipv6-api/popa3d-after/virtual.c>

5.2 Further Extensions

When we rewrote `standalone.c`, we decided to use single address-family specified via command-line argument (`-4` or `-6`). You may want to extend `standalone.c` to open multiple sockets, based on the return value from `getaddrinfo(3)` `AI_PASSIVE` case, and deal with multiple sockets using `poll(2)` or `select(2)` API. By doing so you will eliminate the need for additional command-line arguments.

This part is left as an exercise for the readers.

5.3 Client Program Example—`nail`

`nail` is a free, redistributable email client, based on BSD Mail (well known as `/bin/mail`). It supports POP3 for accessing incoming emails in remote mailboxes, as well as SMTP for delivering outgoing emails.

The actual code is not shown here. You can grab the code from: <http://omnibus.ruf.uni-freiburg.de/~gritter/> or <http://www.ascii.co.jp/books/ipv6-api/nail-before/>.

5.3.1 Identifying Where to Rewrite

Now, you have your *mail* source code in your current directory.

```
% tar xzf mail-10.3.tar.gz
% cd mail-10.3
```

Let us identify which source code you will need to rewrite:

```
% grep AF_INET *.c[h]
pop3.c: if ((sockfd = socket(AF_INET, SOCK_STREAM, 0)) == -1) {
pop3.c: servaddr.sin_family = AF_INET;
smtp.c: if ((sockfd = socket(AF_INET, SOCK_STREAM, 0)) == -1) {
smtp.c: servaddr.sin_family = AF_INET;
% grep in_addr *.c[h]
pop3.c: struct in_addr **pptr;
pop3.c: pptr = (struct in_addr **)hp->h_addr_list;
pop3.c: memcpy(&servaddr.sin_addr, *pptr, sizeof(struct in_addr));
smtp.c: struct in_addr **pptr;
smtp.c: pptr = (struct in_addr **) hp->h_addr_list;
smtp.c: memcpy(&servaddr.sin_addr, *pptr, sizeof(struct in_addr));
% grep sockaddr_in *.c[h]
pop3.c: struct sockaddr_in servaddr;
smtp.c: struct sockaddr_in servaddr;
% grep hostent *.c[h] pop3.c: struct hostent *hp;
smtp.c: struct hostent *hent;
smtp.c: struct hostent *hp;
% grep gethostby *.c[h]
pop3.c: if ((hp = gethostbyname(server)) == NULL) {
smtp.c: hent = gethostbyname(hn);
smtp.c: if ((hp = gethostbyname(server)) == NULL) {
```

It seems that what we need to rewrite are *pop3.c* and *smtp.c*. Let us check these source codes.

Modifying *pop3.c*

pop3.c provides accesses to incoming emails in remote mailboxes via the POP3 protocol.

IPv4-dependent code is in *pop3_open()*. The code is as follows (very simplified, and most of the code is translated into comments).

```
static enum okay pop3_open(xserver, mp, use_ssl, uhp)
    const char *xserver; struct mailbox *mp;

    const char *uhp;
{
    struct sockaddr_in sin;
    struct hostent *hp;
```

```

char *portstr = use_ssl ? "pop3s" : "pop3", *cp;
char *server = xserver;

if ((cp = strchr(server, ':')) != NULL) {
    portstr = &cp[1];
    /*
     * convert portstr into numeric using strtol,
     * chop off part after colon from "server".
     */
} else {
    /*
     * use the default port.
     * convert portstr into numeric using getservbyport(3).
     */
}

if ((hp = gethostbyname(server)) == NULL) {
    /* error */
    return STOP;
}

pptr = (struct in_addr **)hp->h_addr_list;
if ((sockfd = socket(AF_INET, SOCK_STREAM, 0)) == -1) {
    /* error */
    return STOP;
}

memset(&servaddr, 0, sizeof servaddr);
servaddr.sin_family = AF_INET;
servaddr.sin_port = port;
memcpy(&servaddr.sin_addr, *pptr, sizeof(struct in_addr));

if (connect(sockfd, (struct sockaddr *)&servaddr, sizeof
    /* error */
    return STOP;
}

mp->mb_sock = sockfd;
return OKAY;
}

```

To make this codepath address-family independent, we would need to:

- Use `getaddrinfo(3)` instead of `gethostbyname(3)` for address resolution.
- Avoid any hardcoded accesses to IPv4 APIs (e.g., `AF_INET`, `sockaddr_in`, etc.).
- Make the function try to connect all the addresses returned by DNS name resolution function, rather than try the first one only.

One issue we need to check is the use of the colon as a separator of a string. The variable `xserver` would contain a string to specify POP3 protocol access to TCP port 1234 on `server.example.com`:

```
server.example.com:1234
```

Fortunately, the function does not allow numeric IPv4 address representation; therefore, we can forget about numeric IPv6 address support, where colons will become ambiguous to `strchr(3)`.

The end result will be as follows:

```
static enum okay pop3_open(xserver, mp, use_ssl, uhp)
    const char *xserver;
    struct mailbox *mp;
    const char *uhp;
{
    int sockfd;
    struct addrinfo hints, *res0, *res;
    char *server = (char *)xserver;
    int error;

    if ((cp = strchr(server, ':')) != NULL) {
        portstr = &cp[1];
        /*
         * chop off part after colon from "server".
         */
    }

    memset(&hints, 0, sizeof(hints));
    hints.ai_socktype = SOCK_STREAM;
    if (getaddrinfo(server, portstr, &hints, &res0) != 0) {
        /* error */
        return STOP;
    }

    sockfd = -1;
    for (res = res0; res; res = res->ai_next) {
        sockfd = socket(res->ai_family, res->ai_socktype,
            res->ai_protocol); if (sockfd < 0)
            continue;
        if (connect(sockfd, res->ai_addr, res->ai_addrlen)
            != 0) {
            close(sockfd);
            sockfd = -1;
            continue;
        }
        break;
    }
    if (sockfd < 0) {
        /* error */ freeaddrinfo(res0);
        return STOP;
    }
    freeaddrinfo(res0);
    mp->mb_sock = sockfd;
    return OKAY;
}
```

Modifying smtp.c

IPv4 dependent functions here are:

`smtp_mta()`

`nodename()`

`smtp_mta()` is pretty much the same as `pop3_open()` in `pop3.c`, and rewriting it will be straightforward once you have rewritten `pop3_open()`. `nodename()` is as follows:

```
char *nodename(void)
{
    static char *hostname;
    char *hn;
    struct utsname ut;
    struct hostent *hent;

    if (hostname == NULL) {
        uname(&ut);
        hn = ut.nodename;

        hent = gethostbyname(hn);
        if (hent != NULL) {
            hn = hent->h_name;
        }
        hostname = (char *)smalloc(strlen(hn) + 1);
        strcpy(hostname, hn);
    }

    return hostname;
}
```

We need to avoid the use of `gethostbyname(3)`, since `gethostbyname(3)` is IPv4-only. After the rewrite, the program will look like this:

```
char *nodename(void)
{
    static char *hostname;
    char *hn;
    struct utsname ut;
    struct addrinfo hints, *res = NULL;

    if (hostname == NULL) {
        uname(&ut);
        hn = ut.nodename;
        memset(&hints, 0, sizeof(hints));
        hints.ai_socktype = SOCK_STREAM;
        hints.ai_flags = AI_CANONNAME;
        if (getaddrinfo(hn, NULL, &hints, &res) == 0) {
            if (res->ai_canonname)
```

```

        hn = res->ai_canonname;
    }
    hostname = (char *)smalloc(strlen(hn) + 1);
    strcpy(hostname, hn);
}
if (res)
    freeaddrinfo(res);
return hostname;
}

```

Here we use `getaddrinfo(3)` with an empty service name (port number), which is `NULL`. What we really need is `res->ai_canonname`, which is equivalent to `hent->h_name`. We do not need to handle port number at all. We actually are not really interested in any of `ai_socktype` or `ai_protocol`; however, it is mandatory to configure `ai_socktype` when we specify numeric or `NULL` in the second argument. Therefore, we put `SOCK_STREAM` into `ai_socktype`.

You can find the actual source code, before and after the rewrite, at the following locations:

<http://www.ascii.co.jp/books/ipv6-api/nail-before/pop3.c>

<http://www.ascii.co.jp/books/ipv6-api/nail-before/smtp.c>

<http://www.ascii.co.jp/books/ipv6-api/nail-after/pop3.c>

<http://www.ascii.co.jp/books/ipv6-api/nail-after/smtp.c>

Program 5.1 *standalone.c in popa3d package (before modification).*

```

/*
 * Standalone POP server: accepts connections, checks the anti-flood
 * limits,
 * logs and starts the actual POP sessions.
 */

#include "params.h"

#if POP_STANDALONE

#include <stdio.h>
#include <unistd.h>
#include <stdlib.h>
#include <string.h>
#include <signal.h>
#include <syslog.h>
#include <time.h>
#include <errno.h>
#include <sys/times.h>
#include <sys/types.h>
#include <sys/wait.h>

```

```

#include <sys/socket.h>
#include <netinet/in.h>
#include <arpa/inet.h>

#if DAEMON_LIBWRAP
#include <tcpd.h>
int allow_severity = SYSLOG_PRI_LO;
int deny_severity = SYSLOG_PRI_HI;
#endif

/*
 * These are defined in pop_root.c.
 */
extern int log_error(char *s);
extern int do_pop_startup(void);
extern int do_pop_session(void);

typedef sig_atomic_t a_int;
typedef volatile a_int va_int;

/*
 * Active POP sessions. Those that were started within the last
 * MIN_DELAY seconds are also considered active (regardless of their
 * actual state), to allow for limiting the logging rate without
 * throwing away critical information about sessions that we could have
 * allowed to proceed.
 */
static struct {
    struct in_addr addr;      /* Source IP address */
    a_int pid;               /* PID of the server, or 0 for none */
    clock_t start;           /* When the server was started */
    clock_t log;              /* When we've last logged a failure */
} sessions[MAX_SESSIONS];

static va_int child_blocked; /* We use blocking to avoid races */
static va_int child_pending; /* Are any dead children waiting? */

/*
 * SIGCHLD handler; can also be called directly with a zero signum.
 */
static void handle_child(int signum)
{
    int saved_errno;
    int pid;
    int i;

    saved_errno = errno;

    if (child_blocked)
        child_pending = 1;
    else {
        child_pending = 0;
    }
}

```

```

        while ((pid = waitpid(0, NULL, WNOHANG)) < 0)
        for (i = 0; i < MAX_SESSIONS; i++)
        if (sessions[i].pid == pid) {
            sessions[i].pid = 0;
            break;
        }
    }

    if (signal(SIGCHLD, handle_child);
    errno = saved_errno;
}

#ifdef DAEMON_LIBWRAP
static void check_access(int sock)
{
    struct request_info request;

    request_init(&request,
                RQ_DAEMON, DAEMON_LIBWRAP_IDENT,
                RQ_FILE, sock,
                0);
    fromhost(&request);

    if (!hosts_access(&request)) {
/* refuse() shouldn't return... */
        refuse(&request);
/* ...but just in case */
        exit(1);
    }
}
#endif

#ifdef POP_OPTIONS
int do_standalone(void)
#else
int main(void)
#endif
{
    int true = 1;
    int sock, new;
    struct sockaddr_in addr;
    int addrlen;
    int pid;
    struct tms buf;
    clock_t now;
    int i, j, n;

    if (do_pop_startup()) return 1;

    if ((sock = socket(AF_INET, SOCK_STREAM, IPPROTO_TCP)) < 0)
        return log_error("socket");
    if (setsockopt(sock, SOL_SOCKET, SO_REUSEADDR,
                  (void *)&true, sizeof(true)))

```

```

        return log_error("setsockopt");

memset(&addr, 0, sizeof(addr));
addr.sin_family = AF_INET;
addr.sin_addr.s_addr = inet_addr(DAEMON_ADDR);
addr.sin_port = htons(DAEMON_PORT);
if (bind(sock, (struct sockaddr *)&addr, sizeof(addr)))
    return log_error("bind");

if (listen(sock, MAX_BACKLOG))
    return log_error("listen");

chdir("/"); setsid();

switch (fork()) {
case -1:
    return log_error("fork");

    case 0:
        break;

default:
    return 0;
}

setsid();

child_blocked = 1;
child_pending = 0;
signal(SIGCHLD, handle_child);

memset((void *)sessions, 0, sizeof(sessions));
new = 0;

while (1) {
    child_blocked = 0;
    if (child_pending) handle_child(0);

    if (new < 0)

        if (close(new)) return log_error("close");
        addrlen = sizeof(addr);
        new = accept(sock, (struct sockaddr *)&addr, &addrlen);
/*
 * I wish there was a portable way to classify errno's... In this case,
 * it appears to be better to risk eating up the CPU on a fatal error
 * rather than risk terminating the entire service because of a minor
 * temporary error having to do with one particular connection attempt.
 */

    if (new < 0) continue;

    now = times(&buf);

```

```

child_blocked = 1;

j = -1; n = 0;
for (i = 0; i < MAX_SESSIONS; i++) {
    if (sessions[i].start == now)
        sessions[i].start = 0;
    if (sessions[i].pid ||
        (sessions[i].start &&
         now - sessions[i].start < MIN_DELAY * CLK_TCK)) {
        if (sessions[i].addr.s_addr ==
            addr.sin_addr.s_addr)
            if (++n == MAX_SESSIONS_PER_SOURCE) break;
    } else
        if (j < 0) j = i;
}

if (n >= MAX_SESSIONS_PER_SOURCE) {
    if (!sessions[i].log ||
        now < sessions[i].log ||
        now - sessions[i].log == MIN_DELAY * CLK_TCK) {
        syslog(SYSLOG_PRI_HI,
            "%s: per source limit reached",
            inet_ntoa(addr.sin_addr));
        sessions[i].log = now;
    }
    continue;
}

if (j < 0) {
    syslog(SYSLOG_PRI_HI, "%s: sessions limit reached",
        inet_ntoa(addr.sin_addr));
    continue;
}

switch ((pid = fork())) {
case -1:
    syslog(SYSLOG_PRI_ERROR, "%s: fork: %m",
        inet_ntoa(addr.sin_addr));
    break;
case 0:
    if (close(sock)) return log_error("close");

    #if DAEMON-LIBWRAP
    check_access(new);
    #endif

    syslog(SYSLOG_PRI_LO, "Session from %s",
        inet_ntoa(addr.sin_addr));
    return do_pop_session();
    if (dup2(new, 0) < 0) return log_error("dup2");
    if (dup2(new, 1) < 0) return log_error("dup2");
    if (dup2(new, 2) < 0) return log_error("dup2");
    if (close (new)) return log_error("close");
    return do_pop_session();
}

```

```

                                default:
                                    sessions[j].addr = addr.sin_addr;
                                    (va_int)sessions[j].pid = pid;
                                    sessions[j].start = now;
                                    sessions[j].log = 0;
                                }
                            }
    }

#endif

```

Program 5.2 *startup.c in popa3d package (before modification).*

```

/*
 * Command line option parsing.
 */

#include "params.h"

#if POP_OPTIONS

#include <unistd.h>
#include <stdio.h>
#include <stdlib.h>

/* pop_root.c */
extern int do_pop_startup(void);
extern int do_pop_session(void);

/* standalone.c */
extern int do_standalone(void);

#ifdef HAVE_PROGNAME
extern char *__progname;
#define progname __progname
#else
static char *progname;
#endif

static void usage(void)
{
    fprintf(stderr, "Usage: %s [-D]\n", progname);
    exit(1);
}

int main(int argc, char **argv) {
    int c;
    int standalone = 0;

#ifdef HAVE_PROGNAME
    if (!(progname = argv[0]))
        progname = POP_SERVER;
#endif
}

```

```

    }

    while ((c = getopt(argc, argv, "D")) != -1) {
        switch (c) {
            case 'D':
                standalone++;
                break;

            default:
                usage();
        }
    }

    if (optind != argc) usage();

    if (standalone)
        return do_standalone();

    if (do_pop_startup()) return 1;
    return do_pop_session();
}
#endif

```

Program 5.3 *standalone.c in popa3d package (after modification: bold portions are modified).*

```

/*
 * Standalone POP server: accepts connections, checks the anti-flood
 * limits, logs and starts the actual POP sessions.
 */

#include "params.h"
#if POP_STANDALONE

#include <stdio.h>
#include <unistd.h>
#include <stdlib.h>
#include <string.h>
#include <signal.h>
#include <syslog.h>
#include <time.h>
#include <errno.h>
#include <netdb.h>
#include <sys/times.h>
#include <sys/types.h>
#include <sys/wait.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <arpa/inet.h>

#if DAEMON_LIBWRAP
#include <tcpd.h>
int allow_severity = SYSLOG_PRI_LO;

```

```

int deny_severity = SYSLOG_PRI_HI;
#endif

/*
 * These are defined in pop_root.c.
 */
extern int log_error(char *s);
extern int do_pop_startup(void);
extern int do_pop_session(void);
extern int af;

typedef sig_atomic_t a_int;
typedef volatile a_int va_int;

/*
 * Active POP sessions. Those that were started within the last
 * MIN_DELAY seconds are also considered active (regardless of their
 * actual state), to allow for limiting the logging rate without
 * throwing away critical information about sessions that we could have
 * allowed to proceed.
 */

static struct {
    char addr[NI_MAXHOST]; /* Source IP address */
    a_int pid;             /* PID of the server, or 0 for none */
    clock_t start;         /* When the server was started */
    clock_t log;           /* When we've last logged a failure */
} sessions[MAX_SESSIONS];

static va_int child_blocked; /* We use blocking to avoid races */
static va_int child_pending; /* Are any dead children waiting? */

/*
 * SIGCHLD handler; can also be called directly with a zero signum.
 */
static void handle_child(int signum)
{
    int saved_errno;
    int pid;
    int i;

    saved_errno = errno;

    if (child_blocked)
        child_pending = 1;
    else {
        child_pending = 0;

        while ((pid = waitpid(0, NULL, WNOHANG)) > 0)
            for (i = 0; i < MAX_SESSIONS; i++)
                if (sessions[i].pid == pid) {
                    sessions[i].pid = 0;
                    break;
                }
    }
}

```

```

    }
}

if (signum) signal(SIGCHLD, handle_child);

errno = saved_errno;
}

#if DAEMON_LIBWRAP
static void check_access(int sock)
{
    struct request_info request;

    request_init(&request,
                RQ_DAEMON, DAEMON_LIBWRAP_IDENT,
                RQ_FILE, sock,
                0);
    fromhost(&request);

    if (!hosts_access(&request)) {
/* refuse() shouldn't return... */
        refuse(&request);
/* ...but just in case */
        exit(1);
    }
}
#endif

#if POP_OPTIONS
int do_standalone(void)
#else
int main(void)
#endif
{
    int true = 1;
    int sock, new;
    struct sockaddr_storage addr;
    int addrlen;
    int pid;
    struct tms buf;
    clock_t now;
    int i, j, n;
    struct addrinfo hints, *res;
    char hbuf[NI_MAXHOST];
    char sbuf[NI_MAXSERV];

    int error;

    if (do_pop_startup()) return 1;

    if ((sock = socket(AF_INET, SOCK_STREAM, IPPROTO_TCP)) < 0)
        return log_error("socket");

```

```

    snprintf(sbuf, sizeof(sbuf), "%u", DAEMON_PORT);
    memset(&hints, 0, sizeof(hints));
    hints.ai_socktype = SOCK_STREAM;
    hints.ai_family = af;
    hints.ai_flags = AI_PASSIVE;
    error = getaddrinfo(NULL, sbuf, &hints, &res);
    if (error)
        return log_error("getaddrinfo");

    sock = socket(res-ai_family, res-ai_socktype, res-ai_protocol);
    if (sock < 0) {
        freeaddrinfo(res);
        return log_error("socket");
    }

    if (setsockopt(sock, SOL_SOCKET, SO_REUSEADDR,
        (void *)&true, sizeof(true))) {
        freeaddrinfo(res);
        return log_error("setsockopt");
    }

#ifdef IPV6_V6ONLY
    if (res->ai_family == AF_INET6 && setsockopt(sock,
        IPPROTO_IPV6, IPV6_V6ONLY, (void *)&true, sizeof(true))) {
        freeaddrinfo(res);
        return log_error("setsockopt");
    }
#endif

    if (bind(sock, res-ai_addr, res-ai_addrlen)) {
        freeaddrinfo(res);
        return log_error("bind");
    }
    freeaddrinfo(res);
    if (listen(sock, MAX_BACKLOG))
        return log_error("listen");

    chdir("/"); setsid();

    switch (fork()) {
    case -1:
        return log_error("fork");

    case 0:
        break;

    default:
        return 0;
    }

    setsid();

    child_blocked = 1;

```

```

child_pending = 0;
signal(SIGCHLD, handle_child);

memset((void *)sessions, 0, sizeof(sessions));
new = 0;

while (1) {
    child_blocked = 0;
    if (child_pending) handle_child(0);

    if (new > 0)
        if (close(new)) return log_error("close");

    addrlen = sizeof(addr);
    new = accept(sock, (struct sockaddr *)&addr, &addrlen);

    error = getnameinfo((struct sockaddr *)&addr, addrlen,
                        hbuf, sizeof(hbuf), NULL, 0, NI_NUMERICHOST);
    if (error)
        ; /* XXX */

/*
 * I wish there was a portable way to classify errno's... In this case,
 * it appears to be better to risk eating up the CPU on a fatal error
 * rather than risk terminating the entire service because of a minor
 * temporary error having to do with one particular connection attempt.
 */
    if (new < 0) continue;

    now = times(&buf);

    child_blocked = 1;

    j = -1; n = 0;
    for (i = 0; i < MAX_SESSIONS; i++) {
        if (sessions[i].start < now)
            sessions[i].start = 0;
        if (sessions[i].pid ||
            (sessions[i].start &&
             now - sessions[i].start < MIN_DELAY * CLK_TCK)) {
            if (strcmp(sessions[i].addr, hbuf) == 0)
                if (++n == MAX_SESSIONS_PER_SOURCE)
                    break;
        }
        else
            if (j < 0) j = i;
    }

    if (n >= MAX_SESSIONS_PER_SOURCE)
        { if (!sessions[i].log ||
            now < sessions[i].log ||
            now - sessions[i].log < MIN_DELAY *
              CLK_TCK) {

```

```

        syslog(SYSLOG_PRI_HI,
               "%s: per source limit reached",
               hbuf);
        sessions[i].log = now;
    }
    continue;
}

if (j < 0) {
    syslog(SYSLOG_PRI_HI, "%s: sessions limit
        reached",
        hbuf);
    continue;
}

switch ((pid = fork())) {
case -1:
    syslog(SYSLOG_PRI_ERROR, "%s: fork: %m", hbuf);
    break;
case 0:
    if (close(sock)) return log_error("close");
    #if DAEMON_LIBWRAP
        check_access(new);
    #endif

    syslog(SYSLOG_PRI_LO, "Session from %s",
        hbuf);
    if (dup2(new, 0) < 0) return log_error("dup2");
    if (dup2(new, 1) < 0) return log_error("dup2");
    if (dup2(new, 2) < 0) return log_error("dup2");
    if (close (new)) return log_error("close");
    return do_pop_session();
default:
    strcpy(sessions[j].addr, hbuf,
        sizeof(sessions[j].addr));
    (va_int)sessions[j].pid = pid;
    sessions[j].start = now;
    sessions[j].log = 0;
}
}

#endif

```

Program 5.4 *startup.c* in *popa3d* package (after modification: bold portions are modified).

```

/*
 * Command line option parsing.
 */

#include "params.h"

```

```

#if POP_OPTIONS

#include <sys/socket.h>
#include <unistd.h>
#include <stdio.h>
#include <stdlib.h>

/* pop_root.c */
extern int do_pop_startup(void);
extern int do_pop_session(void);

/* standalone.c */
extern int do_standalone(void);

#ifdef HAVE_PROGNAME
extern char *__progname;
#define progname __progname
#else
static char *progname;
#endif

int af = AF_INET;

static void usage(void)
{
    fprintf(stderr, "Usage: %s [-D]\n", progname);
    exit(1);
}

int main(int argc, char **argv) {
    int c;
    int standalone = 0;
#ifdef HAVE_PROGNAME
    if (!(progname = argv[0]))
        progname = POP_SERVER;
#endif

    while ((c = getopt(argc, argv, "D46")) != -1) {
        switch (c) {
            case 'D':
                standalone++;
                break;
            case '4':
                af = AF_INET;
                break;
            case '6':
                af = AF_INET6;
                break;

            default:
                usage();
        }
    }
}

```

```
        if (optind != argc)
            usage();

        if (standalone)
            return do_standalone();

        if (do_pop_startup()) return 1;
        return do_pop_session();
    }

#endif
```

Coming updates to IPv6 APIs

In the IETF and IEEE (Posix committee), there are efforts to revise IPv6-related APIs. Updates to RFC2553 is available as RFC3493. The only major change is the inclusion of IPV6_V6ONLY socket option. In this book we have already described IPV6_V6ONLY, and sample programs made use of it.

RFC2292/3542 defines advanced IPv6 API, as discussed previously.

RFC2553 and RFC2292 are not very useful with respect to manipulation of traffic class/flow label value on the IPv6 header. RFC3542 document defines ways to specify/inspect traffic class value. The API for flow label value is still unspecified, as the semantics for flow label itself is still under discussion (draft-ietf-ipv6-flow-label-07.txt). The following appendices contain:

B

RFC2553 “Basic Socket Interface Extensions for IPv6”

C

RFC3493 “Basic Socket Interface Extension for IPv6”

D

RFC2292 “Advanced Sockets API for IPv6”

E

RFC3542 “Advanced Sockets API for IPv6”

F

IPv4-Mapped Address API Considered Harmful

draft-cmetz-v6ops-v4mapped-api-harmful-00.txt
can be obtained from <ftp://ftp.itojun.org/pub/paper/>

G

IPv4-Mapped Addresses on the Wire Considered Harmful
draft-itojun-v6ops-v4mapped-harmful-01.txt
can be obtained from <ftp://ftp.itojun.org/pub/paper/>

H

Possible Abuse Against IPv6 Transition Technologies
draft-itojun-ipv6-transition-abuse-01.txt
can be obtained from <ftp://ftp.itojun.org/pub/paper/>

I

An Extension of Format for IPv6 Scoped Addresses
draft-ietf-ipngwg-scopedaddr-format-02.txt

The document is now integrated into draft-ietf-ipv6-scoping-arch-00.txt, however, the authors felt that the revision is more suitable for this book. Therefore, the revision is included here.

J

Protocol Independence Using the Sockets API

The paper was presented at USENIX annual conference, June 2000. The paper is included here under permission from USENIX and the author, Mr Craig Metz. The original paper can be found at the following URL: <http://www.usenix.org/events/usenix2000/freenix/metzprotoocl.html>

*RFC2553 “Basic Socket Interface Extensions
for IPv6”*

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March 1999

Basic Socket Interface Extensions for IPv6

Status of this Memo

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Abstract

The de facto standard application program interface (API) for TCP/IP applications is the "sockets" interface. Although this API was developed for Unix in the early 1980s it has also been implemented on a wide variety of non-Unix systems. TCP/IP applications written using the sockets API have in the past enjoyed a high degree of portability and we would like the same portability with IPv6 applications. But changes are required to the sockets API to support IPv6 and this memo describes these changes. These include a new socket address structure to carry IPv6 addresses, new address conversion functions, and some new socket options. These extensions are designed to provide access to the basic IPv6 features required by TCP and UDP applications, including multicasting, while introducing a minimum of change into the system and providing complete compatibility for existing IPv4 applications. Additional extensions for advanced IPv6 features (raw sockets and access to the IPv6 extension headers) are defined in another document [4].

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1. Introduction

While IPv4 addresses are 32 bits long, IPv6 interfaces are identified by 128-bit addresses. The socket interface makes the size of an IP address quite visible to an application; virtually all TCP/IP applications for BSD-based systems have knowledge of the size of an IP address. Those parts of the API that expose the addresses must be changed to accommodate the larger IPv6 address size. IPv6 also introduces new features (e.g., traffic class and flowlabel), some of which must be made visible to applications via the API. This memo defines a set of extensions to the socket interface to support the larger address size and new features of IPv6.

2. Design Considerations

There are a number of important considerations in designing changes to this well-worn API:

- The API changes should provide both source and binary compatibility for programs written to the original API. That is, existing program binaries should continue to operate when run on a system supporting the new API. In addition, existing applications that are re-compiled and run on a system supporting the new API should continue to operate. Simply put, the API changes for IPv6 should not break existing programs. An additional mechanism for implementations to verify this is to verify the new symbols are protected by Feature Test Macros as described in IEEE Std 1003.1. (Such Feature Test Macros are not defined by this RFC.)
- The changes to the API should be as small as possible in order to simplify the task of converting existing IPv4 applications to IPv6.
- Where possible, applications should be able to use this API to interoperate with both IPv6 and IPv4 hosts. Applications should not need to know which type of host they are communicating with.
- IPv6 addresses carried in data structures should be 64-bit aligned. This is necessary in order to obtain optimum performance on 64-bit machine architectures.

Because of the importance of providing IPv4 compatibility in the API, these extensions are explicitly designed to operate on machines that provide complete support for both IPv4 and IPv6. A subset of this API could probably be designed for operation on systems that support only IPv6. However, this is not addressed in this memo.

2.1 What Needs to be Changed

The socket interface API consists of a few distinct components:

- Core socket functions.
- Address data structures.
- Name-to-address translation functions.
- Address conversion functions.

The core socket functions -- those functions that deal with such things as setting up and tearing down TCP connections, and sending and receiving UDP packets -- were designed to be transport independent. Where protocol addresses are passed as function arguments, they are carried via opaque pointers. A protocol-specific address data structure is defined for each protocol that the socket functions support. Applications must cast pointers to these protocol-specific address structures into pointers to the generic "sockaddr" address structure when using the socket functions. These functions need not change for IPv6, but a new IPv6-specific address data structure is needed.

The "sockaddr_in" structure is the protocol-specific data structure for IPv4. This data structure actually includes 8-octets of unused space, and it is tempting to try to use this space to adapt the sockaddr_in structure to IPv6. Unfortunately, the sockaddr_in structure is not large enough to hold the 16-octet IPv6 address as well as the other information (address family and port number) that is needed. So a new address data structure must be defined for IPv6.

IPv6 addresses are scoped [2] so they could be link-local, site, organization, global, or other scopes at this time undefined. To support applications that want to be able to identify a set of interfaces for a specific scope, the IPv6 sockaddr_in structure must support a field that can be used by an implementation to identify a set of interfaces identifying the scope for an IPv6 address.

The name-to-address translation functions in the socket interface are gethostbyname() and gethostbyaddr(). These are left as is and new functions are defined to support IPv4 and IPv6. Additionally, the POSIX 1003.g draft [3] specifies a new nodename-to-address translation function which is protocol independent. This function can also be used with IPv4 and IPv6.

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The address conversion functions -- `inet_ntoa()` and `inet_addr()` -- convert IPv4 addresses between binary and printable form. These functions are quite specific to 32-bit IPv4 addresses. We have designed two analogous functions that convert both IPv4 and IPv6 addresses, and carry an address type parameter so that they can be extended to other protocol families as well.

Finally, a few miscellaneous features are needed to support IPv6. New interfaces are needed to support the IPv6 traffic class, flow label, and hop limit header fields. New socket options are needed to control the sending and receiving of IPv6 multicast packets.

The socket interface will be enhanced in the future to provide access to other IPv6 features. These extensions are described in [4].

2.2 Data Types

The data types of the structure elements given in this memo are intended to be examples, not absolute requirements. Whenever possible, data types from Draft 6.6 (March 1997) of POSIX 1003.1g are used: `uintN_t` means an unsigned integer of exactly N bits (e.g., `uint16_t`). We also assume the argument data types from 1003.1g when possible (e.g., the final argument to `setsockopt()` is a `size_t` value). Whenever buffer sizes are specified, the POSIX 1003.1 `size_t` data type is used (e.g., the two length arguments to `getnameinfo()`).

2.3 Headers

When function prototypes and structures are shown we show the headers that must be `#included` to cause that item to be defined.

2.4 Structures

When structures are described the members shown are the ones that must appear in an implementation. Additional, nonstandard members may also be defined by an implementation. As an additional precaution nonstandard members could be verified by Feature Test Macros as described in IEEE Std 1003.1. (Such Feature Test Macros are not defined by this RFC.)

The ordering shown for the members of a structure is the recommended ordering, given alignment considerations of multibyte members, but an implementation may order the members differently.

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3. Socket Interface

This section specifies the socket interface changes for IPv6.

3.1 IPv6 Address Family and Protocol Family

A new address family name, `AF_INET6`, is defined in `<sys/socket.h>`. The `AF_INET6` definition distinguishes between the original `sockaddr_in` address data structure, and the new `sockaddr_in6` data structure.

A new protocol family name, `PF_INET6`, is defined in `<sys/socket.h>`. Like most of the other protocol family names, this will usually be defined to have the same value as the corresponding address family name:

```
#define PF_INET6            AF_INET6
```

The `PF_INET6` is used in the first argument to the `socket()` function to indicate that an IPv6 socket is being created.

3.2 IPv6 Address Structure

A new `in6_addr` structure holds a single IPv6 address and is defined as a result of including `<netinet/in.h>`:

```
struct in6_addr {  
    uint8_t  s6_addr[16];        /* IPv6 address */  
};
```

This data structure contains an array of sixteen 8-bit elements, which make up one 128-bit IPv6 address. The IPv6 address is stored in network byte order.

The structure `in6_addr` above is usually implemented with an embedded union with extra fields that force the desired alignment level in a manner similar to BSD implementations of "struct in_addr". Those additional implementation details are omitted here for simplicity.

An example is as follows:

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```

struct in6_addr {
    union {
        uint8_t  _S6_u8[16];
        uint32_t _S6_u32[4];
        uint64_t _S6_u64[2];
    } _S6_un;
};
#define s6_addr _S6_un._S6_u8

```

3.3 Socket Address Structure for 4.3BSD-Based Systems

In the socket interface, a different protocol-specific data structure is defined to carry the addresses for each protocol suite. Each protocol-specific data structure is designed so it can be cast into a protocol-independent data structure -- the "sockaddr" structure. Each has a "family" field that overlays the "sa_family" of the sockaddr data structure. This field identifies the type of the data structure.

The sockaddr_in structure is the protocol-specific address data structure for IPv4. It is used to pass addresses between applications and the system in the socket functions. The following sockaddr_in6 structure holds IPv6 addresses and is defined as a result of including the <netinet/in.h> header:

```

struct sockaddr_in6 {
    sa_family_t   sin6_family;   /* AF_INET6 */
    in_port_t     sin6_port;     /* transport layer port # */
    uint32_t      sin6_flowinfo; /* IPv6 traffic class & flow info */
    struct in6_addr sin6_addr;    /* IPv6 address */
    uint32_t      sin6_scope_id; /* set of interfaces for a scope */
};

```

This structure is designed to be compatible with the sockaddr data structure used in the 4.3BSD release.

The sin6_family field identifies this as a sockaddr_in6 structure. This field overlays the sa_family field when the buffer is cast to a sockaddr data structure. The value of this field must be AF_INET6.

The sin6_port field contains the 16-bit UDP or TCP port number. This field is used in the same way as the sin_port field of the sockaddr_in structure. The port number is stored in network byte order.

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The `sin6_flowinfo` field is a 32-bit field that contains two pieces of information: the traffic class and the flow label. The contents and interpretation of this member is specified in [1]. The `sin6_flowinfo` field SHOULD be set to zero by an implementation prior to using the `sockaddr_in6` structure by an application on receive operations.

The `sin6_addr` field is a single `in6_addr` structure (defined in the previous section). This field holds one 128-bit IPv6 address. The address is stored in network byte order.

The ordering of elements in this structure is specifically designed so that when `sin6_addr` field is aligned on a 64-bit boundary, the start of the structure will also be aligned on a 64-bit boundary. This is done for optimum performance on 64-bit architectures.

The `sin6_scope_id` field is a 32-bit integer that identifies a set of interfaces as appropriate for the scope of the address carried in the `sin6_addr` field. For a link scope `sin6_addr` `sin6_scope_id` would be an interface index. For a site scope `sin6_addr`, `sin6_scope_id` would be a site identifier. The mapping of `sin6_scope_id` to an interface or set of interfaces is left to implementation and future specifications on the subject of site identifiers.

Notice that the `sockaddr_in6` structure will normally be larger than the generic `sockaddr` structure. On many existing implementations the `sizeof(struct sockaddr_in)` equals `sizeof(struct sockaddr)`, with both being 16 bytes. Any existing code that makes this assumption needs to be examined carefully when converting to IPv6.

3.4 Socket Address Structure for 4.4BSD-Based Systems

The 4.4BSD release includes a small, but incompatible change to the socket interface. The `"sa_family"` field of the `sockaddr` data structure was changed from a 16-bit value to an 8-bit value, and the space saved used to hold a length field, named `"sa_len"`. The `sockaddr_in6` data structure given in the previous section cannot be correctly cast into the newer `sockaddr` data structure. For this reason, the following alternative IPv6 address data structure is provided to be used on systems based on 4.4BSD. It is defined as a result of including the `<netinet/in.h>` header.

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```
struct sockaddr_in6 {
    uint8_t      sin6_len;      /* length of this struct */
    sa_family_t  sin6_family;   /* AF_INET6 */
    in_port_t    sin6_port;     /* transport layer port # */
    uint32_t     sin6_flowinfo; /* IPv6 flow information */
    struct in6_addr sin6_addr;   /* IPv6 address */
    uint32_t     sin6_scope_id; /* set of interfaces for a scope */
};
```

The only differences between this data structure and the 4.3BSD variant are the inclusion of the length field, and the change of the family field to a 8-bit data type. The definitions of all the other fields are identical to the structure defined in the previous section.

Systems that provide this version of the `sockaddr_in6` data structure must also declare `SIN6_LEN` as a result of including the `<netinet/in.h>` header. This macro allows applications to determine whether they are being built on a system that supports the 4.3BSD or 4.4BSD variants of the data structure.

3.5 The Socket Functions

Applications call the `socket()` function to create a socket descriptor that represents a communication endpoint. The arguments to the `socket()` function tell the system which protocol to use, and what format address structure will be used in subsequent functions. For example, to create an IPv4/TCP socket, applications make the call:

```
s = socket(PF_INET, SOCK_STREAM, 0);
```

To create an IPv4/UDP socket, applications make the call:

```
s = socket(PF_INET, SOCK_DGRAM, 0);
```

Applications may create IPv6/TCP and IPv6/UDP sockets by simply using the constant `PF_INET6` instead of `PF_INET` in the first argument. For example, to create an IPv6/TCP socket, applications make the call:

```
s = socket(PF_INET6, SOCK_STREAM, 0);
```

To create an IPv6/UDP socket, applications make the call:

```
s = socket(PF_INET6, SOCK_DGRAM, 0);
```

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Once the application has created a PF_INET6 socket, it must use the `sockaddr_in6` address structure when passing addresses in to the system. The functions that the application uses to pass addresses into the system are:

```
bind()
connect()
sendmsg()
sendto()
```

The system will use the `sockaddr_in6` address structure to return addresses to applications that are using PF_INET6 sockets. The functions that return an address from the system to an application are:

```
accept()
recvfrom()
recvmsg()
getpeername()
getsockname()
```

No changes to the syntax of the socket functions are needed to support IPv6, since all of the "address carrying" functions use an opaque address pointer, and carry an address length as a function argument.

3.6 Compatibility with IPv4 Applications

In order to support the large base of applications using the original API, system implementations must provide complete source and binary compatibility with the original API. This means that systems must continue to support PF_INET sockets and the `sockaddr_in` address structure. Applications must be able to create IPv4/TCP and IPv4/UDP sockets using the PF_INET constant in the `socket()` function, as described in the previous section. Applications should be able to hold a combination of IPv4/TCP, IPv4/UDP, IPv6/TCP and IPv6/UDP sockets simultaneously within the same process.

Applications using the original API should continue to operate as they did on systems supporting only IPv4. That is, they should continue to interoperate with IPv4 nodes.

3.7 Compatibility with IPv4 Nodes

The API also provides a different type of compatibility: the ability for IPv6 applications to interoperate with IPv4 applications. This feature uses the IPv4-mapped IPv6 address format defined in the IPv6 addressing architecture specification [2]. This address format

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allows the IPv4 address of an IPv4 node to be represented as an IPv6 address. The IPv4 address is encoded into the low-order 32 bits of the IPv6 address, and the high-order 96 bits hold the fixed prefix 0:0:0:0:0:FFFF. IPv4-mapped addresses are written as follows:

```
::FFFF:<IPv4-address>
```

These addresses can be generated automatically by the `getipnodebyname()` function when the specified host has only IPv4 addresses (as described in Section 6.1).

Applications may use `PF_INET6` sockets to open TCP connections to IPv4 nodes, or send UDP packets to IPv4 nodes, by simply encoding the destination's IPv4 address as an IPv4-mapped IPv6 address, and passing that address, within a `sockaddr_in6` structure, in the `connect()` or `sendto()` call. When applications use `PF_INET6` sockets to accept TCP connections from IPv4 nodes, or receive UDP packets from IPv4 nodes, the system returns the peer's address to the application in the `accept()`, `recvfrom()`, or `getpeername()` call using a `sockaddr_in6` structure encoded this way.

Few applications will likely need to know which type of node they are interoperating with. However, for those applications that do need to know, the `IN6_IS_ADDR_V4MAPPED()` macro, defined in Section 6.7, is provided.

3.8 IPv6 Wildcard Address

While the `bind()` function allows applications to select the source IP address of UDP packets and TCP connections, applications often want the system to select the source address for them. With IPv4, one specifies the address as the symbolic constant `INADDR_ANY` (called the "wildcard" address) in the `bind()` call, or simply omits the `bind()` entirely.

Since the IPv6 address type is a structure (`struct in6_addr`), a symbolic constant can be used to initialize an IPv6 address variable, but cannot be used in an assignment. Therefore systems provide the IPv6 wildcard address in two forms.

The first version is a global variable named `"in6addr_any"` that is an `in6_addr` structure. The extern declaration for this variable is defined in `<netinet/in.h>`:

```
extern const struct in6_addr in6addr_any;
```

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Applications use `in6addr_any` similarly to the way they use `INADDR_ANY` in IPv4. For example, to bind a socket to port number 23, but let the system select the source address, an application could use the following code:

```
struct sockaddr_in6 sin6;
...
sin6.sin6_family = AF_INET6;
sin6.sin6_flowinfo = 0;
sin6.sin6_port = htons(23);
sin6.sin6_addr = in6addr_any; /* structure assignment */
...
if (bind(s, (struct sockaddr *) &sin6, sizeof(sin6)) == -1)
```

The other version is a symbolic constant named `IN6ADDR_ANY_INIT` and is defined in `<netinet/in.h>`. This constant can be used to initialize an `in6_addr` structure:

```
struct in6_addr anyaddr = IN6ADDR_ANY_INIT;
```

Note that this constant can be used ONLY at declaration time. It can not be used to assign a previously declared `in6_addr` structure. For example, the following code will not work:

```
/* This is the WRONG way to assign an unspecified address */
struct sockaddr_in6 sin6;
...
sin6.sin6_addr = IN6ADDR_ANY_INIT; /* will NOT compile */
```

Be aware that the IPv4 `INADDR_xxx` constants are all defined in host byte order but the IPv6 `IN6ADDR_xxx` constants and the IPv6 `in6addr_xxx` externals are defined in network byte order.

3.9 IPv6 Loopback Address

Applications may need to send UDP packets to, or originate TCP connections to, services residing on the local node. In IPv4, they can do this by using the constant IPv4 address `INADDR_LOOPBACK` in their `connect()`, `sendto()`, or `sendmsg()` call.

IPv6 also provides a loopback address to contact local TCP and UDP services. Like the unspecified address, the IPv6 loopback address is provided in two forms -- a global variable and a symbolic constant.

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The global variable is an `in6_addr` structure named `"in6addr_loopback."` The extern declaration for this variable is defined in `<netinet/in.h>`:

```
extern const struct in6_addr in6addr_loopback;
```

Applications use `in6addr_loopback` as they would use `INADDR_LOOPBACK` in IPv4 applications (but beware of the byte ordering difference mentioned at the end of the previous section). For example, to open a TCP connection to the local telnet server, an application could use the following code:

```
struct sockaddr_in6 sin6;
. . .
sin6.sin6_family = AF_INET6;
sin6.sin6_flowinfo = 0;
sin6.sin6_port = htons(23);
sin6.sin6_addr = in6addr_loopback; /* structure assignment */
. . .
if (connect(s, (struct sockaddr *) &sin6, sizeof(sin6)) == -1)
. . .
```

The symbolic constant is named `IN6ADDR_LOOPBACK_INIT` and is defined in `<netinet/in.h>`. It can be used at declaration time ONLY; for example:

```
struct in6_addr loopbackaddr = IN6ADDR_LOOPBACK_INIT;
```

Like `IN6ADDR_ANY_INIT`, this constant cannot be used in an assignment to a previously declared IPv6 address variable.

3.10 Portability Additions

One simple addition to the sockets API that can help application writers is the "struct `sockaddr_storage`". This data structure can simplify writing code portable across multiple address families and platforms. This data structure is designed with the following goals.

- It has a large enough implementation specific maximum size to store the desired set of protocol specific socket address data structures. Specifically, it is at least large enough to accommodate `sockaddr_in` and `sockaddr_in6` and possibly other protocol specific socket addresses too.
- It is aligned at an appropriate boundary so protocol specific socket address data structure pointers can be cast to it and access their fields without alignment problems. (e.g. pointers to `sockaddr_in6` and/or `sockaddr_in` can be cast to it and access fields without alignment problems).

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- It has the initial field(s) isomorphic to the fields of the "struct sockaddr" data structure on that implementation which can be used as a discriminants for deriving the protocol in use. These initial field(s) would on most implementations either be a single field of type "sa_family_t" (isomorphic to sa_family field, 16 bits) or two fields of type uint8_t and sa_family_t respectively, (isomorphic to sa_len and sa_family_t, 8 bits each).

An example implementation design of such a data structure would be as follows.

```
/*
 * Desired design of maximum size and alignment
 */
#define _SS_MAXSIZE    128 /* Implementation specific max size */
#define _SS_ALIGNSIZE (sizeof (int64_t))
                        /* Implementation specific desired alignment */
/*
 * Definitions used for sockaddr_storage structure paddings design.
 */
#define _SS_PAD1SIZE   (_SS_ALIGNSIZE - sizeof (sa_family_t))
#define _SS_PAD2SIZE   (_SS_MAXSIZE - (sizeof (sa_family_t)+
                        _SS_PAD1SIZE + _SS_ALIGNSIZE))
struct sockaddr_storage {
    sa_family_t __ss_family; /* address family */
    /* Following fields are implementation specific */
    char        __ss_pad1[_SS_PAD1SIZE];
                /* 6 byte pad, this is to make implementation
                /* specific pad up to alignment field that */
                /* follows explicit in the data structure */
    int64_t     __ss_align; /* field to force desired structure */
                /* storage alignment */
    char        __ss_pad2[_SS_PAD2SIZE];
                /* 112 byte pad to achieve desired size, */
                /* _SS_MAXSIZE value minus size of ss_family */
                /* __ss_pad1, __ss_align fields is 112 */
};
```

On implementations where sockaddr data structure includes a "sa_len", field this data structure would look like this:

```
/*
 * Definitions used for sockaddr_storage structure paddings design.
 */
#define _SS_PAD1SIZE   (_SS_ALIGNSIZE -
                        (sizeof (uint8_t) + sizeof (sa_family_t)))
#define _SS_PAD2SIZE   (_SS_MAXSIZE - (sizeof (sa_family_t)+
```

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```

                                _SS_PAD1SIZE + _SS_ALIGNSIZE))
struct sockaddr_storage {
    uint8_t    __ss_len;        /* address length */
    sa_family_t __ss_family;    /* address family */
    /* Following fields are implementation specific */
    char       __ss_pad1[_SS_PAD1SIZE];
                /* 6 byte pad, this is to make implementation
                /* specific pad up to alignment field that */
                /* follows explicit in the data structure */
    int64_t    __ss_align; /* field to force desired structure */
                /* storage alignment */
    char       __ss_pad2[_SS_PAD2SIZE];
                /* 112 byte pad to achieve desired size, */
                /* _SS_MAXSIZE value minus size of ss_len, */
                /* __ss_family, __ss_pad1, __ss_align fields is 112 */
};

```

The above example implementation illustrates a data structure which will align on a 64 bit boundary. An implementation specific field `__ss_align` along `__ss_pad1` is used to force a 64-bit alignment which covers proper alignment good enough for needs of `sockaddr_in6` (IPv6), `sockaddr_in` (IPv4) address data structures. The size of padding fields `__ss_pad1` depends on the chosen alignment boundary. The size of padding field `__ss_pad2` depends on the value of overall size chosen for the total size of the structure. This size and alignment are represented in the above example by implementation specific (not required) constants `_SS_MAXSIZE` (chosen value 128) and `_SS_ALIGNMENT` (with chosen value 8). Constants `_SS_PAD1SIZE` (derived value 6) and `_SS_PAD2SIZE` (derived value 112) are also for illustration and not required. The implementation specific definitions and structure field names above start with an underscore to denote implementation private namespace. Portable code is not expected to access or reference those fields or constants.

The `sockaddr_storage` structure solves the problem of declaring storage for automatic variables which is large enough and aligned enough for storing socket address data structure of any family. For example, code with a file descriptor and without the context of the address family can pass a pointer to a variable of this type where a pointer to a socket address structure is expected in calls such as `getpeername()` and determine the address family by accessing the received content after the call.

The `sockaddr_storage` structure may also be useful and applied to certain other interfaces where a generic socket address large enough and aligned for use with multiple address families may be needed. A discussion of those interfaces is outside the scope of this document.

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Also, much existing code assumes that any socket address structure can fit in a generic `sockaddr` structure. While this has been true for IPv4 socket address structures, it has always been false for Unix domain socket address structures (but in practice this has not been a problem) and it is also false for IPv6 socket address structures (which can be a problem).

So now an application can do the following:

```
struct sockaddr_storage __ss;
struct sockaddr_in6 *sin6;
sin6 = (struct sockaddr_in6 *) &__ss;
```

4. Interface Identification

This API uses an interface index (a small positive integer) to identify the local interface on which a multicast group is joined (Section 5.3). Additionally, the advanced API [4] uses these same interface indexes to identify the interface on which a datagram is received, or to specify the interface on which a datagram is to be sent.

Interfaces are normally known by names such as `"le0"`, `"sl1"`, `"ppp2"`, and the like. On Berkeley-derived implementations, when an interface is made known to the system, the kernel assigns a unique positive integer value (called the interface index) to that interface. These are small positive integers that start at 1. (Note that 0 is never used for an interface index.) There may be gaps so that there is no current interface for a particular positive interface index.

This API defines two functions that map between an interface name and index, a third function that returns all the interface names and indexes, and a fourth function to return the dynamic memory allocated by the previous function. How these functions are implemented is left up to the implementation. 4.4BSD implementations can implement these functions using the existing `sysctl()` function with the `NET_RT_IFLIST` command. Other implementations may wish to use `ioctl()` for this purpose.

4.1 Name-to-Index

The first function maps an interface name into its corresponding index.

```
#include <net/if.h>

unsigned int if_nametoindex(const char *ifname);
```


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If the specified interface name does not exist, the return value is 0, and `errno` is set to `ENXIO`. If there was a system error (such as running out of memory), the return value is 0 and `errno` is set to the proper value (e.g., `ENOMEM`).

4.2 Index-to-Name

The second function maps an interface index into its corresponding name.

```
#include <net/if.h>

char *if_indextoname(unsigned int ifindex, char *ifname);
```

The `ifname` argument must point to a buffer of at least `IF_NAMESIZE` bytes into which the interface name corresponding to the specified index is returned. (`IF_NAMESIZE` is also defined in `<net/if.h>` and its value includes a terminating null byte at the end of the interface name.) This pointer is also the return value of the function. If there is no interface corresponding to the specified index, `NULL` is returned, and `errno` is set to `ENXIO`, if there was a system error (such as running out of memory), `if_indextoname` returns `NULL` and `errno` would be set to the proper value (e.g., `ENOMEM`).

4.3 Return All Interface Names and Indexes

The `if_nameindex` structure holds the information about a single interface and is defined as a result of including the `<net/if.h>` header.

```
struct if_nameindex {
    unsigned int   if_index; /* 1, 2, ... */
    char          *if_name; /* null terminated name: "le0", ... */
};
```

The final function returns an array of `if_nameindex` structures, one structure per interface.

```
struct if_nameindex *if_nameindex(void);
```

The end of the array of structures is indicated by a structure with an `if_index` of 0 and an `if_name` of `NULL`. The function returns a `NULL` pointer upon an error, and would set `errno` to the appropriate value.

The memory used for this array of structures along with the interface names pointed to by the `if_name` members is obtained dynamically. This memory is freed by the next function.

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4.4 Free Memory

The following function frees the dynamic memory that was allocated by `if_nameindex()`.

```
#include <net/if.h>

void if_freenameindex(struct if_nameindex *ptr);
```

The argument to this function must be a pointer that was returned by `if_nameindex()`.

Currently `net/if.h` doesn't have prototype definitions for functions and it is recommended that these definitions be defined in `net/if.h` as well and the struct `if_nameindex()`.

5. Socket Options

A number of new socket options are defined for IPv6. All of these new options are at the `IPPROTO_IPV6` level. That is, the "level" parameter in the `getsockopt()` and `setsockopt()` calls is `IPPROTO_IPV6` when using these options. The constant name prefix `IPV6_` is used in all of the new socket options. This serves to clearly identify these options as applying to IPv6.

The declaration for `IPPROTO_IPV6`, the new IPv6 socket options, and related constants defined in this section are obtained by including the header `<netinet/in.h>`.

5.1 Unicast Hop Limit

A new `setsockopt()` option controls the hop limit used in outgoing unicast IPv6 packets. The name of this option is `IPV6_UNICAST_HOPS`, and it is used at the `IPPROTO_IPV6` layer. The following example illustrates how it is used:

```
int hoplimit = 10;

if (setsockopt(s, IPPROTO_IPV6, IPV6_UNICAST_HOPS,
              (char *) &hoplimit, sizeof(hoplimit)) == -1)
    perror("setsockopt IPV6_UNICAST_HOPS");
```

When the `IPV6_UNICAST_HOPS` option is set with `setsockopt()`, the option value given is used as the hop limit for all subsequent unicast packets sent via that socket. If the option is not set, the system selects a default value. The integer hop limit value (called `x`) is interpreted as follows:

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```

x < -1:      return an error of EINVAL
x == -1:     use kernel default
0 <= x <= 255: use x
x >= 256:    return an error of EINVAL

```

The IPV6_UNICAST_HOPS option may be used with getsockopt() to determine the hop limit value that the system will use for subsequent unicast packets sent via that socket. For example:

```

int  hoplimit;
size_t len = sizeof(hoplimit);

if (getsockopt(s, IPPROTO_IPV6, IPV6_UNICAST_HOPS,
              (char *) &hoplimit, &len) == -1)
    perror("getsockopt IPV6_UNICAST_HOPS");
else
    printf("Using %d for hop limit.\n", hoplimit);

```

5.2 Sending and Receiving Multicast Packets

IPv6 applications may send UDP multicast packets by simply specifying an IPv6 multicast address in the address argument of the sendto() function.

Three socket options at the IPPROTO_IPV6 layer control some of the parameters for sending multicast packets. Setting these options is not required: applications may send multicast packets without using these options. The setsockopt() options for controlling the sending of multicast packets are summarized below. These three options can also be used with getsockopt().

IPV6_MULTICAST_IF

Set the interface to use for outgoing multicast packets. The argument is the index of the interface to use.

Argument type: unsigned int

IPV6_MULTICAST_HOPS

Set the hop limit to use for outgoing multicast packets. (Note a separate option - IPV6_UNICAST_HOPS - is provided to set the hop limit to use for outgoing unicast packets.)

The interpretation of the argument is the same as for the IPV6_UNICAST_HOPS option:

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```

x < -1:      return an error of EINVAL
x == -1:     use kernel default
0 <= x <= 255: use x
x >= 256:    return an error of EINVAL

```

If IPV6_MULTICAST_HOPS is not set, the default is 1
(same as IPv4 today)

Argument type: int

IPV6_MULTICAST_LOOP

If a multicast datagram is sent to a group to which the sending host itself belongs (on the outgoing interface), a copy of the datagram is looped back by the IP layer for local delivery if this option is set to 1. If this option is set to 0 a copy is not looped back. Other option values return an error of EINVAL.

If IPV6_MULTICAST_LOOP is not set, the default is 1 (loopback; same as IPv4 today).

Argument type: unsigned int

The reception of multicast packets is controlled by the two `setsockopt()` options summarized below. An error of `EOPNOTSUPP` is returned if these two options are used with `getsockopt()`.

IPV6_JOIN_GROUP

Join a multicast group on a specified local interface. If the interface index is specified as 0, the kernel chooses the local interface. For example, some kernels look up the multicast group in the normal IPv6 routing table and using the resulting interface.

Argument type: struct `ipv6_mreq`

IPV6_LEAVE_GROUP

Leave a multicast group on a specified interface.

Argument type: struct `ipv6_mreq`

The argument type of both of these options is the `ipv6_mreq` structure, defined as a result of including the `<netinet/in.h>` header;

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```
struct ipv6_mreq {
    struct in6_addr ipv6mr_multiaddr; /* IPv6 multicast addr */
    unsigned int    ipv6mr_interface; /* interface index */
};
```

Note that to receive multicast datagrams a process must join the multicast group and bind the UDP port to which datagrams will be sent. Some processes also bind the multicast group address to the socket, in addition to the port, to prevent other datagrams destined to that same port from being delivered to the socket.

6. Library Functions

New library functions are needed to perform a variety of operations with IPv6 addresses. Functions are needed to lookup IPv6 addresses in the Domain Name System (DNS). Both forward lookup (nodename-to-address translation) and reverse lookup (address-to-nodename translation) need to be supported. Functions are also needed to convert IPv6 addresses between their binary and textual form.

We note that the two existing functions, `gethostbyname()` and `gethostbyaddr()`, are left as-is. New functions are defined to handle both IPv4 and IPv6 addresses.

6.1 Nodename-to-Address Translation

The commonly used function `gethostbyname()` is inadequate for many applications, first because it provides no way for the caller to specify anything about the types of addresses desired (IPv4 only, IPv6 only, IPv4-mapped IPv6 are OK, etc.), and second because many implementations of this function are not thread safe. RFC 2133 defined a function named `gethostbyname2()` but this function was also inadequate, first because its use required setting a global option (`RES_USE_INET6`) when IPv6 addresses were required, and second because a flag argument is needed to provide the caller with additional control over the types of addresses required.

The following function is new and must be thread safe:

```
#include <sys/socket.h>
#include <netdb.h>

struct hostent *getipnodebyname(const char *name, int af, int flags
                                int *error_num);
```

The `name` argument can be either a node name or a numeric address string (i.e., a dotted-decimal IPv4 address or an IPv6 hex address). The `af` argument specifies the address family, either `AF_INET` or

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AF_INET6. The error_num value is returned to the caller, via a pointer, with the appropriate error code in error_num, to support thread safe error code returns. error_num will be set to one of the following values:

HOST_NOT_FOUND

No such host is known.

NO_ADDRESS

The server recognised the request and the name but no address is available. Another type of request to the name server for the domain might return an answer.

NO_RECOVERY

An unexpected server failure occurred which cannot be recovered.

TRY_AGAIN

A temporary and possibly transient error occurred, such as a failure of a server to respond.

The flags argument specifies the types of addresses that are searched for, and the types of addresses that are returned. We note that a special flags value of AI_DEFAULT (defined below) should handle most applications.

That is, porting simple applications to use IPv6 replaces the call

```
hptr = gethostbyname(name);
```

with

```
hptr = getipnodebyname(name, AF_INET6, AI_DEFAULT, &error_num);
```

and changes any subsequent error diagnosis code to use error_num instead of externally declared variables, such as h_errno.

Applications desiring finer control over the types of addresses searched for and returned, can specify other combinations of the flags argument.

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A flags of 0 implies a strict interpretation of the af argument:

- If flags is 0 and af is AF_INET, then the caller wants only IPv4 addresses. A query is made for A records. If successful, the IPv4 addresses are returned and the h_length member of the hostent structure will be 4, else the function returns a NULL pointer.
- If flags is 0 and if af is AF_INET6, then the caller wants only IPv6 addresses. A query is made for AAAA records. If successful, the IPv6 addresses are returned and the h_length member of the hostent structure will be 16, else the function returns a NULL pointer.

Other constants can be logically-ORed into the flags argument, to modify the behavior of the function.

- If the AI_V4MAPPED flag is specified along with an af of AF_INET6, then the caller will accept IPv4-mapped IPv6 addresses. That is, if no AAAA records are found then a query is made for A records and any found are returned as IPv4-mapped IPv6 addresses (h_length will be 16). The AI_V4MAPPED flag is ignored unless af equals AF_INET6.
- The AI_ALL flag is used in conjunction with the AI_V4MAPPED flag, and is only used with the IPv6 address family. When AI_ALL is logically or'd with AI_V4MAPPED flag then the caller wants all addresses: IPv6 and IPv4-mapped IPv6. A query is first made for AAAA records and if successful, the IPv6 addresses are returned. Another query is then made for A records and any found are returned as IPv4-mapped IPv6 addresses. h_length will be 16. Only if both queries fail does the function return a NULL pointer. This flag is ignored unless af equals AF_INET6.
- The AI_ADDRCONFIG flag specifies that a query for AAAA records should occur only if the node has at least one IPv6 source address configured and a query for A records should occur only if the node has at least one IPv4 source address configured.

For example, if the node has no IPv6 source addresses configured, and af equals AF_INET6, and the node name being looked up has both AAAA and A records, then:

- (a) if only AI_ADDRCONFIG is specified, the function returns a NULL pointer;
- (b) if AI_ADDRCONFIG | AI_V4MAPPED is specified, the A records are returned as IPv4-mapped IPv6 addresses;

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The special flags value of `AI_DEFAULT` is defined as

```
#define AI_DEFAULT (AI_V4MAPPED | AI_ADDRCONFIG)
```

We noted that the `getipnodebyname()` function must allow the name argument to be either a node name or a literal address string (i.e., a dotted-decimal IPv4 address or an IPv6 hex address). This saves applications from having to call `inet_pton()` to handle literal address strings.

There are four scenarios based on the type of literal address string and the value of the `af` argument.

The two simple cases are:

When name is a dotted-decimal IPv4 address and `af` equals `AF_INET`, or when name is an IPv6 hex address and `af` equals `AF_INET6`. The members of the returned hostent structure are: `h_name` points to a copy of the name argument, `h_aliases` is a NULL pointer, `h_addrtype` is a copy of the `af` argument, `h_length` is either 4 (for `AF_INET`) or 16 (for `AF_INET6`), `h_addr_list[0]` is a pointer to the 4-byte or 16-byte binary address, and `h_addr_list[1]` is a NULL pointer.

When name is a dotted-decimal IPv4 address and `af` equals `AF_INET6`, and flags equals `AI_V4MAPPED`, an IPv4-mapped IPv6 address is returned: `h_name` points to an IPv6 hex address containing the IPv4-mapped IPv6 address, `h_aliases` is a NULL pointer, `h_addrtype` is `AF_INET6`, `h_length` is 16, `h_addr_list[0]` is a pointer to the 16-byte binary address, and `h_addr_list[1]` is a NULL pointer. If `AI_V4MAPPED` is set (with or without `AI_ALL`) return IPv4-mapped otherwise return NULL.

It is an error when name is an IPv6 hex address and `af` equals `AF_INET`. The function's return value is a NULL pointer and `error_num` equals `HOST_NOT_FOUND`.

6.2 Address-To-Nodename Translation

The following function has the same arguments as the existing `gethostbyaddr()` function, but adds an error number.

```
#include <sys/socket.h> #include <netdb.h>

struct hostent *getipnodebyaddr(const void *src, size_t len,
                                int af, int *error_num);
```


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As with `getipnodebyname()`, `getipnodebyaddr()` must be thread safe. The `error_num` value is returned to the caller with the appropriate error code, to support thread safe error code returns. The following error conditions may be returned for `error_num`:

`HOST_NOT_FOUND`

No such host is known.

`NO_ADDRESS`

The server recognized the request and the name but no address is available. Another type of request to the name server for the domain might return an answer.

`NO_RECOVERY`

An unexpected server failure occurred which cannot be recovered.

`TRY_AGAIN`

A temporary and possibly transient error occurred, such as a failure of a server to respond.

One possible source of confusion is the handling of IPv4-mapped IPv6 addresses and IPv4-compatible IPv6 addresses, but the following logic should apply.

1. If `af` is `AF_INET6`, and if `len` equals 16, and if the IPv6 address is an IPv4-mapped IPv6 address or an IPv4-compatible IPv6 address, then skip over the first 12 bytes of the IPv6 address, set `af` to `AF_INET`, and set `len` to 4.
2. If `af` is `AF_INET`, lookup the name for the given IPv4 address (e.g., query for a PTR record in the `in-addr.arpa` domain).
3. If `af` is `AF_INET6`, lookup the name for the given IPv6 address (e.g., query for a PTR record in the `ip6.int` domain).
4. If the function is returning success, then the single address that is returned in the `hostent` structure is a copy of the first argument to the function with the same address family that was passed as an argument to this function.

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All four steps listed are performed, in order. Also note that the IPv6 hex addresses "::" and "::1" MUST NOT be treated as IPv4-compatible addresses, and if the address is "::", HOST_NOT_FOUND MUST be returned and a query of the address not performed.

Also for the macro in section 6.7 IN6_IS_ADDR_V4COMPAT MUST return false for "::" and "::1".

6.3 Freeing memory for getipnodebyname and getipnodebyaddr

The hostent structure does not change from its existing definition. This structure, and the information pointed to by this structure, are dynamically allocated by getipnodebyname and getipnodebyaddr. The following function frees this memory:

```
#include <netdb.h>

void freehostent(struct hostent *ptr);
```

6.4 Protocol-Independent Nodename and Service Name Translation

Nodename-to-address translation is done in a protocol-independent fashion using the getaddrinfo() function that is taken from the Institute of Electrical and Electronic Engineers (IEEE) POSIX 1003.1g (Protocol Independent Interfaces) draft specification [3].

The official specification for this function will be the final POSIX standard, with the following additional requirements:

- getaddrinfo() (along with the getnameinfo() function described in the next section) must be thread safe.
- The AI_NUMERICHOST is new with this document.
- All fields in socket address structures returned by getaddrinfo() that are not filled in through an explicit argument (e.g., sin6_flowinfo and sin_zero) must be set to 0. (This makes it easier to compare socket address structures.)
- getaddrinfo() must fill in the length field of a socket address structure (e.g., sin6_len) on systems that support this field.

We are providing this independent description of the function because POSIX standards are not freely available (as are IETF documents).

```
#include <sys/socket.h>
#include <netdb.h>
```

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```
int getaddrinfo(const char *nodename, const char *servname,
               const struct addrinfo *hints,
               struct addrinfo **res);
```

The `addrinfo` structure is defined as a result of including the `<netdb.h>` header.

```
struct addrinfo {
    int     ai_flags;      /* AI_PASSIVE, AI_CANONNAME, AI_NUMERICHOST */
    int     ai_family;     /* PF_XXX */
    int     ai_socktype;   /* SOCK_XXX */
    int     ai_protocol;   /* 0 or IPPROTO_XXX for IPv4 and IPv6 */
    size_t  ai_addrlen;    /* length of ai_addr */
    char    *ai_canonname; /* canonical name for nodename */
    struct sockaddr *ai_addr; /* binary address */
    struct addrinfo *ai_next; /* next structure in linked list */
};
```

The return value from the function is 0 upon success or a nonzero error code. The following names are the nonzero error codes from `getaddrinfo()`, and are defined in `<netdb.h>`:

<code>EAI_ADDRFAMILY</code>	address family for nodename not supported
<code>EAI_AGAIN</code>	temporary failure in name resolution
<code>EAI_BADFLAGS</code>	invalid value for <code>ai_flags</code>
<code>EAI_FAIL</code>	non-recoverable failure in name resolution
<code>EAI_FAMILY</code>	<code>ai_family</code> not supported
<code>EAI_MEMORY</code>	memory allocation failure
<code>EAI_NODATA</code>	no address associated with nodename
<code>EAI_NONAME</code>	nodename nor servname provided, or not known
<code>EAI_SERVICE</code>	servname not supported for <code>ai_socktype</code>
<code>EAI_SOCKTYPE</code>	<code>ai_socktype</code> not supported
<code>EAI_SYSTEM</code>	system error returned in <code>errno</code>

The `nodename` and `servname` arguments are pointers to null-terminated strings or `NULL`. One or both of these two arguments must be a non-`NULL` pointer. In the normal client scenario, both the `nodename` and `servname` are specified. In the normal server scenario, only the `servname` is specified. A non-`NULL` `nodename` string can be either a node name or a numeric host address string (i.e., a dotted-decimal IPv4 address or an IPv6 hex address). A non-`NULL` `servname` string can be either a service name or a decimal port number.

The caller can optionally pass an `addrinfo` structure, pointed to by the third argument, to provide hints concerning the type of socket that the caller supports. In this hints structure all members other than `ai_flags`, `ai_family`, `ai_socktype`, and `ai_protocol` must be zero or a `NULL` pointer. A value of `PF_UNSPEC` for `ai_family` means the

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caller will accept any protocol family. A value of 0 for `ai_socktype` means the caller will accept any socket type. A value of 0 for `ai_protocol` means the caller will accept any protocol. For example, if the caller handles only TCP and not UDP, then the `ai_socktype` member of the hints structure should be set to `SOCK_STREAM` when `getaddrinfo()` is called. If the caller handles only IPv4 and not IPv6, then the `ai_family` member of the hints structure should be set to `PF_INET` when `getaddrinfo()` is called. If the third argument to `getaddrinfo()` is a NULL pointer, this is the same as if the caller had filled in an `addrinfo` structure initialized to zero with `ai_family` set to `PF_UNSPEC`.

Upon successful return a pointer to a linked list of one or more `addrinfo` structures is returned through the final argument. The caller can process each `addrinfo` structure in this list by following the `ai_next` pointer, until a NULL pointer is encountered. In each returned `addrinfo` structure the three members `ai_family`, `ai_socktype`, and `ai_protocol` are the corresponding arguments for a call to the `socket()` function. In each `addrinfo` structure the `ai_addr` member points to a filled-in socket address structure whose length is specified by the `ai_addrlen` member.

If the `AI_PASSIVE` bit is set in the `ai_flags` member of the hints structure, then the caller plans to use the returned socket address structure in a call to `bind()`. In this case, if the `nodename` argument is a NULL pointer, then the IP address portion of the socket address structure will be set to `INADDR_ANY` for an IPv4 address or `IN6ADDR_ANY_INIT` for an IPv6 address.

If the `AI_PASSIVE` bit is not set in the `ai_flags` member of the hints structure, then the returned socket address structure will be ready for a call to `connect()` (for a connection-oriented protocol) or either `connect()`, `sendto()`, or `sendmsg()` (for a connectionless protocol). In this case, if the `nodename` argument is a NULL pointer, then the IP address portion of the socket address structure will be set to the loopback address.

If the `AI_CANONNAME` bit is set in the `ai_flags` member of the hints structure, then upon successful return the `ai_canonname` member of the first `addrinfo` structure in the linked list will point to a null-terminated string containing the canonical name of the specified `nodename`.

If the `AI_NUMERICHOST` bit is set in the `ai_flags` member of the hints structure, then a non-NULL `nodename` string must be a numeric host address string. Otherwise an error of `EAI_NONAME` is returned. This flag prevents any type of name resolution service (e.g., the DNS) from being called.

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All of the information returned by `getaddrinfo()` is dynamically allocated: the `addrinfo` structures, and the socket address structures and canonical node name strings pointed to by the `addrinfo` structures. To return this information to the system the function `freeaddrinfo()` is called:

```
#include <sys/socket.h> #include <netdb.h>

void freeaddrinfo(struct addrinfo *ai);
```

The `addrinfo` structure pointed to by the `ai` argument is freed, along with any dynamic storage pointed to by the structure. This operation is repeated until a NULL `ai_next` pointer is encountered.

To aid applications in printing error messages based on the `EAI_XXX` codes returned by `getaddrinfo()`, the following function is defined.

```
#include <sys/socket.h> #include <netdb.h>

char *gai_strerror(int ecode);
```

The argument is one of the `EAI_XXX` values defined earlier and the return value points to a string describing the error. If the argument is not one of the `EAI_XXX` values, the function still returns a pointer to a string whose contents indicate an unknown error.

6.5 Socket Address Structure to Nodename and Service Name

The POSIX 1003.1g specification includes no function to perform the reverse conversion from `getaddrinfo()`: to look up a nodename and service name, given the binary address and port. Therefore, we define the following function:

```
#include <sys/socket.h>
#include <netdb.h>

int getnameinfo(const struct sockaddr *sa, socklen_t salen,
                char *host, size_t hostlen,
                char *serv, size_t servlen,
                int flags);
```

This function looks up an IP address and port number provided by the caller in the DNS and system-specific database, and returns text strings for both in buffers provided by the caller. The function indicates successful completion by a zero return value; a non-zero return value indicates failure.

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The first argument, `sa`, points to either a `sockaddr_in` structure (for IPv4) or a `sockaddr_in6` structure (for IPv6) that holds the IP address and port number. The `salen` argument gives the length of the `sockaddr_in` or `sockaddr_in6` structure.

The function returns the nodename associated with the IP address in the buffer pointed to by the `host` argument. The caller provides the size of this buffer via the `hostlen` argument. The service name associated with the port number is returned in the buffer pointed to by `serv`, and the `servlen` argument gives the length of this buffer. The caller specifies not to return either string by providing a zero value for the `hostlen` or `servlen` arguments. Otherwise, the caller must provide buffers large enough to hold the nodename and the service name, including the terminating null characters.

Unfortunately most systems do not provide constants that specify the maximum size of either a fully-qualified domain name or a service name. Therefore to aid the application in allocating buffers for these two returned strings the following constants are defined in `<netdb.h>`:

```
#define NI_MAXHOST 1025
#define NI_MAXSERV 32
```

The first value is actually defined as the constant `MAXDNAME` in recent versions of BIND's `<arpa/nameser.h>` header (older versions of BIND define this constant to be 256) and the second is a guess based on the services listed in the current Assigned Numbers RFC.

The final argument is a flag that changes the default actions of this function. By default the fully-qualified domain name (FQDN) for the host is looked up in the DNS and returned. If the flag bit `NI_NOFQDN` is set, only the nodename portion of the FQDN is returned for local hosts.

If the flag bit `NI_NUMERICHOST` is set, or if the host's name cannot be located in the DNS, the numeric form of the host's address is returned instead of its name (e.g., by calling `inet_ntop()` instead of `getipnodebyaddr()`). If the flag bit `NI_NAMEREQD` is set, an error is returned if the host's name cannot be located in the DNS.

If the flag bit `NI_NUMERICSERV` is set, the numeric form of the service address is returned (e.g., its port number) instead of its name. The two `NI_NUMERICxx` flags are required to support the `"-n"` flag that many commands provide.

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A fifth flag bit, `NI_DGRAM`, specifies that the service is a datagram service, and causes `getservbyport()` to be called with a second argument of `"udp"` instead of its default of `"tcp"`. This is required for the few ports (e.g. 512-514) that have different services for UDP and TCP.

These `NI_XXX` flags are defined in `<netdb.h>` along with the `AI_XXX` flags already defined for `getaddrinfo()`.

6.6 Address Conversion Functions

The two functions `inet_addr()` and `inet_ntoa()` convert an IPv4 address between binary and text form. IPv6 applications need similar functions. The following two functions convert both IPv6 and IPv4 addresses:

```
#include <sys/socket.h>
#include <arpa/inet.h>

int inet_pton(int af, const char *src, void *dst);

const char *inet_ntop(int af, const void *src,
                      char *dst, size_t size);
```

The `inet_pton()` function converts an address in its standard text presentation form into its numeric binary form. The `af` argument specifies the family of the address. Currently the `AF_INET` and `AF_INET6` address families are supported. The `src` argument points to the string being passed in. The `dst` argument points to a buffer into which the function stores the numeric address. The address is returned in network byte order. `inet_pton()` returns 1 if the conversion succeeds, 0 if the input is not a valid IPv4 dotted-decimal string or a valid IPv6 address string, or -1 with `errno` set to `EAFNOSUPPORT` if the `af` argument is unknown. The calling application must ensure that the buffer referred to by `dst` is large enough to hold the numeric address (e.g., 4 bytes for `AF_INET` or 16 bytes for `AF_INET6`).

If the `af` argument is `AF_INET`, the function accepts a string in the standard IPv4 dotted-decimal form:

```
ddd.ddd.ddd.ddd
```

where `ddd` is a one to three digit decimal number between 0 and 255. Note that many implementations of the existing `inet_addr()` and `inet_aton()` functions accept nonstandard input: octal numbers, hexadecimal numbers, and fewer than four numbers. `inet_pton()` does not accept these formats.

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If the `af` argument is `AF_INET6`, then the function accepts a string in one of the standard IPv6 text forms defined in Section 2.2 of the addressing architecture specification [2].

The `inet_ntop()` function converts a numeric address into a text string suitable for presentation. The `af` argument specifies the family of the address. This can be `AF_INET` or `AF_INET6`. The `src` argument points to a buffer holding an IPv4 address if the `af` argument is `AF_INET`, or an IPv6 address if the `af` argument is `AF_INET6`, the address must be in network byte order. The `dst` argument points to a buffer where the function will store the resulting text string. The `size` argument specifies the size of this buffer. The application must specify a non-NULL `dst` argument. For IPv6 addresses, the buffer must be at least 46-octets. For IPv4 addresses, the buffer must be at least 16-octets. In order to allow applications to easily declare buffers of the proper size to store IPv4 and IPv6 addresses in string form, the following two constants are defined in `<netinet/in.h>`:

```
#define INET_ADDRSTRLEN    16
#define INET6_ADDRSTRLEN   46
```

The `inet_ntop()` function returns a pointer to the buffer containing the text string if the conversion succeeds, and NULL otherwise. Upon failure, `errno` is set to `EAFNOSUPPORT` if the `af` argument is invalid or `ENOSPC` if the size of the result buffer is inadequate.

6.7 Address Testing Macros

The following macros can be used to test for special IPv6 addresses.

```
#include <netinet/in.h>

int IN6_IS_ADDR_UNSPECIFIED (const struct in6_addr *);
int IN6_IS_ADDR_LOOPBACK   (const struct in6_addr *);
int IN6_IS_ADDR_MULTICAST  (const struct in6_addr *);
int IN6_IS_ADDR_LINKLOCAL  (const struct in6_addr *);
int IN6_IS_ADDR_SITELOCAL  (const struct in6_addr *);
int IN6_IS_ADDR_V4MAPPED   (const struct in6_addr *);
int IN6_IS_ADDR_V4COMPAT   (const struct in6_addr *);

int IN6_IS_ADDR_MC_NODELOCAL(const struct in6_addr *);
int IN6_IS_ADDR_MC_LINKLOCAL(const struct in6_addr *);
int IN6_IS_ADDR_MC_SITELOCAL(const struct in6_addr *);
int IN6_IS_ADDR_MC_ORGLocal (const struct in6_addr *);
int IN6_IS_ADDR_MC_GLOBAL   (const struct in6_addr *);
```


The first seven macros return true if the address is of the specified type, or false otherwise. The last five test the scope of a multicast address and return true if the address is a multicast address of the specified scope or false if the address is either not a multicast address or not of the specified scope. Note that `IN6_IS_ADDR_LINKLOCAL` and `IN6_IS_ADDR_SITELOCAL` return true only for the two local-use IPv6 unicast addresses. These two macros do not return true for IPv6 multicast addresses of either link-local scope or site-local scope.

7. Summary of New Definitions

The following list summarizes the constants, structure, and extern definitions discussed in this memo, sorted by header.

```

<net/if.h>      IF_NAMESIZE
<net/if.h>      struct if_nameindex();

<netdb.h>       AI_ADDRCONFIG
<netdb.h>       AI_DEFAULT
<netdb.h>       AI_ALL
<netdb.h>       AI_CANONNAME
<netdb.h>       AI_NUMERICHOST
<netdb.h>       AI_PASSIVE
<netdb.h>       AI_V4MAPPED
<netdb.h>       EAI_ADDRFAMILY
<netdb.h>       EAI_AGAIN
<netdb.h>       EAI_BADFLAGS
<netdb.h>       EAI_FAIL
<netdb.h>       EAI_FAMILY
<netdb.h>       EAI_MEMORY
<netdb.h>       EAI_NODATA
<netdb.h>       EAI_NONAME
<netdb.h>       EAI_SERVICE
<netdb.h>       EAI_SOCKTYPE
<netdb.h>       EAI_SYSTEM
<netdb.h>       NI_DGRAM
<netdb.h>       NI_MAXHOST
<netdb.h>       NI_MAXSERV
<netdb.h>       NI_NAMEREQD
<netdb.h>       NI_NOFQDN
<netdb.h>       NI_NUMERICHOST
<netdb.h>       NI_NUMERICSERV
<netdb.h>       struct addrinfo();

<netinet/in.h>  IN6ADDR_ANY_INIT
<netinet/in.h>  IN6ADDR_LOOPBACK_INIT
<netinet/in.h>  INET6_ADDRSTRLEN

```

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```

<netinet/in.h>  INET_ADDRSTRLEN
<netinet/in.h>  IPPROTO_IPV6
<netinet/in.h>  IPV6_JOIN_GROUP
<netinet/in.h>  IPV6_LEAVE_GROUP
<netinet/in.h>  IPV6_MULTICAST_HOPS
<netinet/in.h>  IPV6_MULTICAST_IF
<netinet/in.h>  IPV6_MULTICAST_LOOP
<netinet/in.h>  IPV6_UNICAST_HOPS
<netinet/in.h>  SIN6_LEN
<netinet/in.h>  extern const struct in6_addr in6addr_any;
<netinet/in.h>  extern const struct in6_addr in6addr_loopback;
<netinet/in.h>  struct in6_addr{};
<netinet/in.h>  struct ipv6_mreq{};
<netinet/in.h>  struct sockaddr_in6{};

<sys/socket.h>  AF_INET6
<sys/socket.h>  PF_INET6
<sys/socket.h>  struct sockaddr_storage;

```

The following list summarizes the function and macro prototypes discussed in this memo, sorted by header.

```

<arpa/inet.h>  int inet_pton(int, const char *, void *);
<arpa/inet.h>  const char *inet_ntop(int, const void *,
                                char *, size_t);

<net/if.h>     char *if_indextoname(unsigned int, char *);
<net/if.h>     unsigned int if_nametoindex(const char *);
<net/if.h>     void if_freenameindex(struct if_nameindex *);
<net/if.h>     struct if_nameindex *if_nameindex(void);

<netdb.h>      int getaddrinfo(const char *, const char *,
                                const struct addrinfo *,
                                struct addrinfo **);
<netdb.h>      int getnameinfo(const struct sockaddr *, socklen_t,
                                char *, size_t, char *, size_t, int);
<netdb.h>      void freeaddrinfo(struct addrinfo *);
<netdb.h>      char *gai_strerror(int);
<netdb.h>      struct hostent *getipnodebyname(const char *, int, int,
                                                int *);
<netdb.h>      struct hostent *getipnodebyaddr(const void *, size_t,
                                                int, int *);
<netdb.h>      void freehostent(struct hostent *);

<netinet/in.h> int IN6_IS_ADDR_LINKLOCAL(const struct in6_addr *);
<netinet/in.h> int IN6_IS_ADDR_LOOPBACK(const struct in6_addr *);
<netinet/in.h> int IN6_IS_ADDR_MC_GLOBAL(const struct in6_addr *);
<netinet/in.h> int IN6_IS_ADDR_MC_LINKLOCAL(const struct in6_addr *);

```

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```
<netinet/in.h> int IN6_IS_ADDR_MC_NODELOCAL(const struct in6_addr *);
<netinet/in.h> int IN6_IS_ADDR_MC_ORGLOCAL(const struct in6_addr *);
<netinet/in.h> int IN6_IS_ADDR_MC_SITELOCAL(const struct in6_addr *);
<netinet/in.h> int IN6_IS_ADDR_MULTICAST(const struct in6_addr *);
<netinet/in.h> int IN6_IS_ADDR_SITELOCAL(const struct in6_addr *);
<netinet/in.h> int IN6_IS_ADDR_UNSPECIFIED(const struct in6_addr *);
<netinet/in.h> int IN6_IS_ADDR_V4COMPAT(const struct in6_addr *);
<netinet/in.h> int IN6_IS_ADDR_V4MAPPED(const struct in6_addr *);
```

8. Security Considerations

IPv6 provides a number of new security mechanisms, many of which need to be accessible to applications. Companion memos detailing the extensions to the socket interfaces to support IPv6 security are being written.

9. Year 2000 Considerations

There are no issues for this memo concerning the Year 2000 issue regarding the use of dates.

Changes From RFC 2133

Changes made in the March 1998 Edition (-01 draft):

Changed all "hostname" to "nodename" for consistency with other IPv6 documents.

Section 3.3: changed comment for `sin6_flowinfo` to be "traffic class & flow info" and updated corresponding text description to current definition of these two fields.

Section 3.10 ("Portability Additions") is new.

Section 6: a new paragraph was added reiterating that the existing `gethostbyname()` and `gethostbyaddr()` are not changed.

Section 6.1: change `gethostbyname3()` to `getnodebyname()`. Add `AI_DEFAULT` to handle majority of applications. Renamed `AI_V6ADDRCONFIG` to `AI_ADDRCONFIG` and define it for A records and IPv4 addresses too. Defined exactly what `getnodebyname()` must return if the name argument is a numeric address string.

Section 6.2: change `gethostbyaddr()` to `getnodebyaddr()`. Reword items 2 and 3 in the description of how to handle IPv4-mapped and IPv4-compatible addresses to "lookup a name" for a given address, instead of specifying what type of DNS query to issue.

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Section 6.3: added two more requirements to `getaddrinfo()`.

Section 7: added the following constants to the list for `<netdb.h>`: `AI_ADDRCONFIG`, `AI_ALL`, and `AI_V4MAPPED`. Add union `sockaddr_union` and `SA_LEN` to the lists for `<sys/socket.h>`.

Updated references.

Changes made in the November 1997 Edition (-00 draft):

The data types have been changed to conform with Draft 6.6 of the Posix 1003.1g standard.

Section 3.2: data type of `s6_addr` changed to `"uint8_t"`.

Section 3.3: data type of `sin6_family` changed to `"sa_family_t"`. data type of `sin6_port` changed to `"in_port_t"`, data type of `sin6_flowinfo` changed to `"uint32_t"`.

Section 3.4: same as Section 3.3, plus data type of `sin6_len` changed to `"uint8_t"`.

Section 6.2: first argument of `gethostbyaddr()` changed from `"const char *"` to `"const void *"` and second argument changed from `"int"` to `"size_t"`.

Section 6.4: second argument of `getnameinfo()` changed from `"size_t"` to `"socklen_t"`.

The wording was changed when new structures were defined, to be more explicit as to which header must be included to define the structure:

Section 3.2 (`in6_addr()`), Section 3.3 (`sockaddr_in6()`), Section 3.4 (`sockaddr_in6()`), Section 4.3 (`if_nameindex()`), Section 5.3 (`ipv6_mreq()`), and Section 6.3 (`addrinfo()`).

Section 4: `NET_RT_LIST` changed to `NET_RT_IPLIST`.

Section 5.1: The `IPV6_ADDRFORM` socket option was removed.

Section 5.3: Added a note that an option value other than 0 or 1 for `IPV6_MULTICAST_LOOP` returns an error. Added a note that `IPV6_MULTICAST_IF`, `IPV6_MULTICAST_HOPS`, and `IPV6_MULTICAST_LOOP` can also be used with `getsockopt()`, but `IPV6_ADD_MEMBERSHIP` and `IPV6_DROP_MEMBERSHIP` cannot be used with `getsockopt()`.

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Section 6.1: Removed the description of `gethostbyname2()` and its associated `RES_USE_INET6` option, replacing it with `gethostbyname3()`.

Section 6.2: Added requirement that `gethostbyaddr()` be thread safe. Reworded step 4 to avoid using the `RES_USE_INET6` option.

Section 6.3: Added the requirement that `getaddrinfo()` and `getnameinfo()` be thread safe. Added the `AI_NUMERICHOST` flag.

Section 6.6: Added clarification about `IN6_IS_ADDR_LINKLOCAL` and `IN6_IS_ADDR_SITELOCAL` macros.

Changes made to the draft -01 specification Sept 98

Changed priority to traffic class in the spec.

Added the need for scope identification in section 2.1.

Added `sin6_scope_id` to struct `sockaddr_in6` in sections 3.3 and 3.4.

Changed 3.10 to use generic storage structure to support holding IPv6 addresses and removed the `SA_LEN` macro.

Distinguished between invalid input parameters and system failures for Interface Identification in Section 4.1 and 4.2.

Added defaults for multicast operations in section 5.2 and changed the names from `ADD` to `JOIN` and `DROP` to `LEAVE` to be consistent with IPv6 multicast terminology.

Changed `getnodebyname` to `getipnodebyname`, `getnodebyaddr` to `getipnodebyaddr`, and added `MT safe` error code to function parameters in section 6.

Moved `freehostent` to its own sub-section after `getipnodebyaddr` now 6.3 (so this bumps all remaining sections in section 6).

Clarified the use of `AI_ALL` and `AI_V4MAPPED` that these are dependent on the `AF` parameter and must be used as a conjunction in section 6.1.

Removed the restriction that literal addresses cannot be used with a `flags` argument in section 6.1.

Added Year 2000 Section to the draft

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Deleted Reference to the following because the attached is deleted from the ID directory and has expired. But the logic from the aforementioned draft still applies, so that was kept in Section 6.2 bullets after 3rd paragraph.

- [7] P. Vixie, "Reverse Name Lookups of Encapsulated IPv4 Addresses in IPv6", Internet-Draft, <draft-vixie-ipng-ipv4ptr-00.txt>, May 1996.

Deleted the following reference as it is no longer referenced. And the draft has expired.

- [3] D. McDonald, "A Simple IP Security API Extension to BSD Sockets", Internet-Draft, <draft-mcdonald-simple-ipsec-api-01.txt>, March 1997.

Deleted the following reference as it is no longer referenced.

- [4] C. Metz, "Network Security API for Sockets", Internet-Draft, <draft-metz-net-security-api-01.txt>, January 1998.

Update current references to current status.

Added alignment notes for `in6_addr` and `sin6_addr`.

Clarified further that `AI_V4MAPPED` must be used with a dotted IPv4 literal address for `getipnodebyname()`, when address family is `AF_INET6`.

Added text to clarify `"::"` and `"::1"` when used by `getipnodebyaddr()`.

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The `getaddrinfo()` and `getnameinfo()` functions are taken from an earlier Internet Draft by Keith Sklower. As noted in that draft, William Durst, Steven Wise, Michael Karels, and Eric Allman provided many useful discussions on the subject of protocol-independent name-to-address translation, and reviewed early versions of Keith Sklower's original proposal. Eric Allman implemented the first prototype of `getaddrinfo()`. The observation that specifying the pair of name and service would suffice for connecting to a service independent of protocol details was made by Marshall Rose in a proposal to X/Open for a "Uniform Network Interface".

Craig Metz, Jack McCann, Erik Nordmark, Tim Hartrick, and Mukesh Kacker made many contributions to this document. Ramesh Govindan made a number of contributions and co-authored an earlier version of this memo.

References

- [1] Deering, S. and R. Hinden, "Internet Protocol, Version 6 (IPv6) Specification", RFC 2460, December 1998.
- [2] Hinden, R. and S. Deering, "IP Version 6 Addressing Architecture", RFC 2373, July 1998.
- [3] IEEE, "Protocol Independent Interfaces", IEEE Std 1003.1g, DRAFT 6.6, March 1997.
- [4] Stevens, W. and M. Thomas, "Advanced Sockets API for IPv6", RFC 2292, February 1998.

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*RFC3493 “Basic Socket Interface Extensions
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Basic Socket Interface Extensions for IPv6

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Abstract

The de facto standard Application Program Interface (API) for TCP/IP applications is the "sockets" interface. Although this API was developed for Unix in the early 1980s it has also been implemented on a wide variety of non-Unix systems. TCP/IP applications written using the sockets API have in the past enjoyed a high degree of portability and we would like the same portability with IPv6 applications. But changes are required to the sockets API to support IPv6 and this memo describes these changes. These include a new socket address structure to carry IPv6 addresses, new address conversion functions, and some new socket options. These extensions are designed to provide access to the basic IPv6 features required by TCP and UDP applications, including multicasting, while introducing a minimum of change into the system and providing complete compatibility for existing IPv4 applications. Additional extensions for advanced IPv6 features (raw sockets and access to the IPv6 extension headers) are defined in another document.

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1. Introduction

While IPv4 addresses are 32 bits long, IPv6 addresses are 128 bits long. The socket interface makes the size of an IP address quite visible to an application; virtually all TCP/IP applications for BSD-based systems have knowledge of the size of an IP address. Those parts of the API that expose the addresses must be changed to accommodate the larger IPv6 address size. IPv6 also introduces new features, some of which must be made visible to applications via the API. This memo defines a set of extensions to the socket interface to support the larger address size and new features of IPv6. It defines "basic" extensions that are of use to a broad range of applications. A companion document, the "advanced" API [4], covers extensions that are of use to more specialized applications, examples of which include routing daemons, and the "ping" and "traceroute" utilities.

The development of this API was started in 1994 in the IETF IPng working group. The API has evolved over the years, published first in RFC 2133, then again in RFC 2553, and reaching its final form in this document.

As the API matured and stabilized, it was incorporated into the Open Group's Networking Services (XNS) specification, issue 5.2, which was subsequently incorporated into a joint Open Group/IEEE/ISO standard [3].

Effort has been made to ensure that this document and [3] contain the same information with regard to the API definitions. However, the reader should note that this document is for informational purposes only, and that the official standard specification of the sockets API is [3].

It is expected that any future standardization work on this API would be done by the Open Group Base Working Group [6].

It should also be noted that this document describes only those portions of the API needed for IPv4 and IPv6 communications. Other potential uses of the API, for example the use of `getaddrinfo()` and `getnameinfo()` with the `AF_UNIX` address family, are beyond the scope of this document.

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2. Design Considerations

There are a number of important considerations in designing changes to this well-worn API:

- The API changes should provide both source and binary compatibility for programs written to the original API. That is, existing program binaries should continue to operate when run on a system supporting the new API. In addition, existing applications that are re-compiled and run on a system supporting the new API should continue to operate. Simply put, the API changes for IPv6 should not break existing programs. An additional mechanism for implementations to verify this is to verify the new symbols are protected by Feature Test Macros as described in [3]. (Such Feature Test Macros are not defined by this RFC.)
- The changes to the API should be as small as possible in order to simplify the task of converting existing IPv4 applications to IPv6.
- Where possible, applications should be able to use this API to interoperate with both IPv6 and IPv4 hosts. Applications should not need to know which type of host they are communicating with.
- IPv6 addresses carried in data structures should be 64-bit aligned. This is necessary in order to obtain optimum performance on 64-bit machine architectures.

Because of the importance of providing IPv4 compatibility in the API, these extensions are explicitly designed to operate on machines that provide complete support for both IPv4 and IPv6. A subset of this API could probably be designed for operation on systems that support only IPv6. However, this is not addressed in this memo.

2.1 What Needs to be Changed

The socket interface API consists of a few distinct components:

- Core socket functions.
- Address data structures.
- Name-to-address translation functions.
- Address conversion functions.

The core socket functions – those functions that deal with such things as setting up and tearing down TCP connections, and sending and receiving UDP packets – were designed to be transport independent. Where protocol addresses are passed as function arguments, they are carried via opaque pointers. A protocol-specific address data structure is defined for each protocol that the socket functions support. Applications must cast pointers to these protocol-specific address structures into pointers to the generic "sockaddr" address structure when using the socket functions. These functions need not change for IPv6, but a new IPv6-specific address data structure is needed.

The "sockaddr_in" structure is the protocol-specific data structure for IPv4. This data structure actually includes 8-octets of unused space, and it is tempting to try to use this space to adapt the sockaddr_in structure to IPv6. Unfortunately, the sockaddr_in structure is not large enough to hold the 16-octet IPv6 address as well as the other information (address family and port number) that is needed. So a new address data structure must be defined for IPv6.

IPv6 addresses are scoped [2] so they could be link-local, site, organization, global, or other scopes at this time undefined. To support applications that want to be able to identify a set of interfaces for a specific scope, the IPv6 sockaddr_in structure must support a field that can be used by an implementation to identify a set of interfaces identifying the scope for an IPv6 address.

The IPv4 name-to-address translation functions in the socket interface are gethostbyname() and gethostbyaddr(). These are left as is, and new functions are defined which support both IPv4 and IPv6.

The IPv4 address conversion functions – inet_ntoa() and inet_addr() – convert IPv4 addresses between binary and printable form. These functions are quite specific to 32-bit IPv4 addresses. We have designed two analogous functions that convert both IPv4 and IPv6 addresses, and carry an address type parameter so that they can be extended to other protocol families as well.

Finally, a few miscellaneous features are needed to support IPv6. A new interface is needed to support the IPv6 hop limit header field. New socket options are needed to control the sending and receiving of IPv6 multicast packets.

The socket interface will be enhanced in the future to provide access to other IPv6 features. Some of these extensions are described in [4].

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2.2 Data Types

The data types of the structure elements given in this memo are intended to track the relevant standards. `uintN_t` means an unsigned integer of exactly N bits (e.g., `uint16_t`). The `sa_family_t` and `in_port_t` types are defined in [3].

2.3 Headers

When function prototypes and structures are shown we show the headers that must be `#included` to cause that item to be defined.

2.4 Structures

When structures are described the members shown are the ones that must appear in an implementation. Additional, nonstandard members may also be defined by an implementation. As an additional precaution nonstandard members could be verified by Feature Test Macros as described in [3]. (Such Feature Test Macros are not defined by this RFC.)

The ordering shown for the members of a structure is the recommended ordering, given alignment considerations of multibyte members, but an implementation may order the members differently.

3. Socket Interface

This section specifies the socket interface changes for IPv6.

3.1 IPv6 Address Family and Protocol Family

A new address family name, `AF_INET6`, is defined in `<sys/socket.h>`. The `AF_INET6` definition distinguishes between the original `sockaddr_in` address data structure, and the new `sockaddr_in6` data structure.

A new protocol family name, `PF_INET6`, is defined in `<sys/socket.h>`. Like most of the other protocol family names, this will usually be defined to have the same value as the corresponding address family name:

```
#define PF_INET6                      AF_INET6
```

The `AF_INET6` is used in the first argument to the `socket()` function to indicate that an IPv6 socket is being created.

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3.2 IPv6 Address Structure

A new `in6_addr` structure holds a single IPv6 address and is defined as a result of including `<netinet/in.h>`:

```
struct in6_addr {
    uint8_t  s6_addr[16];      /* IPv6 address */
};
```

This data structure contains an array of sixteen 8-bit elements, which make up one 128-bit IPv6 address. The IPv6 address is stored in network byte order.

The structure `in6_addr` above is usually implemented with an embedded union with extra fields that force the desired alignment level in a manner similar to BSD implementations of "struct in_addr". Those additional implementation details are omitted here for simplicity.

An example is as follows:

```
struct in6_addr {
    union {
        uint8_t  _S6_u8[16];
        uint32_t _S6_u32[4];
        uint64_t _S6_u64[2];
    } _S6_un;
};
#define s6_addr _S6_un._S6_u8
```

3.3 Socket Address Structure for 4.3BSD-Based Systems

In the socket interface, a different protocol-specific data structure is defined to carry the addresses for each protocol suite. Each protocol-specific data structure is designed so it can be cast into a protocol-independent data structure – the "sockaddr" structure. Each has a "family" field that overlays the "sa_family" of the sockaddr data structure. This field identifies the type of the data structure.

The `sockaddr_in` structure is the protocol-specific address data structure for IPv4. It is used to pass addresses between applications and the system in the socket functions. The following `sockaddr_in6` structure holds IPv6 addresses and is defined as a result of including the `<netinet/in.h>` header:

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```
struct sockaddr_in6 {
    sa_family_t      sin6_family;    /* AF_INET6 */
    in_port_t        sin6_port;      /* transport layer port # */
    uint32_t          sin6_flowinfo; /* IPv6 flow information */
    struct in6_addr   sin6_addr;      /* IPv6 address */
    uint32_t          sin6_scope_id; /* set of interfaces for a scope */
};
```

This structure is designed to be compatible with the `sockaddr` data structure used in the 4.3BSD release.

The `sin6_family` field identifies this as a `sockaddr_in6` structure. This field overlays the `sa_family` field when the buffer is cast to a `sockaddr` data structure. The value of this field must be `AF_INET6`.

The `sin6_port` field contains the 16-bit UDP or TCP port number. This field is used in the same way as the `sin_port` field of the `sockaddr_in` structure. The port number is stored in network byte order.

The `sin6_flowinfo` field is a 32-bit field intended to contain flow-related information. The exact way this field is mapped to or from a packet is not currently specified. Until such time as its use is specified, applications should set this field to zero when constructing a `sockaddr_in6`, and ignore this field in a `sockaddr_in6` structure constructed by the system.

The `sin6_addr` field is a single `in6_addr` structure (defined in the previous section). This field holds one 128-bit IPv6 address. The address is stored in network byte order.

The ordering of elements in this structure is specifically designed so that when `sin6_addr` field is aligned on a 64-bit boundary, the start of the structure will also be aligned on a 64-bit boundary. This is done for optimum performance on 64-bit architectures.

The `sin6_scope_id` field is a 32-bit integer that identifies a set of interfaces as appropriate for the scope [2] of the address carried in the `sin6_addr` field. The mapping of `sin6_scope_id` to an interface or set of interfaces is left to implementation and future specifications on the subject of scoped addresses.

Notice that the `sockaddr_in6` structure will normally be larger than the generic `sockaddr` structure. On many existing implementations the `sizeof(struct sockaddr_in)` equals `sizeof(struct sockaddr)`, with both being 16 bytes. Any existing code that makes this assumption needs to be examined carefully when converting to IPv6.

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3.4 Socket Address Structure for 4.4BSD-Based Systems

The 4.4BSD release includes a small, but incompatible change to the socket interface. The "sa_family" field of the sockaddr data structure was changed from a 16-bit value to an 8-bit value, and the space saved used to hold a length field, named "sa_len". The sockaddr_in6 data structure given in the previous section cannot be correctly cast into the newer sockaddr data structure. For this reason, the following alternative IPv6 address data structure is provided to be used on systems based on 4.4BSD. It is defined as a result of including the <netinet/in.h> header.

```
struct sockaddr_in6 {
    uint8_t      sin6_len;          /* length of this struct */
    sa_family_t  sin6_family;      /* AF_INET6 */
    in_port_t    sin6_port;        /* transport layer port # */
    uint32_t     sin6_flowinfo;     /* IPv6 flow information */
    struct in6_addr sin6_addr;      /* IPv6 address */
    uint32_t     sin6_scope_id;     /* set of interfaces for a scope */
};
```

The only differences between this data structure and the 4.3BSD variant are the inclusion of the length field, and the change of the family field to a 8-bit data type. The definitions of all the other fields are identical to the structure defined in the previous section.

Systems that provide this version of the sockaddr_in6 data structure must also declare SIN6_LEN as a result of including the <netinet/in.h> header. This macro allows applications to determine whether they are being built on a system that supports the 4.3BSD or 4.4BSD variants of the data structure.

3.5 The Socket Functions

Applications call the socket() function to create a socket descriptor that represents a communication endpoint. The arguments to the socket() function tell the system which protocol to use, and what format address structure will be used in subsequent functions. For example, to create an IPv4/TCP socket, applications make the call:

```
s = socket(AF_INET, SOCK_STREAM, 0);
```

To create an IPv4/UDP socket, applications make the call:

```
s = socket(AF_INET, SOCK_DGRAM, 0);
```

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Applications may create IPv6/TCP and IPv6/UDP sockets (which may also handle IPv4 communication as described in section 3.7) by simply using the constant `AF_INET6` instead of `AF_INET` in the first argument. For example, to create an IPv6/TCP socket, applications make the call:

```
s = socket(AF_INET6, SOCK_STREAM, 0);
```

To create an IPv6/UDP socket, applications make the call:

```
s = socket(AF_INET6, SOCK_DGRAM, 0);
```

Once the application has created a `AF_INET6` socket, it must use the `sockaddr_in6` address structure when passing addresses in to the system. The functions that the application uses to pass addresses into the system are:

```
bind()
connect()
sendmsg()
sendto()
```

The system will use the `sockaddr_in6` address structure to return addresses to applications that are using `AF_INET6` sockets. The functions that return an address from the system to an application are:

```
accept()
recvfrom()
recvmsg()
getpeername()
getsockname()
```

No changes to the syntax of the socket functions are needed to support IPv6, since all of the "address carrying" functions use an opaque address pointer, and carry an address length as a function argument.

3.6 Compatibility with IPv4 Applications

In order to support the large base of applications using the original API, system implementations must provide complete source and binary compatibility with the original API. This means that systems must continue to support `AF_INET` sockets and the `sockaddr_in` address structure. Applications must be able to create IPv4/TCP and IPv4/UDP sockets using the `AF_INET` constant in the `socket()` function, as

described in the previous section. Applications should be able to hold a combination of IPv4/TCP, IPv4/UDP, IPv6/TCP and IPv6/UDP sockets simultaneously within the same process.

Applications using the original API should continue to operate as they did on systems supporting only IPv4. That is, they should continue to interoperate with IPv4 nodes.

3.7 Compatibility with IPv4 Nodes

The API also provides a different type of compatibility: the ability for IPv6 applications to interoperate with IPv4 applications. This feature uses the IPv4-mapped IPv6 address format defined in the IPv6 addressing architecture specification [2]. This address format allows the IPv4 address of an IPv4 node to be represented as an IPv6 address. The IPv4 address is encoded into the low-order 32 bits of the IPv6 address, and the high-order 96 bits hold the fixed prefix 0:0:0:0:0:FFFF. IPv4-mapped addresses are written as follows:

```
::FFFF:<IPv4-address>
```

These addresses can be generated automatically by the `getaddrinfo()` function, as described in Section 6.1.

Applications may use `AF_INET6` sockets to open TCP connections to IPv4 nodes, or send UDP packets to IPv4 nodes, by simply encoding the destination's IPv4 address as an IPv4-mapped IPv6 address, and passing that address, within a `sockaddr_in6` structure, in the `connect()` or `sendto()` call. When applications use `AF_INET6` sockets to accept TCP connections from IPv4 nodes, or receive UDP packets from IPv4 nodes, the system returns the peer's address to the application in the `accept()`, `recvfrom()`, or `getpeername()` call using a `sockaddr_in6` structure encoded this way.

Few applications will likely need to know which type of node they are interoperating with. However, for those applications that do need to know, the `IN6_IS_ADDR_V4MAPPED()` macro, defined in Section 6.4, is provided.

3.8 IPv6 Wildcard Address

While the `bind()` function allows applications to select the source IP address of UDP packets and TCP connections, applications often want the system to select the source address for them. With IPv4, one specifies the address as the symbolic constant `INADDR_ANY` (called the "wildcard" address) in the `bind()` call, or simply omits the `bind()` entirely.

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Since the IPv6 address type is a structure (struct in6_addr), a symbolic constant can be used to initialize an IPv6 address variable, but cannot be used in an assignment. Therefore systems provide the IPv6 wildcard address in two forms.

The first version is a global variable named "in6addr_any" that is an in6_addr structure. The extern declaration for this variable is defined in <netinet/in.h>

```
extern const struct in6_addr in6addr_any;
```

Applications use in6addr_any similarly to the way they use INADDR_ANY in IPv4. For example, to bind a socket to port number 23, but let the system select the source address, an application could use the following code:

```
struct sockaddr_in6 sin6;
. . .
sin6.sin6_family = AF_INET6;
sin6.sin6_flowinfo = 0;
sin6.sin6_port = htons(23);
sin6.sin6_addr = in6addr_any; /* structure assignment */
. . .
if (bind(s, (struct sockaddr *) &sin6, sizeof(sin6)) == -1)
. . .
```

The other version is a symbolic constant named IN6ADDR_ANY_INIT and is defined in <netinet/in.h>. This constant can be used to initialize an in6_addr structure:

```
struct in6_addr anyaddr = IN6ADDR_ANY_INIT;
```

Note that this constant can be used ONLY at declaration time. It can not be used to assign a previously declared in6_addr structure. For example, the following code will not work:

```
/* This is the WRONG way to assign an unspecified address */
struct sockaddr_in6 sin6;
. . .
sin6.sin6_addr = IN6ADDR_ANY_INIT; /* will NOT compile */
```

Be aware that the IPv4 INADDR_xxx constants are all defined in host byte order but the IPv6 IN6ADDR_xxx constants and the IPv6 in6addr_xxx externals are defined in network byte order.

3.9 IPv6 Loopback Address

Applications may need to send UDP packets to, or originate TCP connections to, services residing on the local node. In IPv4, they can do this by using the constant IPv4 address `INADDR_LOOPBACK` in their `connect()`, `sendto()`, or `sendmsg()` call.

IPv6 also provides a loopback address to contact local TCP and UDP services. Like the unspecified address, the IPv6 loopback address is provided in two forms – a global variable and a symbolic constant.

The global variable is an `in6_addr` structure named `"in6addr_loopback."` The extern declaration for this variable is defined in `<netinet/in.h>`

```
extern const struct in6_addr in6addr_loopback;
```

Applications use `in6addr_loopback` as they would use `INADDR_LOOPBACK` in IPv4 applications (but beware of the byte ordering difference mentioned at the end of the previous section). For example, to open a TCP connection to the local telnet server, an application could use the following code:

```
struct sockaddr_in6 sin6;
. . .
sin6.sin6_family = AF_INET6;
sin6.sin6_flowinfo = 0;
sin6.sin6_port = htons(23);
sin6.sin6_addr = in6addr_loopback; /* structure assignment */
. . .
if (connect(s, (struct sockaddr *) &sin6, sizeof(sin6)) == -1)
. . .
```

The symbolic constant is named `IN6ADDR_LOOPBACK_INIT` and is defined in `<netinet/in.h>`. It can be used at declaration time ONLY; for example:

```
struct in6_addr loopbackaddr = IN6ADDR_LOOPBACK_INIT;
```

Like `IN6ADDR_ANY_INIT`, this constant cannot be used in an assignment to a previously declared IPv6 address variable.

3.10 Portability Additions

One simple addition to the sockets API that can help application writers is the "struct sockaddr_storage". This data structure can simplify writing code that is portable across multiple address families and platforms. This data structure is designed with the following goals.

- Large enough to accommodate all supported protocol-specific address structures.
- Aligned at an appropriate boundary so that pointers to it can be cast as pointers to protocol specific address structures and used to access the fields of those structures without alignment problems.

The `sockaddr_storage` structure contains field `ss_family` which is of type `sa_family_t`. When a `sockaddr_storage` structure is cast to a `sockaddr` structure, the `ss_family` field of the `sockaddr_storage` structure maps onto the `sa_family` field of the `sockaddr` structure. When a `sockaddr_storage` structure is cast as a protocol specific address structure, the `ss_family` field maps onto a field of that structure that is of type `sa_family_t` and that identifies the protocol's address family.

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An example implementation design of such a data structure would be as follows.

```
/*
 * Desired design of maximum size and alignment
 */
#define _SS_MAXSIZE      128 /* Implementation specific max size */
#define _SS_ALIGNSIZE    (sizeof (int64_t))
                        /* Implementation specific desired alignment */

/*
 * Definitions used for sockaddr_storage structure paddings design.
 */
#define _SS_PAD1SIZE     (_SS_ALIGNSIZE - sizeof (sa_family_t))
#define _SS_PAD2SIZE     (_SS_MAXSIZE - (sizeof (sa_family_t) +
                        _SS_PAD1SIZE + _SS_ALIGNSIZE))

struct sockaddr_storage {
    sa_family_t  ss_family;      /* address family */
    /* Following fields are implementation specific */
    char         __ss_pad1[_SS_PAD1SIZE];
                /* 6 byte pad, this is to make implementation
                /* specific pad up to alignment field that */
                /* follows explicit in the data structure */

    int64_t      __ss_align;     /* field to force desired structure */
                /* storage alignment */

    char         __ss_pad2[_SS_PAD2SIZE];
                /* 112 byte pad to achieve desired size, */
                /* _SS_MAXSIZE value minus size of ss_family */
                /* __ss_pad1, __ss_align fields is 112 */
};
```

The above example implementation illustrates a data structure which will align on a 64-bit boundary. An implementation-specific field "`__ss_align`" along with "`__ss_pad1`" is used to force a 64-bit alignment which covers proper alignment good enough for the needs of `sockaddr_in6` (IPv6), `sockaddr_in` (IPv4) address data structures. The size of padding field `__ss_pad1` depends on the chosen alignment boundary. The size of padding field `__ss_pad2` depends on the value of overall size chosen for the total size of the structure. This size and alignment are represented in the above example by implementation specific (not required) constants `_SS_MAXSIZE` (chosen value 128) and `_SS_ALIGNSIZE` (with chosen value 8). Constants `_SS_PAD1SIZE` (derived value 6) and `_SS_PAD2SIZE` (derived value 112) are also for illustration and not required. The derived values assume `sa_family_t` is 2 bytes. The implementation specific definitions and structure field names above start with an underscore to denote implementation private namespace. Portable code is not expected to access or reference those fields or constants.

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On implementations where the sockaddr data structure includes a "sa_len" field this data structure would look like this:

```
/*
 * Definitions used for sockaddr_storage structure paddings design.
 */
#define _SS_PAD1SIZE (_SS_ALIGNSIZE -
                    (sizeof (uint8_t) + sizeof (sa_family_t))
#define _SS_PAD2SIZE (_SS_MAXSIZE -
                    (sizeof (uint8_t) + sizeof (sa_family_t) +
                     _SS_PAD1SIZE + _SS_ALIGNSIZE))

struct sockaddr_storage {
    uint8_t      ss_len;          /* address length */
    sa_family_t  ss_family;      /* address family */
    /* Following fields are implementation specific */
    char         __ss_pad1[_SS_PAD1SIZE];
    /* 6 byte pad, this is to make implementation
     * specific pad up to alignment field that */
    /* follows explicit in the data structure */
    int64_t      __ss_align;     /* field to force desired structure */
    /* storage alignment */
    char         __ss_pad2[_SS_PAD2SIZE];
    /* 112 byte pad to achieve desired size, */
    /* _SS_MAXSIZE value minus size of ss_len, */
    /* __ss_family, __ss_pad1, __ss_align fields is 112 */
};
```

4. Interface Identification

This API uses an interface index (a small positive integer) to identify the local interface on which a multicast group is joined (Section 5.2). Additionally, the advanced API [4] uses these same interface indexes to identify the interface on which a datagram is received, or to specify the interface on which a datagram is to be sent.

Interfaces are normally known by names such as "le0", "sl1", "ppp2", and the like. On Berkeley-derived implementations, when an interface is made known to the system, the kernel assigns a unique positive integer value (called the interface index) to that interface. These are small positive integers that start at 1. (Note that 0 is never used for an interface index.) There may be gaps so that there is no current interface for a particular positive interface index.

This API defines two functions that map between an interface name and index, a third function that returns all the interface names and indexes, and a fourth function to return the dynamic memory allocated by the previous function. How these functions are implemented is

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left up to the implementation. 4.4BSD implementations can implement these functions using the existing `sysctl()` function with the `NET_RT_IFLIST` command. Other implementations may wish to use `ioctl()` for this purpose.

4.1 Name-to-Index

The first function maps an interface name into its corresponding index.

```
#include <net/if.h>

unsigned int  if_nametoindex(const char *ifname);
```

If `ifname` is the name of an interface, the `if_nametoindex()` function shall return the interface index corresponding to name `ifname`; otherwise, it shall return zero. No errors are defined.

4.2 Index-to-Name

The second function maps an interface index into its corresponding name.

```
#include <net/if.h>

char *if_indextoname(unsigned int ifindex, char *ifname);
```

When this function is called, the `ifname` argument shall point to a buffer of at least `IF_NAMESIZE` bytes. The function shall place in this buffer the name of the interface with index `ifindex`. (`IF_NAMESIZE` is also defined in `<net/if.h>` and its value includes a terminating null byte at the end of the interface name.) If `ifindex` is an interface index, then the function shall return the value supplied in `ifname`, which points to a buffer now containing the interface name. Otherwise, the function shall return a NULL pointer and set `errno` to indicate the error. If there is no interface corresponding to the specified index, `errno` is set to `ENXIO`. If there was a system error (such as running out of memory), `errno` would be set to the proper value (e.g., `ENOMEM`).

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4.3 Return All Interface Names and Indexes

The `if_nameindex` structure holds the information about a single interface and is defined as a result of including the `<net/if.h>` header.

```
struct if_nameindex {
    unsigned int    if_index; /* 1, 2, ... */
    char           *if_name;  /* null terminated name: "le0", ... */
};
```

The final function returns an array of `if_nameindex` structures, one structure per interface.

```
#include <net/if.h>
```

```
struct if_nameindex *if_nameindex(void);
```

The end of the array of structures is indicated by a structure with an `if_index` of 0 and an `if_name` of NULL. The function returns a NULL pointer upon an error, and would set `errno` to the appropriate value.

The memory used for this array of structures along with the interface names pointed to by the `if_name` members is obtained dynamically. This memory is freed by the next function.

4.4 Free Memory

The following function frees the dynamic memory that was allocated by `if_nameindex()`.

```
#include <net/if.h>
```

```
void if_freenameindex(struct if_nameindex *ptr);
```

The `ptr` argument shall be a pointer that was returned by `if_nameindex()`. After `if_freenameindex()` has been called, the application shall not use the array of which `ptr` is the address.

5. Socket Options

A number of new socket options are defined for IPv6. All of these new options are at the `IPPROTO_IPV6` level. That is, the "level" parameter in the `getsockopt()` and `setsockopt()` calls is `IPPROTO_IPV6` when using these options. The constant name prefix `IPV6_` is used in all of the new socket options. This serves to clearly identify these options as applying to IPv6.

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The declaration for IPPROTO_IPV6, the new IPv6 socket options, and related constants defined in this section are obtained by including the header `<netinet/in.h>`

5.1 Unicast Hop Limit

A new `setsockopt()` option controls the hop limit used in outgoing unicast IPv6 packets. The name of this option is `IPV6_UNICAST_HOPS`, and it is used at the `IPPROTO_IPV6` layer. The following example illustrates how it is used:

```
int  hoplimit = 10;

if (setsockopt(s, IPPROTO_IPV6, IPV6_UNICAST_HOPS,
              (char *) &hoplimit, sizeof(hoplimit)) == -1)
    perror("setsockopt IPV6_UNICAST_HOPS");
```

When the `IPV6_UNICAST_HOPS` option is set with `setsockopt()`, the option value given is used as the hop limit for all subsequent unicast packets sent via that socket. If the option is not set, the system selects a default value. The integer hop limit value (called `x`) is interpreted as follows:

```
x -1:          return an error of EINVAL
x == -1:       use kernel default
0 <= x <= 255: use x
x >= 256:      return an error of EINVAL
```

The `IPV6_UNICAST_HOPS` option may be used with `getsockopt()` to determine the hop limit value that the system will use for subsequent unicast packets sent via that socket. For example:

```
int  hoplimit;
socklen_t  len = sizeof(hoplimit);

if (getsockopt(s, IPPROTO_IPV6, IPV6_UNICAST_HOPS,
              (char *) &hoplimit, &len) == -1)
    perror("getsockopt IPV6_UNICAST_HOPS");
else
    printf("Using %d for hop limit.\n", hoplimit);
```

5.2 Sending and Receiving Multicast Packets

IPv6 applications may send multicast packets by simply specifying an IPv6 multicast address as the destination address, for example in the destination address argument of the `sendto()` function.

Three socket options at the IPPROTO_IPV6 layer control some of the parameters for sending multicast packets. Setting these options is not required: applications may send multicast packets without using these options. The setsockopt() options for controlling the sending of multicast packets are summarized below. These three options can also be used with getsockopt().

IPV6_MULTICAST_IF

Set the interface to use for outgoing multicast packets. The argument is the index of the interface to use. If the interface index is specified as zero, the system selects the interface (for example, by looking up the address in a routing table and using the resulting interface).

Argument type: unsigned int

IPV6_MULTICAST_HOPS

Set the hop limit to use for outgoing multicast packets. (Note a separate option - IPV6_UNICAST_HOPS - is provided to set the hop limit to use for outgoing unicast packets.)

The interpretation of the argument is the same as for the IPV6_UNICAST_HOPS option:

```
x -1:          return an error of EINVAL
x == -1:       use kernel default
0 <= x <= 255: use x
x >= 256:      return an error of EINVAL
```

If IPV6_MULTICAST_HOPS is not set, the default is 1 (same as IPv4 today)

Argument type: int

IPV6_MULTICAST_LOOP

If a multicast datagram is sent to a group to which the sending host itself belongs (on the outgoing interface), a copy of the datagram is looped back by the IP layer for local delivery if this option is set to 1. If this option is set to 0 a copy is not looped back. Other option values return an error of EINVAL.

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If `IPV6_MULTICAST_LOOP` is not set, the default is 1 (loopback; same as IPv4 today).

Argument type: unsigned int

The reception of multicast packets is controlled by the two `setsockopt()` options summarized below. An error of `EOPNOTSUPP` is returned if these two options are used with `getsockopt()`.

`IPV6_JOIN_GROUP`

Join a multicast group on a specified local interface. If the interface index is specified as 0, the kernel chooses the local interface. For example, some kernels look up the multicast group in the normal IPv6 routing table and use the resulting interface.

Argument type: struct `ipv6_mreq`

`IPV6_LEAVE_GROUP`

Leave a multicast group on a specified interface. If the interface index is specified as 0, the system may choose a multicast group membership to drop by matching the multicast address only.

Argument type: struct `ipv6_mreq`

The argument type of both of these options is the `ipv6_mreq` structure, defined as a result of including the `<netinet/in.h>` header;

```
struct ipv6_mreq {
    struct in6_addr ipv6mr_multiaddr; /* IPv6 multicast addr */
    unsigned int    ipv6mr_interface; /* interface index */
};
```

Note that to receive multicast datagrams a process must join the multicast group to which datagrams will be sent. UDP applications must also bind the UDP port to which datagrams will be sent. Some processes also bind the multicast group address to the socket, in addition to the port, to prevent other datagrams destined to that same port from being delivered to the socket.

5.3 IPV6_V6ONLY option for AF_INET6 Sockets

This socket option restricts AF_INET6 sockets to IPv6 communications only. As stated in section <3.7 Compatibility with IPv4 Nodes>, AF_INET6 sockets may be used for both IPv4 and IPv6 communications. Some applications may want to restrict their use of an AF_INET6 socket to IPv6 communications only. For these applications the IPV6_V6ONLY socket option is defined. When this option is turned on, the socket can be used to send and receive IPv6 packets only. This is an IPPROTO_IPV6 level option. This option takes an int value. This is a boolean option. By default this option is turned off.

Here is an example of setting this option:

```
int on = 1;

if (setsockopt(s, IPPROTO_IPV6, IPV6_V6ONLY,
              (char *)&on, sizeof(on)) == -1)
    perror("setsockopt IPV6_V6ONLY");
else
    printf("IPV6_V6ONLY set\n");
```

Note - This option has no effect on the use of IPv4 Mapped addresses which enter a node as a valid IPv6 addresses for IPv6 communications as defined by Stateless IP/ICMP Translation Algorithm (SIIT) [5].

An example use of this option is to allow two versions of the same server process to run on the same port, one providing service over IPv6, the other providing the same service over IPv4.

6. Library Functions

New library functions are needed to perform a variety of operations with IPv6 addresses. Functions are needed to lookup IPv6 addresses in the Domain Name System (DNS). Both forward lookup (nodename-to-address translation) and reverse lookup (address-to-nodename translation) need to be supported. Functions are also needed to convert IPv6 addresses between their binary and textual form.

We note that the two existing functions, gethostbyname() and gethostbyaddr(), are left as-is. New functions are defined to handle both IPv4 and IPv6 addresses.

The commonly used function gethostbyname() is inadequate for many applications, first because it provides no way for the caller to specify anything about the types of addresses desired (IPv4 only, IPv6 only, IPv4-mapped IPv6 are OK, etc.), and second because many implementations of this function are not thread safe. RFC 2133

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defined a function named `gethostbyname2()` but this function was also inadequate, first because its use required setting a global option (`RES_USE_INET6`) when IPv6 addresses were required, and second because a flag argument is needed to provide the caller with additional control over the types of addresses required. The `gethostbyname2()` function was deprecated in RFC 2553 and is no longer part of the basic API.

6.1 Protocol-Independent Nodename and Service Name Translation

Nodename-to-address translation is done in a protocol-independent fashion using the `getaddrinfo()` function.

```
#include <sys/socket.h>
#include <netdb.h>

int getaddrinfo(const char *nodename, const char *servname,
                const struct addrinfo *hints, struct addrinfo **res);

void freeaddrinfo(struct addrinfo *ai);

struct addrinfo {
    int      ai_flags;      /* AI_PASSIVE, AI_CANONNAME,
                           AI_NUMERICHOST, .. */
    int      ai_family;     /* AF_XXX */
    int      ai_socktype;   /* SOCK_XXX */
    int      ai_protocol;   /* 0 or IPPROTO_XXX for IPv4 and IPv6 */
    socklen_t ai_addrlen;   /* length of ai_addr */
    char     *ai_canonname; /* canonical name for nodename */
    struct sockaddr *ai_addr; /* binary address */
    struct addrinfo *ai_next; /* next structure in linked list */
};
```

The `getaddrinfo()` function translates the name of a service location (for example, a host name) and/or a service name and returns a set of socket addresses and associated information to be used in creating a socket with which to address the specified service.

The `nodename` and `servname` arguments are either null pointers or pointers to null-terminated strings. One or both of these two arguments must be a non-null pointer.

The format of a valid name depends on the address family or families. If a specific family is not given and the name could be interpreted as valid within multiple supported families, the implementation will attempt to resolve the name in all supported families and, in absence of errors, one or more results shall be returned.

If the nodename argument is not null, it can be a descriptive name or can be an address string. If the specified address family is AF_INET, AF_INET6, or AF_UNSPEC, valid descriptive names include host names. If the specified address family is AF_INET or AF_UNSPEC, address strings using Internet standard dot notation as specified in inet_addr() are valid. If the specified address family is AF_INET6 or AF_UNSPEC, standard IPv6 text forms described in inet_pton() are valid.

If nodename is not null, the requested service location is named by nodename; otherwise, the requested service location is local to the caller.

If servname is null, the call shall return network-level addresses for the specified nodename. If servname is not null, it is a null-terminated character string identifying the requested service. This can be either a descriptive name or a numeric representation suitable for use with the address family or families. If the specified address family is AF_INET, AF_INET6 or AF_UNSPEC, the service can be specified as a string specifying a decimal port number.

If the argument hints is not null, it refers to a structure containing input values that may direct the operation by providing options and by limiting the returned information to a specific socket type, address family and/or protocol. In this hints structure every member other than ai_flags, ai_family, ai_socktype and ai_protocol shall be set to zero or a null pointer. A value of AF_UNSPEC for ai_family means that the caller shall accept any address family. A value of zero for ai_socktype means that the caller shall accept any socket type. A value of zero for ai_protocol means that the caller shall accept any protocol. If hints is a null pointer, the behavior shall be as if it referred to a structure containing the value zero for the ai_flags, ai_socktype and ai_protocol fields, and AF_UNSPEC for the ai_family field.

Note:

1. If the caller handles only TCP and not UDP, for example, then the ai_protocol member of the hints structure should be set to IPPROTO_TCP when getaddrinfo() is called.
2. If the caller handles only IPv4 and not IPv6, then the ai_family member of the hints structure should be set to AF_INET when getaddrinfo() is called.

The `ai_flags` field to which hints parameter points shall be set to zero or be the bitwise-inclusive OR of one or more of the values `AI_PASSIVE`, `AI_CANONNAME`, `AI_NUMERICHOST`, `AI_NUMERICSERV`, `AI_V4MAPPED`, `AI_ALL`, and `AI_ADDRCONFIG`.

If the `AI_PASSIVE` flag is specified, the returned address information shall be suitable for use in binding a socket for accepting incoming connections for the specified service (i.e., a call to `bind()`). In this case, if the `nodename` argument is null, then the IP address portion of the socket address structure shall be set to `INADDR_ANY` for an IPv4 address or `IN6ADDR_ANY_INIT` for an IPv6 address. If the `AI_PASSIVE` flag is not specified, the returned address information shall be suitable for a call to `connect()` (for a connection-mode protocol) or for a call to `connect()`, `sendto()` or `sendmsg()` (for a connectionless protocol). In this case, if the `nodename` argument is null, then the IP address portion of the socket address structure shall be set to the loopback address. This flag is ignored if the `nodename` argument is not null.

If the `AI_CANONNAME` flag is specified and the `nodename` argument is not null, the function shall attempt to determine the canonical name corresponding to `nodename` (for example, if `nodename` is an alias or shorthand notation for a complete name).

If the `AI_NUMERICHOST` flag is specified, then a non-null `nodename` string supplied shall be a numeric host address string. Otherwise, an `[EAI_NONAME]` error is returned. This flag shall prevent any type of name resolution service (for example, the DNS) from being invoked.

If the `AI_NUMERICSERV` flag is specified, then a non-null `servname` string supplied shall be a numeric port string. Otherwise, an `[EAI_NONAME]` error shall be returned. This flag shall prevent any type of name resolution service (for example, NIS+) from being invoked.

If the `AI_V4MAPPED` flag is specified along with an `ai_family` of `AF_INET6`, then `getaddrinfo()` shall return IPv4-mapped IPv6 addresses on finding no matching IPv6 addresses (`ai_addrlen` shall be 16).

For example, when using the DNS, if no AAAA records are found then a query is made for A records and any found are returned as IPv4-mapped IPv6 addresses.

The `AI_V4MAPPED` flag shall be ignored unless `ai_family` equals `AF_INET6`.

If the `AI_ALL` flag is used with the `AI_V4MAPPED` flag, then `getaddrinfo()` shall return all matching IPv6 and IPv4 addresses.

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For example, when using the DNS, queries are made for both AAAA records and A records, and `getaddrinfo()` returns the combined results of both queries. Any IPv4 addresses found are returned as IPv4-mapped IPv6 addresses.

The `AI_ALL` flag without the `AI_V4MAPPED` flag is ignored.

Note:

When `ai_family` is not specified (`AF_UNSPEC`), `AI_V4MAPPED` and `AI_ALL` flags will only be used if `AF_INET6` is supported.

If the `AI_ADDRCONFIG` flag is specified, IPv4 addresses shall be returned only if an IPv4 address is configured on the local system, and IPv6 addresses shall be returned only if an IPv6 address is configured on the local system. The loopback address is not considered for this case as valid as a configured address.

For example, when using the DNS, a query for AAAA records should occur only if the node has at least one IPv6 address configured (other than IPv6 loopback) and a query for A records should occur only if the node has at least one IPv4 address configured (other than the IPv4 loopback).

The `ai_socktype` field to which argument hints points specifies the socket type for the service, as defined for `socket()`. If a specific socket type is not given (for example, a value of zero) and the service name could be interpreted as valid with multiple supported socket types, the implementation shall attempt to resolve the service name for all supported socket types and, in the absence of errors, all possible results shall be returned. A non-zero socket type value shall limit the returned information to values with the specified socket type.

If the `ai_family` field to which hints points has the value `AF_UNSPEC`, addresses shall be returned for use with any address family that can be used with the specified nodename and/or servname. Otherwise, addresses shall be returned for use only with the specified address family. If `ai_family` is not `AF_UNSPEC` and `ai_protocol` is not zero, then addresses are returned for use only with the specified address family and protocol; the value of `ai_protocol` shall be interpreted as in a call to the `socket()` function with the corresponding values of `ai_family` and `ai_protocol`.

The `freeaddrinfo()` function frees one or more `addrinfo` structures returned by `getaddrinfo()`, along with any additional storage associated with those structures (for example, storage pointed to by the `ai_canonname` and `ai_addr` fields; an application must not

reference this storage after the associated `addrinfo` structure has been freed). If the `ai_next` field of the structure is not null, the entire list of structures is freed. The `freeaddrinfo()` function must support the freeing of arbitrary sublists of an `addrinfo` list originally returned by `getaddrinfo()`.

Functions `getaddrinfo()` and `freeaddrinfo()` must be thread-safe.

A zero return value for `getaddrinfo()` indicates successful completion; a non-zero return value indicates failure. The possible values for the failures are listed below under Error Return Values.

Upon successful return of `getaddrinfo()`, the location to which `res` points shall refer to a linked list of `addrinfo` structures, each of which shall specify a socket address and information for use in creating a socket with which to use that socket address. The list shall include at least one `addrinfo` structure. The `ai_next` field of each structure contains a pointer to the next structure on the list, or a null pointer if it is the last structure on the list. Each structure on the list shall include values for use with a call to the `socket()` function, and a socket address for use with the `connect()` function or, if the `AI_PASSIVE` flag was specified, for use with the `bind()` function. The fields `ai_family`, `ai_socktype`, and `ai_protocol` shall be usable as the arguments to the `socket()` function to create a socket suitable for use with the returned address. The fields `ai_addr` and `ai_addrlen` are usable as the arguments to the `connect()` or `bind()` functions with such a socket, according to the `AI_PASSIVE` flag.

If `nodename` is not null, and if requested by the `AI_CANONNAME` flag, the `ai_canonname` field of the first returned `addrinfo` structure shall point to a null-terminated string containing the canonical name corresponding to the input `nodename`; if the canonical name is not available, then `ai_canonname` shall refer to the `nodename` argument or a string with the same contents. The contents of the `ai_flags` field of the returned structures are undefined.

All fields in socket address structures returned by `getaddrinfo()` that are not filled in through an explicit argument (for example, `sin6_flowinfo`) shall be set to zero.

Note: This makes it easier to compare socket address structures.

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Error Return Values:

The `getaddrinfo()` function shall fail and return the corresponding value if:

[EAI_AGAIN]	The name could not be resolved at this time. Future attempts may succeed.
[EAI_BADFLAGS]	The flags parameter had an invalid value.
[EAI_FAIL]	A non-recoverable error occurred when attempting to resolve the name.
[EAI_FAMILY]	The address family was not recognized.
[EAI_MEMORY]	There was a memory allocation failure when trying to allocate storage for the return value.
[EAI_NONAME]	The name does not resolve for the supplied parameters. Neither <code>nodename</code> nor <code>servname</code> were supplied. At least one of these must be supplied.
[EAI_SERVICE]	The service passed was not recognized for the specified socket type.
[EAI_SOCKTYPE]	The intended socket type was not recognized.
[EAI_SYSTEM]	A system error occurred; the error code can be found in <code>errno</code> .

The `gai_strerror()` function provides a descriptive text string corresponding to an `EAI_XXX` error value.

```
#include <netdb.h>
```

```
const char *gai_strerror(int ecode);
```

The argument is one of the `EAI_XXX` values defined for the `getaddrinfo()` and `getnameinfo()` functions. The return value points to a string describing the error. If the argument is not one of the `EAI_XXX` values, the function still returns a pointer to a string whose contents indicate an unknown error.

6.2 Socket Address Structure to Node Name and Service Name

The `getnameinfo()` function is used to translate the contents of a socket address structure to a node name and/or service name.

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```
#include <sys/socket.h>
#include <netdb.h>

int getnameinfo(const struct sockaddr *sa, socklen_t salen,
                char *node, socklen_t nodelen,
                char *service, socklen_t servicelen,
                int flags);
```

The `getnameinfo()` function shall translate a socket address to a node name and service location, all of which are defined as in `getaddrinfo()`.

The `sa` argument points to a socket address structure to be translated.

The `salen` argument holds the size of the socket address structure pointed to by `sa`.

If the socket address structure contains an IPv4-mapped IPv6 address or an IPv4-compatible IPv6 address, the implementation shall extract the embedded IPv4 address and lookup the node name for that IPv4 address.

Note: The IPv6 unspecified address ("`:::`") and the IPv6 loopback address ("`:::1`") are not IPv4-compatible addresses. If the address is the IPv6 unspecified address ("`:::`"), a lookup is not performed, and the `[EAI_NONAME]` error is returned.

If the `node` argument is non-NULL and the `nodelen` argument is nonzero, then the `node` argument points to a buffer able to contain up to `nodelen` characters that receives the node name as a null-terminated string. If the `node` argument is NULL or the `nodelen` argument is zero, the node name shall not be returned. If the node's name cannot be located, the numeric form of the node's address is returned instead of its name.

If the `service` argument is non-NULL and the `servicelen` argument is non-zero, then the `service` argument points to a buffer able to contain up to `servicelen` bytes that receives the service name as a null-terminated string. If the `service` argument is NULL or the `servicelen` argument is zero, the service name shall not be returned. If the service's name cannot be located, the numeric form of the service address (for example, its port number) shall be returned instead of its name.

The arguments `node` and `service` cannot both be NULL.

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The flags argument is a flag that changes the default actions of the function. By default the fully-qualified domain name (FQDN) for the host shall be returned, but:

- If the flag bit NI_NOFQDN is set, only the node name portion of the FQDN shall be returned for local hosts.
- If the flag bit NI_NUMERICHOST is set, the numeric form of the host's address shall be returned instead of its name, under all circumstances.
- If the flag bit NI_NAMEREQD is set, an error shall be returned if the host's name cannot be located.
- If the flag bit NI_NUMERICSERV is set, the numeric form of the service address shall be returned (for example, its port number) instead of its name, under all circumstances.
- If the flag bit NI_DGRAM is set, this indicates that the service is a datagram service (SOCK_DGRAM). The default behavior shall assume that the service is a stream service (SOCK_STREAM).

Note:

1. The NI_NUMERICxxx flags are required to support the "-n" flags that many commands provide.
2. The NI_DGRAM flag is required for the few AF_INET and AF_INET6 port numbers (for example, [512,514]) that represent different services for UDP and TCP.

The getnameinfo() function shall be thread safe.

A zero return value for getnameinfo() indicates successful completion; a non-zero return value indicates failure.

Upon successful completion, getnameinfo() shall return the node and service names, if requested, in the buffers provided. The returned names are always null-terminated strings.

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Error Return Values:

The `getnameinfo()` function shall fail and return the corresponding value if:

- [EAI_AGAIN] The name could not be resolved at this time.
 Future attempts may succeed.
- [EAI_BADFLAGS] The flags had an invalid value.
- [EAI_FAIL] A non-recoverable error occurred.
- [EAI_FAMILY] The address family was not recognized or the address
 length was invalid for the specified family.
- [EAI_MEMORY] There was a memory allocation failure.
- [EAI_NONAME] The name does not resolve for the supplied parameters.
 NI_NAMEREQD is set and the host's name cannot be
 located, or both `nodename` and `servname` were null.
- [EAI_OVERFLOW] An argument buffer overflowed.
- [EAI_SYSTEM] A system error occurred. The error code can be found
 in `errno`.

6.3 Address Conversion Functions

The two IPv4 functions `inet_addr()` and `inet_ntoa()` convert an IPv4 address between binary and text form. IPv6 applications need similar functions. The following two functions convert both IPv6 and IPv4 addresses:

```
#include <arpa/inet.h>
```

```
int inet_pton(int af, const char *src, void *dst);
```

```
const char *inet_ntop(int af, const void *src,  
                      char *dst, socklen_t size);
```

The `inet_pton()` function shall convert an address in its standard text presentation form into its numeric binary form. The `af` argument shall specify the family of the address. The `AF_INET` and `AF_INET6` address families shall be supported. The `src` argument points to the string being passed in. The `dst` argument points to a buffer into which the function stores the numeric address; this shall be large enough to hold the numeric address (32 bits for `AF_INET`, 128 bits for `AF_INET6`). The `inet_pton()` function shall return 1 if the conversion

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succeeds, with the address pointed to by `dst` in network byte order. It shall return 0 if the input is not a valid IPv4 dotted-decimal string or a valid IPv6 address string, or -1 with `errno` set to `EAFNOSUPPORT` if the `af` argument is unknown.

If the `af` argument of `inet_pton()` is `AF_INET`, the `src` string shall be in the standard IPv4 dotted-decimal form:

```
ddd.ddd.ddd.ddd
```

where "ddd" is a one to three digit decimal number between 0 and 255. The `inet_pton()` function does not accept other formats (such as the octal numbers, hexadecimal numbers, and fewer than four numbers that `inet_addr()` accepts).

If the `af` argument of `inet_pton()` is `AF_INET6`, the `src` string shall be in one of the standard IPv6 text forms defined in Section 2.2 of the addressing architecture specification [2].

The `inet_ntop()` function shall convert a numeric address into a text string suitable for presentation. The `af` argument shall specify the family of the address. This can be `AF_INET` or `AF_INET6`. The `src` argument points to a buffer holding an IPv4 address if the `af` argument is `AF_INET`, or an IPv6 address if the `af` argument is `AF_INET6`; the address must be in network byte order. The `dst` argument points to a buffer where the function stores the resulting text string; it shall not be `NULL`. The `size` argument specifies the size of this buffer, which shall be large enough to hold the text string (`INET_ADDRSTRLEN` characters for IPv4, `INET6_ADDRSTRLEN` characters for IPv6).

In order to allow applications to easily declare buffers of the proper size to store IPv4 and IPv6 addresses in string form, the following two constants are defined in `<netinet/in.h>`

```
#define INET_ADDRSTRLEN    16
#define INET6_ADDRSTRLEN   46
```

The `inet_ntop()` function shall return a pointer to the buffer containing the text string if the conversion succeeds, and `NULL` otherwise. Upon failure, `errno` is set to `EAFNOSUPPORT` if the `af` argument is invalid or `ENOSPC` if the size of the result buffer is inadequate.

6.4 Address Testing Macros

The following macros can be used to test for special IPv6 addresses.

```
#include <netinet.h>

int  IN6_IS_ADDR_UNSPECIFIED (const struct in6_addr *);
int  IN6_IS_ADDR_LOOPBACK    (const struct in6_addr *);
int  IN6_IS_ADDR_MULTICAST   (const struct in6_addr *);
int  IN6_IS_ADDR_LINKLOCAL    (const struct in6_addr *);
int  IN6_IS_ADDR_SITELOCAL    (const struct in6_addr *);
int  IN6_IS_ADDR_V4MAPPED     (const struct in6_addr *);
int  IN6_IS_ADDR_V4COMPAT     (const struct in6_addr *);

int  IN6_IS_ADDR_MC_NODELOCAL (const struct in6_addr *);
int  IN6_IS_ADDR_MC_LINKLOCAL (const struct in6_addr *);
int  IN6_IS_ADDR_MC_SITELOCAL (const struct in6_addr *);
int  IN6_IS_ADDR_MC_ORGLocal  (const struct in6_addr *);
int  IN6_IS_ADDR_MC_GLOBAL    (const struct in6_addr *);
```

The first seven macros return true if the address is of the specified type, or false otherwise. The last five test the scope of a multicast address and return true if the address is a multicast address of the specified scope or false if the address is either not a multicast address or not of the specified scope.

Note that `IN6_IS_ADDR_LINKLOCAL` and `IN6_IS_ADDR_SITELOCAL` return true only for the two types of local-use IPv6 unicast addresses (Link-Local and Site-Local) defined in [2], and that by this definition, the `IN6_IS_ADDR_LINKLOCAL` macro returns false for the IPv6 loopback address (`:::1`). These two macros do not return true for IPv6 multicast addresses of either link-local scope or site-local scope.

7. Summary of New Definitions

The following list summarizes the constants, structure, and extern definitions discussed in this memo, sorted by header.

```
<net/if.h>      IF_NAMESIZE
<net/if.h>      struct if_nameindex{};

<netdb.h>       AI_ADDRCONFIG
<netdb.h>       AI_ALL
<netdb.h>       AI_CANONNAME
<netdb.h>       AI_NUMERICHOST
<netdb.h>       AI_NUMERICSERV
<netdb.h>       AI_PASSIVE
<netdb.h>       AI_V4MAPPED
```

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```

<netdb.h>                    EAI_AGAIN
<netdb.h>                    EAI_BADFLAGS
<netdb.h>                    EAI_FAIL
<netdb.h>                    EAI_FAMILY
<netdb.h>                    EAI_MEMORY
<netdb.h>                    EAI_NONAME
<netdb.h>                    EAI_OVERFLOW
<netdb.h>                    EAI_SERVICE
<netdb.h>                    EAI_SOCKTYPE
<netdb.h>                    EAI_SYSTEM
<netdb.h>                    NI_DGRAM
<netdb.h>                    NI_NAMEREQD
<netdb.h>                    NI_NOFQDN
<netdb.h>                    NI_NUMERICHOST
<netdb.h>                    NI_NUMERICSERV
<netdb.h>                    struct addrinfo{};

<netinet/in.h>              IN6ADDR_ANY_INIT
<netinet/in.h>              IN6ADDR_LOOPBACK_INIT
<netinet/in.h>              INET6_ADDRSTRLEN
<netinet/in.h>              INET_ADDRSTRLEN
<netinet/in.h>              IPPROTO_IPV6
<netinet/in.h>              IPV6_JOIN_GROUP
<netinet/in.h>              IPV6_LEAVE_GROUP
<netinet/in.h>              IPV6_MULTICAST_HOPS
<netinet/in.h>              IPV6_MULTICAST_IF
<netinet/in.h>              IPV6_MULTICAST_LOOP
<netinet/in.h>              IPV6_UNICAST_HOPS
<netinet/in.h>              IPV6_V6ONLY
<netinet/in.h>              SIN6_LEN
<netinet/in.h>              extern const struct in6_addr in6addr_any;
<netinet/in.h>              extern const struct in6_addr in6addr_loopback;
<netinet/in.h>              struct in6_addr{};
<netinet/in.h>              struct ipv6_mreq{};
<netinet/in.h>              struct sockaddr_in6{};

<sys/socket.h>              AF_INET6
<sys/socket.h>              PF_INET6
<sys/socket.h>              struct sockaddr_storage;

```

The following list summarizes the function and macro prototypes discussed in this memo, sorted by header.

```

<arpa/inet.h>              int inet_pton(int, const char *, void *);

<arpa/inet.h>              const char *inet_ntop(int, const void *,
                           char *, socklen_t);

```

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```

<net/if.h>      char *if_indextoname(unsigned int, char *);
<net/if.h>      unsigned int if_nametoindex(const char *);
<net/if.h>      void if_freenameindex(struct if_nameindex *);
<net/if.h>      struct if_nameindex *if_nameindex(void);

<netdb.h>       int getaddrinfo(const char *, const char *,
                               const struct addrinfo *,
                               struct addrinfo **);
<netdb.h>       int getnameinfo(const struct sockaddr *, socklen_t,
                               char *, socklen_t, char *, socklen_t, int);
<netdb.h>       void freeaddrinfo(struct addrinfo *);
<netdb.h>       const char *gai_strerror(int);

<netinet/in.h> int IN6_IS_ADDR_LINKLOCAL(const struct in6_addr *);
<netinet/in.h> int IN6_IS_ADDR_LOOPBACK(const struct in6_addr *);
<netinet/in.h> int IN6_IS_ADDR_MC_GLOBAL(const struct in6_addr *);
<netinet/in.h> int IN6_IS_ADDR_MC_LINKLOCAL(const struct in6_addr *);
<netinet/in.h> int IN6_IS_ADDR_MC_NODELOCAL(const struct in6_addr *);
<netinet/in.h> int IN6_IS_ADDR_MC_ORGLOCAL(const struct in6_addr *);
<netinet/in.h> int IN6_IS_ADDR_MC_SITELOCAL(const struct in6_addr *);
<netinet/in.h> int IN6_IS_ADDR_MULTICAST(const struct in6_addr *);
<netinet/in.h> int IN6_IS_ADDR_SITELOCAL(const struct in6_addr *);
<netinet/in.h> int IN6_IS_ADDR_UNSPECIFIED(const struct in6_addr *);
<netinet/in.h> int IN6_IS_ADDR_V4COMPAT(const struct in6_addr *);
<netinet/in.h> int IN6_IS_ADDR_V4MAPPED(const struct in6_addr *);

```

8. Security Considerations

IPv6 provides a number of new security mechanisms, many of which need to be accessible to applications. Companion memos detailing the extensions to the socket interfaces to support IPv6 security are being written.

9. Changes from RFC 2553

1. Add brief description of the history of this API and its relation to the Open Group/IEEE/ISO standards.
2. Alignments with [3].
3. Removed all references to `getipnodebyname()` and `getipnodebyaddr()`, which are deprecated in favor of `getaddrinfo()` and `getnameinfo()`.
4. Added `IPV6_V6ONLY` IP level socket option to permit nodes to not process IPv4 packets as IPv4 Mapped addresses in implementations.
5. Added SIIT to references and added new contributors.

6. In previous versions of this specification, the `sin6_flowinfo` field was associated with the IPv6 traffic class and flow label, but its usage was not completely specified. The complete definition of the `sin6_flowinfo` field, including its association with the traffic class or flow label, is now deferred to a future specification.

10. Acknowledgments

This specification's evolution and completeness were significantly influenced by the efforts of Richard Stevens, who has passed on. Richard's wisdom and talent made the specification what it is today. The co-authors will long think of Richard with great respect.

Thanks to the many people who made suggestions and provided feedback to this document, including:

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The `getaddrinfo()` and `getnameinfo()` functions are taken from an earlier document by Keith Sklower. As noted in that document, William Durst, Steven Wise, Michael Karels, and Eric Allman provided many useful discussions on the subject of protocol-independent name-to-address translation, and reviewed early versions of Keith Sklower's original proposal. Eric Allman implemented the first prototype of `getaddrinfo()`. The observation that specifying the pair of name and service would suffice for connecting to a service independent of protocol details was made by Marshall Rose in a proposal to X/Open for a "Uniform Network Interface".

Craig Metz, Jack McCann, Erik Nordmark, Tim Hartrick, and Mukesh Kacker made many contributions to this document. Ramesh Govindan made a number of contributions and co-authored an earlier version of this memo.

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- [1] Deering, S. and R. Hinden, "Internet Protocol, Version 6 (IPv6) Specification", RFC 2460, December 1998.
- [2] Hinden, R. and S. Deering, "IP Version 6 Addressing Architecture", RFC 2373, July 1998.
- [3] IEEE Std. 1003.1-2001 Standard for Information Technology – Portable Operating System Interface (POSIX). Open Group Technical Standard: Base Specifications, Issue 6, December 2001. ISO/IEC 9945:2002. <http://www.opengroup.org/austin>
- [4] Stevens, W. and M. Thomas, "Advanced Sockets API for IPv6", RFC 2292, February 1998.
- [5] Nordmark, E., "Stateless IP/ICMP Translation Algorithm (SIIT)", RFC 2765, February 2000.
- [6] The Open Group Base Working Group
<http://www.opengroup.org/platform/base.html>

RFC 3493 Basic Socket Interface Extensions for IPv6 February 2003

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RFC2292 “Advanced Sockets API for IPv6”

RFC 2292

Advanced Sockets API for IPv6

February 1998

Network Working Group
Request for Comments: 2292
Category: Informational

W. Stevens
Consultant
M. Thomas
AltaVista
February 1998

Advanced Sockets API for IPv6

Status of this Memo

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Abstract

Specifications are in progress for changes to the sockets API to support IP version 6 [RFC-2133]. These changes are for TCP and UDP-based applications and will support most end-user applications in use today: Telnet and FTP clients and servers, HTTP clients and servers, and the like.

But another class of applications exists that will also be run under IPv6. We call these "advanced" applications and today this includes programs such as Ping, Traceroute, routing daemons, multicast routing daemons, router discovery daemons, and the like. The API feature typically used by these programs that make them "advanced" is a raw socket to access ICMPv4, IGMPv4, or IPv4, along with some knowledge of the packet header formats used by these protocols. To provide portability for applications that use raw sockets under IPv6, some standardization is needed for the advanced API features.

There are other features of IPv6 that some applications will need to access: interface identification (specifying the outgoing interface and determining the incoming interface) and IPv6 extension headers that are not addressed in [RFC-2133]: Hop-by-Hop options, Destination options, and the Routing header (source routing). This document provides API access to these features too.

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1. Introduction

Specifications are in progress for changes to the sockets API to support IP version 6 [RFC-2133]. These changes are for TCP and UDP-based applications. The current document defines some the "advanced" features of the sockets API that are required for applications to take advantage of additional features of IPv6.

Today, the portability of applications using IPv4 raw sockets is quite high, but this is mainly because most IPv4 implementations started from a common base (the Berkeley source code) or at least started with the Berkeley headers. This allows programs such as Ping and Traceroute, for example, to compile with minimal effort on many hosts that support the sockets API. With IPv6, however, there is no common source code base that implementors are starting from, and the possibility for divergence at this level between different implementations is high. To avoid a complete lack of portability amongst applications that use raw IPv6 sockets, some standardization is necessary.

There are also features from the basic IPv6 specification that are not addressed in [RFC-2133]: sending and receiving Hop-by-Hop options, Destination options, and Routing headers, specifying the outgoing interface, and being told of the receiving interface.

This document can be divided into the following main sections.

1. Definitions of the basic constants and structures required for applications to use raw IPv6 sockets. This includes structure definitions for the IPv6 and ICMPv6 headers and all associated constants (e.g., values for the Next Header field).
2. Some basic semantic definitions for IPv6 raw sockets. For example, a raw ICMPv4 socket requires the application to calculate and store the ICMPv4 header checksum. But with IPv6 this would require the application to choose the source IPv6 address because the source address is part of the pseudo header that ICMPv6 now uses for its checksum computation. It should be defined that with a raw ICMPv6 socket the kernel always calculates and stores the ICMPv6 header checksum.
3. Packet information: how applications can obtain the received interface, destination address, and received hop limit, along with specifying these values on a per-packet basis. There are a class of applications that need this capability and the technique should be portable.
4. Access to the optional Hop-by-Hop, Destination, and Routing headers.
5. Additional features required for IPv6 application portability.

The packet information along with access to the extension headers (Hop-by-Hop options, Destination options, and Routing header) are specified using the "ancillary data" fields that were added to the 4.3BSD Reno sockets API in 1990. The reason is that these ancillary data fields are part of the Posix.1g standard (which should be approved in 1997) and should therefore be adopted by most vendors.

This document does not address application access to either the authentication header or the encapsulating security payload header.

All examples in this document omit error checking in favor of brevity and clarity.

We note that many of the functions and socket options defined in this document may have error returns that are not defined in this document. Many of these possible error returns will be recognized only as implementations proceed.

Datatypes in this document follow the Posix.1g format: `intN_t` means a signed integer of exactly N bits (e.g., `int16_t`) and `uintN_t` means an unsigned integer of exactly N bits (e.g., `uint32_t`).

Note that we use the (unofficial) terminology ICMPv4, IGMPv4, and ARPv4 to avoid any confusion with the newer ICMPv6 protocol.

2. Common Structures and Definitions

Many advanced applications examine fields in the IPv6 header and set and examine fields in the various ICMPv6 headers. Common structure definitions for these headers are required, along with common constant definitions for the structure members.

Two new headers are defined: `<netinet/ip6.h>` and `<netinet/icmp6.h>`.

When an include file is specified, that include file is allowed to include other files that do the actual declaration or definition.

2.1. The `ip6_hdr` Structure

The following structure is defined as a result of including `<netinet/ip6.h>`. Note that this is a new header.

```
struct ip6_hdr {
    union {
        struct ip6_hdrctl {
            uint32_t ip6_un1_flow;      /* 24 bits of flow-ID */
            uint16_t ip6_un1_plen;      /* payload length */
            uint8_t  ip6_un1_nxt;       /* next header */
            uint8_t  ip6_un1_hlim;      /* hop limit */
        } ip6_un1;
        uint8_t ip6_un2_vfc;            /* 4 bits version, 4 bits priority */
    } ip6_ctlun;
    struct in6_addr ip6_src;            /* source address */
    struct in6_addr ip6_dst;           /* destination address */
};
```

```
#define ip6_vfc    ip6_ctlun.ip6_un2_vfc
#define ip6_flow   ip6_ctlun.ip6_un1.ip6_un1_flow
#define ip6_plen   ip6_ctlun.ip6_un1.ip6_un1_plen
#define ip6_nxt     ip6_ctlun.ip6_un1.ip6_un1_nxt
#define ip6_hlim    ip6_ctlun.ip6_un1.ip6_un1_hlim
#define ip6_hops    ip6_ctlun.ip6_un1.ip6_un1_hlim
```

2.1.1. IPv6 Next Header Values

IPv6 defines many new values for the Next Header field. The following constants are defined as a result of including `<netinet/in.h>`.

```
#define IPPROTO_HOPOPTS      0 /* IPv6 Hop-by-Hop options */
#define IPPROTO_IPV6         41 /* IPv6 header */
#define IPPROTO_ROUTING      43 /* IPv6 Routing header */
#define IPPROTO_FRAGMENT     44 /* IPv6 fragmentation header */
#define IPPROTO_ESP          50 /* encapsulating security payload */
#define IPPROTO_AH           51 /* authentication header */
#define IPPROTO_ICMPV6       58 /* ICMPv6 */
#define IPPROTO_NONE         59 /* IPv6 no next header */
#define IPPROTO_DSTOPTS      60 /* IPv6 Destination options */
```

Berkeley-derived IPv4 implementations also define `IPPROTO_IP` to be 0. This should not be a problem since `IPPROTO_IP` is used only with IPv4 sockets and `IPPROTO_HOPOPTS` only with IPv6 sockets.

2.1.2. IPv6 Extension Headers

Six extension headers are defined for IPv6. We define structures for all except the Authentication header and Encapsulating Security Payload header, both of which are beyond the scope of this document. The following structures are defined as a result of including `<netinet/ip6.h>`.

```
/* Hop-by-Hop options header */
/* XXX should we pad it to force alignment on an 8-byte boundary? */
struct ip6_hbh {
    uint8_t ip6h_nxt;      /* next header */
    uint8_t ip6h_len;      /* length in units of 8 octets */
    /* followed by options */
};

/* Destination options header */
/* XXX should we pad it to force alignment on an 8-byte boundary? */
struct ip6_dest {
    uint8_t ip6d_nxt;      /* next header */
    uint8_t ip6d_len;      /* length in units of 8 octets */
    /* followed by options */
};

/* Routing header */
struct ip6_rthdr {
```



```

uint8_t ip6r_nxt;          /* next header */
uint8_t ip6r_len;          /* length in units of 8 octets */
uint8_t ip6r_type;         /* routing type */
uint8_t ip6r_segleft;      /* segments left */
/* followed by routing type specific data */
};

/* Type 0 Routing header */
struct ip6_rthdr0 {
    uint8_t ip6r0_nxt;      /* next header */
    uint8_t ip6r0_len;      /* length in units of 8 octets */
    uint8_t ip6r0_type;     /* always zero */
    uint8_t ip6r0_segleft;  /* segments left */
    uint8_t ip6r0_reserved; /* reserved field */
    uint8_t ip6r0_slmap[3]; /* strict/loose bit map */
    struct in6_addr ip6r0_addr[1]; /* up to 23 addresses */
};

/* Fragment header */
struct ip6_frag {
    uint8_t ip6f_nxt;      /* next header */
    uint8_t ip6f_reserved; /* reserved field */
    uint16_t ip6f_offlg;   /* offset, reserved, and flag */
    uint32_t ip6f_ident;   /* identification */
};

#if BYTE_ORDER == BIG_ENDIAN
#define IP6F_OFF_MASK      0xfff8 /* mask out offset from _offlg */
#define IP6F_RESERVED_MASK 0x0006 /* reserved bits in ip6f_offlg */
#define IP6F_MORE_FRAG     0x0001 /* more-fragments flag */
#else /* BYTE_ORDER == LITTLE_ENDIAN */
#define IP6F_OFF_MASK      0xf8ff /* mask out offset from _offlg */
#define IP6F_RESERVED_MASK 0x0600 /* reserved bits in ip6f_offlg */
#define IP6F_MORE_FRAG     0x0100 /* more-fragments flag */
#endif

```

Defined constants for fields larger than 1 byte depend on the byte ordering that is used. This API assumes that the fields in the protocol headers are left in the network byte order, which is big-endian for the Internet protocols. If not, then either these constants or the fields being tested must be converted at run-time, using something like `htons()` or `htonl()`.

(Note: We show an implementation that supports both big-endian and little-endian byte ordering, assuming a hypothetical compile-time `#if` test to determine the byte ordering. The constant that we show,

BYTE_ORDER, with values of BIG_ENDIAN and LITTLE_ENDIAN, are for example purposes only. If an implementation runs on only one type of hardware it need only define the set of constants for that hardware's byte ordering.)

2.2. The icmp6_hdr Structure

The ICMPv6 header is needed by numerous IPv6 applications including Ping, Traceroute, router discovery daemons, and neighbor discovery daemons. The following structure is defined as a result of including <netinet/icmp6.h>. Note that this is a new header.

```
struct icmp6_hdr {
    uint8_t    icmp6_type;    /* type field */
    uint8_t    icmp6_code;    /* code field */
    uint16_t   icmp6_cksum;    /* checksum field */
    union {
        uint32_t icmp6_un_data32[1]; /* type-specific field */
        uint16_t icmp6_un_data16[2]; /* type-specific field */
        uint8_t  icmp6_un_data8[4];  /* type-specific field */
    } icmp6_dataun;
};

#define icmp6_data32    icmp6_dataun.icmp6_un_data32
#define icmp6_data16    icmp6_dataun.icmp6_un_data16
#define icmp6_data8     icmp6_dataun.icmp6_un_data8
#define icmp6_pptr      icmp6_data32[0] /* parameter prob */
#define icmp6_mtu        icmp6_data32[0] /* packet too big */
#define icmp6_id         icmp6_data16[0] /* echo request/reply */
#define icmp6_seq        icmp6_data16[1] /* echo request/reply */
#define icmp6_maxdelay   icmp6_data16[0] /* mcast group membership */
```

2.2.1. ICMPv6 Type and Code Values

In addition to a common structure for the ICMPv6 header, common definitions are required for the ICMPv6 type and code fields. The following constants are also defined as a result of including <netinet/icmp6.h>.

```
#define ICMP6_DST_UNREACH          1
#define ICMP6_PACKET_TOO_BIG      2
#define ICMP6_TIME_EXCEEDED       3
#define ICMP6_PARAM_PROB          4

#define ICMP6_INFOMSG_MASK        0x80 /* all informational messages */

#define ICMP6_ECHO_REQUEST        128
#define ICMP6_ECHO_REPLY          129
```

```

#define ICMP6_MEMBERSHIP_QUERY      130
#define ICMP6_MEMBERSHIP_REPORT     131
#define ICMP6_MEMBERSHIP_REDUCTION  132

#define ICMP6_DST_UNREACH_NOROUTE    0 /* no route to destination */
#define ICMP6_DST_UNREACH_ADMIN      1 /* communication with */
                                     /* destination */
                                     /* administratively */
                                     /* prohibited */
#define ICMP6_DST_UNREACH_NOTNEIGHBOR 2 /* not a neighbor */
#define ICMP6_DST_UNREACH_ADDR       3 /* address unreachable */
#define ICMP6_DST_UNREACH_NOPORT     4 /* bad port */

#define ICMP6_TIME_EXCEED_TRANSIT    0 /* Hop Limit == 0 in transit */
#define ICMP6_TIME_EXCEED_REASSEMBLY 1 /* Reassembly time out */

#define ICMP6_PARAMPROB_HEADER        0 /* erroneous header field */
#define ICMP6_PARAMPROB_NEXTHEADER   1 /* unrecognized Next Header */
#define ICMP6_PARAMPROB_OPTION        2 /* unrecognized IPv6 option */

```

The five ICMP message types defined by IPv6 neighbor discovery (133-137) are defined in the next section.

2.2.2. ICMPv6 Neighbor Discovery Type and Code Values

The following structures and definitions are defined as a result of including <netinet/icmp6.h>.

```

#define ND_ROUTER_SOLICIT      133
#define ND_ROUTER_ADVERT       134
#define ND_NEIGHBOR_SOLICIT    135
#define ND_NEIGHBOR_ADVERT     136
#define ND_REDIRECT            137

struct nd_router_solicit {      /* router solicitation */
    struct icmp6_hdr nd_rs_hdr;
    /* could be followed by options */
};

#define nd_rs_type          nd_rs_hdr.icmp6_type
#define nd_rs_code          nd_rs_hdr.icmp6_code
#define nd_rs_cksum         nd_rs_hdr.icmp6_cksum
#define nd_rs_reserved      nd_rs_hdr.icmp6_data32[0]

struct nd_router_advert {      /* router advertisement */
    struct icmp6_hdr nd_ra_hdr;
    uint32_t nd_ra_reachable; /* reachable time */
    uint32_t nd_ra_retransmit; /* retransmit timer */

```

```

    /* could be followed by options */
};

#define nd_ra_type          nd_ra_hdr.icmp6_type
#define nd_ra_code          nd_ra_hdr.icmp6_code
#define nd_ra_cksum         nd_ra_hdr.icmp6_cksum
#define nd_ra_curhoplimit   nd_ra_hdr.icmp6_data8[0]
#define nd_ra_flags_reserved nd_ra_hdr.icmp6_data8[1]
#define ND_RA_FLAG_MANAGED  0x80
#define ND_RA_FLAG_OTHER    0x40
#define nd_ra_router_lifetime nd_ra_hdr.icmp6_data16[1]

struct nd_neighbor_solicit { /* neighbor solicitation */
    struct icmp6_hdr nd_ns_hdr;
    struct in6_addr nd_ns_target; /* target address */
    /* could be followed by options */
};

#define nd_ns_type          nd_ns_hdr.icmp6_type
#define nd_ns_code          nd_ns_hdr.icmp6_code
#define nd_ns_cksum         nd_ns_hdr.icmp6_cksum
#define nd_ns_reserved      nd_ns_hdr.icmp6_data32[0]

struct nd_neighbor_advert { /* neighbor advertisement */
    struct icmp6_hdr nd_na_hdr;
    struct in6_addr nd_na_target; /* target address */
    /* could be followed by options */
};

#define nd_na_type          nd_na_hdr.icmp6_type
#define nd_na_code          nd_na_hdr.icmp6_code
#define nd_na_cksum         nd_na_hdr.icmp6_cksum
#define nd_na_flags_reserved nd_na_hdr.icmp6_data32[0]
#if BYTE_ORDER == BIG_ENDIAN
#define ND_NA_FLAG_ROUTER    0x80000000
#define ND_NA_FLAG_SOLICITED 0x40000000
#define ND_NA_FLAG_OVERRIDE 0x20000000
#else /* BYTE_ORDER == LITTLE_ENDIAN */
#define ND_NA_FLAG_ROUTER    0x00000080
#define ND_NA_FLAG_SOLICITED 0x00000040
#define ND_NA_FLAG_OVERRIDE 0x00000020
#endif

struct nd_redirect { /* redirect */
    struct icmp6_hdr nd_rd_hdr;
    struct in6_addr nd_rd_target; /* target address */
    struct in6_addr nd_rd_dst; /* destination address */
    /* could be followed by options */
};

```

```

};

#define nd_rd_type          nd_rd_hdr.icmp6_type
#define nd_rd_code          nd_rd_hdr.icmp6_code
#define nd_rd_cksum         nd_rd_hdr.icmp6_cksum
#define nd_rd_reserved      nd_rd_hdr.icmp6_data32[0]

struct nd_opt_hdr {          /* Neighbor discovery option header */
    uint8_t  nd_opt_type;
    uint8_t  nd_opt_len;      /* in units of 8 octets */
    /* followed by option specific data */
};

#define ND_OPT_SOURCE_LINKADDR      1
#define ND_OPT_TARGET_LINKADDR      2
#define ND_OPT_PREFIX_INFORMATION   3
#define ND_OPT_REDIRECTED_HEADER     4
#define ND_OPT_MTU                   5

struct nd_opt_prefix_info {    /* prefix information */
    uint8_t  nd_opt_pi_type;
    uint8_t  nd_opt_pi_len;
    uint8_t  nd_opt_pi_prefix_len;
    uint8_t  nd_opt_pi_flags_reserved;
    uint32_t nd_opt_pi_valid_time;
    uint32_t nd_opt_pi_preferred_time;
    uint32_t nd_opt_pi_reserved2;
    struct in6_addr nd_opt_pi_prefix;
};

#define ND_OPT_PI_FLAG_ONLINK      0x80
#define ND_OPT_PI_FLAG_AUTO       0x40

struct nd_opt_rd_hdr {        /* redirected header */
    uint8_t  nd_opt_rh_type;
    uint8_t  nd_opt_rh_len;
    uint16_t nd_opt_rh_reserved1;
    uint32_t nd_opt_rh_reserved2;
    /* followed by IP header and data */
};

struct nd_opt_mtu {           /* MTU option */
    uint8_t  nd_opt_mtu_type;
    uint8_t  nd_opt_mtu_len;
    uint16_t nd_opt_mtu_reserved;
    uint32_t nd_opt_mtu_mtu;
};

```

We note that the `nd_na_flags_reserved` flags have the same byte ordering problems as we discussed with `ip6f_offlg`.

2.3. Address Testing Macros

The basic API ([RFC-2133]) defines some macros for testing an IPv6 address for certain properties. This API extends those definitions with additional address testing macros, defined as a result of including `<netinet/in.h>`.

```
int  IN6_ARE_ADDR_EQUAL(const struct in6_addr *,
                        const struct in6_addr *);
```

2.4. Protocols File

Many hosts provide the file `/etc/protocols` that contains the names of the various IP protocols and their protocol number (e.g., the value of the protocol field in the IPv4 header for that protocol, such as 1 for ICMP). Some programs then call the function `getprotobyname()` to obtain the protocol value that is then specified as the third argument to the `socket()` function. For example, the Ping program contains code of the form

```
struct protoent *proto;

proto = getprotobyname("icmp");

s = socket(AF_INET, SOCK_RAW, proto->p_proto);
```

Common names are required for the new IPv6 protocols in this file, to provide portability of applications that call the `getprotoXXX()` functions.

We define the following protocol names with the values shown. These are taken from `ftp://ftp.isi.edu/in-notes/iana/assignments/protocol-numbers`.

<code>hopopt</code>	0	# hop-by-hop options for ipv6
<code>ipv6</code>	41	# ipv6
<code>ipv6-route</code>	43	# routing header for ipv6
<code>ipv6-frag</code>	44	# fragment header for ipv6
<code>esp</code>	50	# encapsulating security payload for ipv6
<code>ah</code>	51	# authentication header for ipv6
<code>ipv6-icmp</code>	58	# icmp for ipv6
<code>ipv6-nonxt</code>	59	# no next header for ipv6
<code>ipv6-opts</code>	60	# destination options for ipv6

3. IPv6 Raw Sockets

Raw sockets bypass the transport layer (TCP or UDP). With IPv4, raw sockets are used to access ICMPv4, IGMPv4, and to read and write IPv4 datagrams containing a protocol field that the kernel does not process. An example of the latter is a routing daemon for OSPF, since it uses IPv4 protocol field 89. With IPv6 raw sockets will be used for ICMPv6 and to read and write IPv6 datagrams containing a Next Header field that the kernel does not process. Examples of the latter are a routing daemon for OSPF for IPv6 and RSVP (protocol field 46).

All data sent via raw sockets **MUST** be in network byte order and all data received via raw sockets will be in network byte order. This differs from the IPv4 raw sockets, which did not specify a byte ordering and typically used the host's byte order.

Another difference from IPv4 raw sockets is that complete packets (that is, IPv6 packets with extension headers) cannot be read or written using the IPv6 raw sockets API. Instead, ancillary data objects are used to transfer the extension headers, as described later in this document. Should an application need access to the complete IPv6 packet, some other technique, such as the datalink interfaces BPF or DLPI, must be used.

All fields in the IPv6 header that an application might want to change (i.e., everything other than the version number) can be modified using ancillary data and/or socket options by the application for output. All fields in a received IPv6 header (other than the version number and Next Header fields) and all extension headers are also made available to the application as ancillary data on input. Hence there is no need for a socket option similar to the IPv4 `IP_HDRINCL` socket option.

When writing to a raw socket the kernel will automatically fragment the packet if its size exceeds the path MTU, inserting the required fragmentation headers. On input the kernel reassembles received fragments, so the reader of a raw socket never sees any fragment headers.

When we say "an ICMPv6 raw socket" we mean a socket created by calling the socket function with the three arguments `PF_INET6`, `SOCK_RAW`, and `IPPROTO_ICMPV6`.

Most IPv4 implementations give special treatment to a raw socket created with a third argument to `socket()` of `IPPROTO_RAW`, whose value is normally 255. We note that this value has no special meaning to an IPv6 raw socket (and the IANA currently reserves the value of 255

when used as a next-header field). (Note: This feature was added to IPv4 in 1988 by Van Jacobson to support traceroute, allowing a complete IP header to be passed by the application, before the `IP_HDRINCL` socket option was added.)

3.1. Checksums

The kernel will calculate and insert the ICMPv6 checksum for ICMPv6 raw sockets, since this checksum is mandatory.

For other raw IPv6 sockets (that is, for raw IPv6 sockets created with a third argument other than `IPPROTO_ICMPV6`), the application must set the new `IPV6_CHECKSUM` socket option to have the kernel (1) compute and store a checksum for output, and (2) verify the received checksum on input, discarding the packet if the checksum is in error. This option prevents applications from having to perform source address selection on the packets they send. The checksum will incorporate the IPv6 pseudo-header, defined in Section 8.1 of [RFC-1883]. This new socket option also specifies an integer offset into the user data of where the checksum is located.

```
int  offset = 2;
setsockopt(fd, IPPROTO_IPV6, IPV6_CHECKSUM, &offset, sizeof(offset));
```

By default, this socket option is disabled. Setting the offset to -1 also disables the option. By disabled we mean (1) the kernel will not calculate and store a checksum for outgoing packets, and (2) the kernel will not verify a checksum for received packets.

(Note: Since the checksum is always calculated by the kernel for an ICMPv6 socket, applications are not able to generate ICMPv6 packets with incorrect checksums (presumably for testing purposes) using this API.)

3.2. ICMPv6 Type Filtering

ICMPv4 raw sockets receive most ICMPv4 messages received by the kernel. (We say "most" and not "all" because Berkeley-derived kernels never pass echo requests, timestamp requests, or address mask requests to a raw socket. Instead these three messages are processed entirely by the kernel.) But ICMPv6 is a superset of ICMPv4, also including the functionality of IGMPv4 and ARPv4. This means that an ICMPv6 raw socket can potentially receive many more messages than would be received with an ICMPv4 raw socket: ICMP messages similar to ICMPv4, along with neighbor solicitations, neighbor advertisements, and the three group membership messages.

Most applications using an ICMPv6 raw socket care about only a small subset of the ICMPv6 message types. To transfer extraneous ICMPv6 messages from the kernel to user can incur a significant overhead. Therefore this API includes a method of filtering ICMPv6 messages by the ICMPv6 type field.

Each ICMPv6 raw socket has an associated filter whose datatype is defined as

```
struct icmp6_filter;
```

This structure, along with the macros and constants defined later in this section, are defined as a result of including the `<netinet/icmp6.h>` header.

The current filter is fetched and stored using `getsockopt()` and `setsockopt()` with a level of `IPPROTO_ICMPV6` and an option name of `ICMP6_FILTER`.

Six macros operate on an `icmp6_filter` structure:

```
void ICMP6_FILTER_SETPASSALL (struct icmp6_filter *);
void ICMP6_FILTER_SETBLOCKALL(struct icmp6_filter *);

void ICMP6_FILTER_SETPASS ( int, struct icmp6_filter *);
void ICMP6_FILTER_SETBLOCK( int, struct icmp6_filter *);

int  ICMP6_FILTER_WILLPASS (int, const struct icmp6_filter *);
int  ICMP6_FILTER_WILLBLOCK(int, const struct icmp6_filter *);
```

The first argument to the last four macros (an integer) is an ICMPv6 message type, between 0 and 255. The pointer argument to all six macros is a pointer to a filter that is modified by the first four macros examined by the last two macros.

The first two macros, `SETPASSALL` and `SETBLOCKALL`, let us specify that all ICMPv6 messages are passed to the application or that all ICMPv6 messages are blocked from being passed to the application.

The next two macros, `SETPASS` and `SETBLOCK`, let us specify that messages of a given ICMPv6 type should be passed to the application or not passed to the application (blocked).

The final two macros, `WILLPASS` and `WILLBLOCK`, return true or false depending whether the specified message type is passed to the application or blocked from being passed to the application by the filter pointed to by the second argument.

When an ICMPv6 raw socket is created, it will by default pass all ICMPv6 message types to the application.

As an example, a program that wants to receive only router advertisements could execute the following:

```
struct icmp6_filter  myfilt;

fd = socket(PF_INET6, SOCK_RAW, IPPROTO_ICMPV6);

ICMP6_FILTER_SETBLOCKALL(&myfilt);
ICMP6_FILTER_SETPASS(ND_ROUTER_ADVERT, &myfilt);
setsockopt(fd, IPPROTO_ICMPV6, ICMP6_FILTER, &myfilt, sizeof(myfilt));
```

The filter structure is declared and then initialized to block all messages types. The filter structure is then changed to allow router advertisement messages to be passed to the application and the filter is installed using `setsockopt()`.

The `icmp6_filter` structure is similar to the `fd_set` datatype used with the `select()` function in the sockets API. The `icmp6_filter` structure is an opaque datatype and the application should not care how it is implemented. All the application does with this datatype is allocate a variable of this type, pass a pointer to a variable of this type to `getsockopt()` and `setsockopt()`, and operate on a variable of this type using the six macros that we just defined.

Nevertheless, it is worth showing a simple implementation of this datatype and the six macros.

```
struct icmp6_filter {
    uint32_t  icmp6_filt[8]; /* 8*32 = 256 bits */
};

#define ICMP6_FILTER_WILLPASS(type, filterp) \
    (((filterp)->icmp6_filt[(type) >> 5]) & (1 << ((type) & 31))) != 0)
#define ICMP6_FILTER_WILLBLOCK(type, filterp) \
    (((filterp)->icmp6_filt[(type) >> 5]) & (1 << ((type) & 31))) == 0)
#define ICMP6_FILTER_SETPASS(type, filterp) \
    (((filterp)->icmp6_filt[(type) >> 5]) |= (1 << ((type) & 31)))
#define ICMP6_FILTER_SETBLOCK(type, filterp) \
    (((filterp)->icmp6_filt[(type) >> 5]) &= ~(1 << ((type) & 31)))
#define ICMP6_FILTER_SETPASSALL(filterp) \
    memset((filterp), 0xFF, sizeof(struct icmp6_filter))
#define ICMP6_FILTER_SETBLOCKALL(filterp) \
    memset((filterp), 0, sizeof(struct icmp6_filter))
```

(Note: These sample definitions have two limitations that an implementation may want to change. The first four macros evaluate their first argument two times. The second two macros require the inclusion of the `<string.h>` header for the `memset()` function.)

4. Ancillary Data

4.2BSD allowed file descriptors to be transferred between separate processes across a UNIX domain socket using the `sendmsg()` and `recvmsg()` functions. Two members of the `msghdr` structure, `msg_accrights` and `msg_accrightslen`, were used to send and receive the descriptors. When the OSI protocols were added to 4.3BSD Reno in 1990 the names of these two fields in the `msghdr` structure were changed to `msg_control` and `msg_controllen`, because they were used by the OSI protocols for "control information", although the comments in the source code call this "ancillary data".

Other than the OSI protocols, the use of ancillary data has been rare. In 4.4BSD, for example, the only use of ancillary data with IPv4 is to return the destination address of a received UDP datagram if the `IP_RECVSTADDR` socket option is set. With Unix domain sockets ancillary data is still used to send and receive descriptors.

Nevertheless the ancillary data fields of the `msghdr` structure provide a clean way to pass information in addition to the data that is being read or written. The inclusion of the `msg_control` and `msg_controllen` members of the `msghdr` structure along with the `cmsghdr` structure that is pointed to by the `msg_control` member is required by the Posix.1g sockets API standard (which should be completed during 1997).

In this document ancillary data is used to exchange the following optional information between the application and the kernel:

1. the send/receive interface and source/destination address,
2. the hop limit,
3. next hop address,
4. Hop-by-Hop options,
5. Destination options, and
6. Routing header.

Before describing these uses in detail, we review the definition of the `msghdr` structure itself, the `cmsghdr` structure that defines an ancillary data object, and some functions that operate on the ancillary data objects.

4.1. The msghdr Structure

The msghdr structure is used by the `recvmsg()` and `sendmsg()` functions. Its Posix.1g definition is:

```
struct msghdr {
    void      *msg_name;           /* ptr to socket address structure */
    socklen_t  msg_namelen;        /* size of socket address structure */
    struct iovec *msg_iov;         /* scatter/gather array */
    size_t     msg_iovlen;         /* # elements in msg_iov */
    void      *msg_control;        /* ancillary data */
    socklen_t  msg_controllen;     /* ancillary data buffer length */
    int        msg_flags;          /* flags on received message */
};
```

The structure is declared as a result of including `<sys/socket.h>`.

(Note: Before Posix.1g the two "void *" pointers were typically "char *", and the two `socklen_t` members and the `size_t` member were typically integers. Earlier drafts of Posix.1g had the two `socklen_t` members as `size_t`, but Draft 6.6 of Posix.1g, apparently the final draft, changed these to `socklen_t` to simplify binary portability for 64-bit implementations and to align Posix.1g with X/Open's Networking Services, Issue 5. The change in `msg_control` to a "void *" pointer affects any code that increments this pointer.)

Most Berkeley-derived implementations limit the amount of ancillary data in a call to `sendmsg()` to no more than 108 bytes (an mbuf). This API requires a minimum of 10240 bytes of ancillary data, but it is recommended that the amount be limited only by the buffer space reserved by the socket (which can be modified by the `SO_SNDBUF` socket option). (Note: This magic number 10240 was picked as a value that should always be large enough. 108 bytes is clearly too small as the maximum size of a Type 0 Routing header is 376 bytes.)

4.2. The cmsghdr Structure

The cmsghdr structure describes ancillary data objects transferred by `recvmsg()` and `sendmsg()`. Its Posix.1g definition is:

```
struct cmsghdr {
    socklen_t  cmsg_len;           /* #bytes, including this header */
    int        cmsg_level;         /* originating protocol */
    int        cmsg_type;          /* protocol-specific type */
    /* followed by unsigned char cmsg_data[]; */
};
```

This structure is declared as a result of including `<sys/socket.h>`.

As shown in this definition, normally there is no member with the name `cmsg_data[]`. Instead, the data portion is accessed using the `MSG_xxx()` macros, as described shortly. Nevertheless, it is common to refer to the `cmsg_data[]` member.

(Note: Before Posix.1g the `cmsg_len` member was an integer, and not a `socklen_t`. See the Note in the previous section for why `socklen_t` is used here.)

When ancillary data is sent or received, any number of ancillary data objects can be specified by the `msg_control` and `msg_controllen` members of the `msghdr` structure, because each object is preceded by a `cmsghdr` structure defining the object's length (the `cmsg_len` member). Historically Berkeley-derived implementations have passed only one object at a time, but this API allows multiple objects to be passed in a single call to `sendmsg()` or `recvmsg()`. The following example shows two ancillary data objects in a control buffer.

```

<----- msg_controllen ----->
<--- ancillary data object --->|<--- ancillary data object ----->|
<----- MSG_SPACE() ----->|<----- MSG_SPACE() ----->|
<----- cmsg_len ----->|<----- cmsg_len ----->|
<----- MSG_LEN() ----->|<----- MSG_LEN() ----->|
+-----+-----+-----+-----+-----+-----+-----+-----+
|cmsg_|cmsg_|cmsg_|XX|XX|cmsg_|cmsg_|cmsg_|XX|XX|
|len_|level|type|XX|cmsg_data[]|XX|len_|level|type|XX|cmsg_data[]|XX|
+-----+-----+-----+-----+-----+-----+-----+-----+
^
|
msg_control
points here

```

The fields shown as "XX" are possible padding, between the `cmsghdr` structure and the data, and between the data and the next `cmsghdr` structure, if required by the implementation.

4.3. Ancillary Data Object Macros

To aid in the manipulation of ancillary data objects, three macros from 4.4BSD are defined by Posix.1g: `MSG_DATA()`, `MSG_NXTHDR()`, and `MSG_FIRSTHDR()`. Before describing these macros, we show the following example of how they might be used with a call to `recvmsg()`.

```

struct msghdr msg;
struct cmsghdr *cmsgptr;

```

```

/* fill in msg */

/* call recvmsg() */

for (cmsgptr = CMSG_FIRSTHDR(&msg); cmsgptr != NULL;
    cmsgptr = CMSG_NXTHDR(&msg, cmsgptr)) {
    if (cmsgptr->cmsg_level == ... && cmsgptr->cmsg_type == ... ) {
        u_char *ptr;

        ptr = CMSG_DATA(cmsgptr);
        /* process data pointed to by ptr */
    }
}

```

We now describe the three Posix.1g macros, followed by two more that are new with this API: `CMSG_SPACE()` and `CMSG_LEN()`. All these macros are defined as a result of including `<sys/socket.h>`.

4.3.1. CMSG_FIRSTHDR

```
struct cmsghdr *CMSG_FIRSTHDR(const struct msghdr *mhdr);
```

`CMSG_FIRSTHDR()` returns a pointer to the first `cmsghdr` structure in the `msghdr` structure pointed to by `mhdr`. The macro returns `NULL` if there is no ancillary data pointed to the by `msghdr` structure (that is, if either `msg_control` is `NULL` or if `msg_controllen` is less than the size of a `cmsghdr` structure).

One possible implementation could be

```

#define CMSG_FIRSTHDR(mhdr) \
    ( (mhdr)->msg_controllen >= sizeof(struct cmsghdr) ? \
      (struct cmsghdr *) (mhdr)->msg_control : \
      (struct cmsghdr *) NULL )

```

(Note: Most existing implementations do not test the value of `msg_controllen`, and just return the value of `msg_control`. The value of `msg_controllen` must be tested, because if the application asks `recvmsg()` to return ancillary data, by setting `msg_control` to point to the application's buffer and setting `msg_controllen` to the length of this buffer, the kernel indicates that no ancillary data is available by setting `msg_controllen` to 0 on return. It is also easier to put this test into this macro, than making the application perform the test.)

4.3.2. CMSG_NXTHDR

```
struct cmsghdr *CMSG_NXTHDR(const struct msghdr *mhdr,
                             const struct cmsghdr *cmsg);
```

CMSG_NXTHDR() returns a pointer to the cmsghdr structure describing the next ancillary data object. mhdr is a pointer to a msghdr structure and cmsg is a pointer to a cmsghdr structure. If there is not another ancillary data object, the return value is NULL.

The following behavior of this macro is new to this API: if the value of the cmsg pointer is NULL, a pointer to the cmsghdr structure describing the first ancillary data object is returned. That is, CMSG_NXTHDR(mhdr, NULL) is equivalent to CMSG_FIRSTHDR(mhdr). If there are no ancillary data objects, the return value is NULL. This provides an alternative way of coding the processing loop shown earlier:

```
struct msghdr msg;
struct cmsghdr *cmsgptr = NULL;

/* fill in msg */

/* call recvmsg() */

while ((cmsgptr = CMSG_NXTHDR(&msg, cmsgptr)) != NULL) {
    if (cmsgptr->cmsg_level == ... && cmsgptr->cmsg_type == ... ) {
        u_char *ptr;

        ptr = CMSG_DATA(cmsgptr);
        /* process data pointed to by ptr */
    }
}
```

One possible implementation could be:

```
#define CMSG_NXTHDR(mhdr, cmsg) \
    ( ((cmsg) == NULL) ? CMSG_FIRSTHDR(mhdr) : \
      (((u_char *) (cmsg) + ALIGN((cmsg)->cmsg_len) \
        + ALIGN(sizeof(struct cmsghdr)) > \
        (u_char *) ((mhdr)->msg_control) + (mhdr)->msg_controllen) ? \
        (struct cmsghdr *) NULL : \
        (struct cmsghdr *) ((u_char *) (cmsg) + ALIGN((cmsg)->cmsg_len))) )
```

The macro ALIGN(), which is implementation dependent, rounds its argument up to the next even multiple of whatever alignment is required (probably a multiple of 4 or 8 bytes).

4.3.3. CMSG_DATA

```
unsigned char *CMSG_DATA(const struct cmsghdr *cmsg);
```

CMSG_DATA() returns a pointer to the data (what is called the `cmsg_data[]` member, even though such a member is not defined in the structure) following a `cmsghdr` structure.

One possible implementation could be:

```
#define CMSG_DATA(cmsg) ( (u_char *) (cmsg) + \
                          ALIGN(sizeof(struct cmsghdr)) )
```

4.3.4. CMSG_SPACE

```
unsigned int CMSG_SPACE(unsigned int length);
```

This macro is new with this API. Given the length of an ancillary data object, CMSG_SPACE() returns the space required by the object and its `cmsghdr` structure, including any padding needed to satisfy alignment requirements. This macro can be used, for example, to allocate space dynamically for the ancillary data. This macro should not be used to initialize the `cmsg_len` member of a `cmsghdr` structure; instead use the CMSG_LEN() macro.

One possible implementation could be:

```
#define CMSG_SPACE(length) ( ALIGN(sizeof(struct cmsghdr)) + \
                             ALIGN(length) )
```

4.3.5. CMSG_LEN

```
unsigned int CMSG_LEN(unsigned int length);
```

This macro is new with this API. Given the length of an ancillary data object, CMSG_LEN() returns the value to store in the `cmsg_len` member of the `cmsghdr` structure, taking into account any padding needed to satisfy alignment requirements.

One possible implementation could be:

```
#define CMSG_LEN(length) ( ALIGN(sizeof(struct cmsghdr)) + length
                           )
```


Note the difference between `CMSG_SPACE()` and `CMSG_LEN()`, shown also in the figure in Section 4.2: the former accounts for any required padding at the end of the ancillary data object and the latter is the actual length to store in the `cmsg_len` member of the ancillary data object.

4.4. Summary of Options Described Using Ancillary Data

There are six types of optional information described in this document that are passed between the application and the kernel using ancillary data:

1. the send/receive interface and source/destination address,
2. the hop limit,
3. next hop address,
4. Hop-by-Hop options,
5. Destination options, and
6. Routing header.

First, to receive any of this optional information (other than the next hop address, which can only be set), the application must call `setsockopt()` to turn on the corresponding flag:

```
int on = 1;

setsockopt(fd, IPPROTO_IPV6, IPV6_PKTINFO, &on, sizeof(on));
setsockopt(fd, IPPROTO_IPV6, IPV6_HOPLIMIT, &on, sizeof(on));
setsockopt(fd, IPPROTO_IPV6, IPV6_HOPOPTS, &on, sizeof(on));
setsockopt(fd, IPPROTO_IPV6, IPV6_DSTOPTS, &on, sizeof(on));
setsockopt(fd, IPPROTO_IPV6, IPV6_RTHDR, &on, sizeof(on));
```

When any of these options are enabled, the corresponding data is returned as control information by `recvmsg()`, as one or more ancillary data objects.

Nothing special need be done to send any of this optional information; the application just calls `sendmsg()` and specifies one or more ancillary data objects as control information.

We also summarize the three `cmsg_hdr` fields that describe the ancillary data objects:

<u>cmsg_level</u>	<u>cmsg_type</u>	<u>cmsg_data[]</u>	<u>#times</u>
IPPROTO_IPV6	IPV6_PKTINFO	in6_pktinfo structure	once
IPPROTO_IPV6	IPV6_HOPLIMIT	int	once
IPPROTO_IPV6	IPV6_NEXTHOP	socket address structure	once
IPPROTO_IPV6	IPV6_HOPOPTS	implementation dependent	mult.

IPPROTO_IPV6	IPV6_DSTOPTS	implementation dependent	mult.
IPPROTO_IPV6	IPV6_RTHDR	implementation dependent	once

The final column indicates how many times an ancillary data object of that type can appear as control information. The Hop-by-Hop and Destination options can appear multiple times, while all the others can appear only one time.

All these options are described in detail in following sections. All the constants beginning with `IPV6_` are defined as a result of including the `<netinet/in.h>` header.

(Note: We intentionally use the same constant for the `cmsg_level` member as is used as the second argument to `getsockopt()` and `setsockopt()` (what is called the "level"), and the same constant for the `cmsg_type` member as is used as the third argument to `getsockopt()` and `setsockopt()` (what is called the "option name"). This is consistent with the existing use of ancillary data in 4.4BSD: returning the destination address of an IPv4 datagram.)

(Note: It is up to the implementation what it passes as ancillary data for the Hop-by-Hop option, Destination option, and Routing header option, since the API to these features is through a set of `inet6_option_XXX()` and `inet6_rthdr_XXX()` functions that we define later. These functions serve two purposes: to simplify the interface to these features (instead of requiring the application to know the intimate details of the extension header formats), and to hide the actual implementation from the application. Nevertheless, we show some examples of these features that store the actual extension header as the ancillary data. Implementations need not use this technique.)

4.5. IPV6_PKTOPTIONS Socket Option

The summary in the previous section assumes a UDP socket. Sending and receiving ancillary data is easy with UDP: the application calls `sendmsg()` and `recvmsg()` instead of `sendto()` and `recvfrom()`.

But there might be cases where a TCP application wants to send or receive this optional information. For example, a TCP client might want to specify a Routing header and this needs to be done before calling `connect()`. Similarly a TCP server might want to know the received interface after `accept()` returns along with any Destination options.

A new socket option is defined that provides access to the optional information described in the previous section, but without using `recvmsg()` and `sendmsg()`. Setting the socket option specifies any of the optional output fields:

```
setsockopt(fd, IPPROTO_IPV6, IPV6_PKTOPTIONS, &buf, len);
```

The fourth argument points to a buffer containing one or more ancillary data objects, and the fifth argument is the total length of all these objects. The application fills in this buffer exactly as if the buffer were being passed to `sendmsg()` as control information.

The options set by calling `setsockopt()` for `IPV6_PKTOPTIONS` are called "sticky" options because once set they apply to all packets sent on that socket. The application can call `setsockopt()` again to change all the sticky options, or it can call `setsockopt()` with a length of 0 to remove all the sticky options for the socket.

The corresponding receive option

```
getsockopt(fd, IPPROTO_IPV6, IPV6_PKTOPTIONS, &buf, &len);
```

returns a buffer with one or more ancillary data objects for all the optional receive information that the application has previously specified that it wants to receive. The fourth argument points to the buffer that is filled in by the call. The fifth argument is a pointer to a value-result integer: when the function is called the integer specifies the size of the buffer pointed to by the fourth argument, and on return this integer contains the actual number of bytes that were returned. The application processes this buffer exactly as if the buffer were returned by `recvmsg()` as control information.

To simplify this document, in the remaining sections when we say "can be specified as ancillary data to `sendmsg()`" we mean "can be specified as ancillary data to `sendmsg()` or specified as a sticky option using `setsockopt()` and the `IPV6_PKTOPTIONS` socket option". Similarly when we say "can be returned as ancillary data by `recvmsg()`" we mean "can be returned as ancillary data by `recvmsg()` or returned by `getsockopt()` with the `IPV6_PKTOPTIONS` socket option".

4.5.1. TCP Sticky Options

When using `getsockopt()` with the `IPV6_PKTOPTIONS` option and a TCP socket, only the options from the most recently received segment are retained and returned to the caller, and only after the socket option has been set. That is, TCP need not start saving a copy of the options until the application says to do so.

The application is not allowed to specify ancillary data in a call to `sendmsg()` on a TCP socket, and none of the ancillary data that we describe in this document is ever returned as control information by `recvmsg()` on a TCP socket.

4.5.2. UDP and Raw Socket Sticky Options

The `IPV6_PKTOPTIONS` socket option can also be used with a UDP socket or with a raw IPv6 socket, normally to set some of the options once, instead of with each call to `sendmsg()`.

Unlike the TCP case, the sticky options can be overridden on a per-packet basis with ancillary data specified in a call to `sendmsg()` on a UDP or raw IPv6 socket. If any ancillary data is specified in a call to `sendmsg()`, none of the sticky options are sent with that datagram.

5. Packet Information

There are four pieces of information that an application can specify for an outgoing packet using ancillary data:

1. the source IPv6 address,
2. the outgoing interface index,
3. the outgoing hop limit, and
4. the next hop address.

Three similar pieces of information can be returned for a received packet as ancillary data:

1. the destination IPv6 address,
2. the arriving interface index, and
3. the arriving hop limit.

The first two pieces of information are contained in an `in6_pktinfo` structure that is sent as ancillary data with `sendmsg()` and received as ancillary data with `recvmsg()`. This structure is defined as a result of including the `<netinet/in.h>` header.

```
struct in6_pktinfo {
    struct in6_addr ipi6_addr;    /* src/dst IPv6 address */
    unsigned int    ipi6_ifindex; /* send/recv interface index */
};
```

In the `cmsghdr` structure containing this ancillary data, the `msg_level` member will be `IPPROTO_IPV6`, the `msg_type` member will be `IPV6_PKTINFO`, and the first byte of `msg_data[]` will be the first byte of the `in6_pktinfo` structure.

This information is returned as ancillary data by `recvmsg()` only if the application has enabled the `IPV6_PKTINFO` socket option:

```
int on = 1;
setsockopt(fd, IPPROTO_IPV6, IPV6_PKTINFO, &on, sizeof(on));
```

Nothing special need be done to send this information: just specify the control information as ancillary data for `sendmsg()`.

(Note: The hop limit is not contained in the `in6_pktinfo` structure for the following reason. Some UDP servers want to respond to client requests by sending their reply out the same interface on which the request was received and with the source IPv6 address of the reply equal to the destination IPv6 address of the request. To do this the application can enable just the `IPV6_PKTINFO` socket option and then use the received control information from `recvmsg()` as the outgoing control information for `sendmsg()`. The application need not examine or modify the `in6_pktinfo` structure at all. But if the hop limit were contained in this structure, the application would have to parse the received control information and change the hop limit member, since the received hop limit is not the desired value for an outgoing packet.)

5.1. Specifying/Receiving the Interface

Interfaces on an IPv6 node are identified by a small positive integer, as described in Section 4 of [RFC-2133]. That document also describes a function to map an interface name to its interface index, a function to map an interface index to its interface name, and a function to return all the interface names and indexes. Notice from this document that no interface is ever assigned an index of 0.

When specifying the outgoing interface, if the `ipi6_ifindex` value is 0, the kernel will choose the outgoing interface. If the application specifies an outgoing interface for a multicast packet, the interface specified by the ancillary data overrides any interface specified by the `IPV6_MULTICAST_IF` socket option (described in [RFC-2133]), for that call to `sendmsg()` only.

When the `IPV6_PKTINFO` socket option is enabled, the received interface index is always returned as the `ipi6_ifindex` member of the `in6_pktinfo` structure.

5.2. Specifying/Receiving Source/Destination Address

The source IPv6 address can be specified by calling `bind()` before each output operation, but supplying the source address together with the data requires less overhead (i.e., fewer system calls) and

requires less state to be stored and protected in a multithreaded application.

When specifying the source IPv6 address as ancillary data, if the `ipi6_addr` member of the `in6_pktinfo` structure is the unspecified address (`IN6ADDR_ANY_INIT`), then (a) if an address is currently bound to the socket, it is used as the source address, or (b) if no address is currently bound to the socket, the kernel will choose the source address. If the `ipi6_addr` member is not the unspecified address, but the socket has already bound a source address, then the `ipi6_addr` value overrides the already-bound source address for this output operation only.

The kernel must verify that the requested source address is indeed a unicast address assigned to the node.

When the `in6_pktinfo` structure is returned as ancillary data by `recvmsg()`, the `ipi6_addr` member contains the destination IPv6 address from the received packet.

5.3. Specifying/Receiving the Hop Limit

The outgoing hop limit is normally specified with either the `IPV6_UNICAST_HOPS` socket option or the `IPV6_MULTICAST_HOPS` socket option, both of which are described in [RFC-2133]. Specifying the hop limit as ancillary data lets the application override either the kernel's default or a previously specified value, for either a unicast destination or a multicast destination, for a single output operation. Returning the received hop limit is useful for programs such as Traceroute and for IPv6 applications that need to verify that the received hop limit is 255 (e.g., that the packet has not been forwarded).

The received hop limit is returned as ancillary data by `recvmsg()` only if the application has enabled the `IPV6_HOPLIMIT` socket option:

```
int  on = 1;
setsockopt(fd, IPPROTO_IPV6, IPV6_HOPLIMIT, &on, sizeof(on));
```

In the `cmsg_hdr` structure containing this ancillary data, the `cmsg_level` member will be `IPPROTO_IPV6`, the `cmsg_type` member will be `IPV6_HOPLIMIT`, and the first byte of `cmsg_data[]` will be the first byte of the integer hop limit.

Nothing special need be done to specify the outgoing hop limit: just specify the control information as ancillary data for `sendmsg()`. As specified in [RFC-2133], the interpretation of the integer hop limit value is

```

x < -1:      return an error of EINVAL
x == -1:     use kernel default
0 <= x <= 255: use x
x >= 256:    return an error of EINVAL

```

5.4. Specifying the Next Hop Address

The IPV6_NEXTHOP ancillary data object specifies the next hop for the datagram as a socket address structure. In the cmsghdr structure containing this ancillary data, the cmsgh_level member will be IPPROTO_IPV6, the cmsgh_type member will be IPV6_NEXTHOP, and the first byte of cmsgh_data[] will be the first byte of the socket address structure.

This is a privileged option. (Note: It is implementation defined and beyond the scope of this document to define what "privileged" means. Unix systems use this term to mean the process must have an effective user ID of 0.)

If the socket address structure contains an IPv6 address (e.g., the sin6_family member is AF_INET6), then the node identified by that address must be a neighbor of the sending host. If that address equals the destination IPv6 address of the datagram, then this is equivalent to the existing SO_DONTROUTE socket option.

5.5. Additional Errors with sendmsg()

With the IPV6_PKTINFO socket option there are no additional errors possible with the call to recvmsg(). But when specifying the outgoing interface or the source address, additional errors are possible from sendmsg(). The following are examples, but some of these may not be provided by some implementations, and some implementations may define additional errors:

ENXIO	The interface specified by ipi6_ifindex does not exist.
ENETDOWN	The interface specified by ipi6_ifindex is not enabled for IPv6 use.
EADDRNOTAVAIL	ipi6_ifindex specifies an interface but the address ipi6_addr is not available for use on that interface.
EHOSTUNREACH	No route to the destination exists over the interface specified by ifi6_ifindex.

6. Hop-By-Hop Options

A variable number of Hop-by-Hop options can appear in a single Hop-by-Hop options header. Each option in the header is TLV-encoded with a type, length, and value.

Today only three Hop-by-Hop options are defined for IPv6 [RFC-1883]: Jumbo Payload, Pad1, and PadN, although a proposal exists for a router-alert Hop-by-Hop option. The Jumbo Payload option should not be passed back to an application and an application should receive an error if it attempts to set it. This option is processed entirely by the kernel. It is indirectly specified by datagram-based applications as the size of the datagram to send and indirectly passed back to these applications as the length of the received datagram. The two pad options are for alignment purposes and are automatically inserted by a sending kernel when needed and ignored by

the receiving kernel. This section of the API is therefore defined for future Hop-by-Hop options that an application may need to specify and receive.

Individual Hop-by-Hop options (and Destination options, which are described shortly, and which are similar to the Hop-by-Hop options) may have specific alignment requirements. For example, the 4-byte Jumbo Payload length should appear on a 4-byte boundary, and IPv6 addresses are normally aligned on an 8-byte boundary. These requirements and the terminology used with these options are discussed in Section 4.2 and Appendix A of [RFC-1883]. The alignment of each option is specified by two values, called x and y , written as " $xn + y$ ". This states that the option must appear at an integer multiple of x bytes from the beginning of the options header (x can have the values 1, 2, 4, or 8), plus y bytes (y can have a value between 0 and 7, inclusive). The Pad1 and PadN options are inserted as needed to maintain the required alignment. Whatever code builds either a Hop-by-Hop options header or a Destination options header must know the values of x and y for each option.

Multiple Hop-by-Hop options can be specified by the application. Normally one ancillary data object describes all the Hop-by-Hop options (since each option is itself TLV-encoded) but the application can specify multiple ancillary data objects for the Hop-by-Hop options, each object specifying one or more options. Care must be taken designing the API for these options since

1. it may be possible for some future Hop-by-Hop options to be generated by the application and processed entirely by the application (e.g., the kernel may not know the alignment restrictions for the option),

2. it must be possible for the kernel to insert its own Hop-by-Hop options in an outgoing packet (e.g., the Jumbo Payload option),
3. the application can place one or more Hop-by-Hop options into a single ancillary data object,
4. if the application specifies multiple ancillary data objects, each containing one or more Hop-by-Hop options, the kernel must combine these a single Hop-by-Hop options header, and
5. it must be possible for the kernel to remove some Hop-by-Hop options from a received packet before returning the remaining Hop-by-Hop options to the application. (This removal might consist of the kernel converting the option into a pad option of the same length.)

Finally, we note that access to some Hop-by-Hop options or to some Destination options, might require special privilege. That is, normal applications (without special privilege) might be forbidden from setting certain options in outgoing packets, and might never see certain options in received packets.

6.1. Receiving Hop-by-Hop Options

To receive Hop-by-Hop options the application must enable the `IPV6_HOPOPTS` socket option:

```
int on = 1;
setsockopt(fd, IPPROTO_IPV6, IPV6_HOPOPTS, &on, sizeof(on));
```

All the Hop-by-Hop options are returned as one ancillary data object described by a `cmsg_hdr` structure. The `cmsg_level` member will be `IPPROTO_IPV6` and the `cmsg_type` member will be `IPV6_HOPOPTS`. These options are then processed by calling the `inet6_option_next()` and `inet6_option_find()` functions, described shortly.

6.2. Sending Hop-by-Hop Options

To send one or more Hop-by-Hop options, the application just specifies them as ancillary data in a call to `sendmsg()`. No socket option need be set.

Normally all the Hop-by-Hop options are specified by a single ancillary data object. Multiple ancillary data objects, each containing one or more Hop-by-Hop options, can also be specified, in which case the kernel will combine all the Hop-by-Hop options into a single Hop-by-Hop extension header. But it should be more efficient to use a single ancillary data object to describe all the Hop-by-Hop

options. The `cmsg_level` member is set to `IPPROTO_IPV6` and the `cmsg_type` member is set to `IPV6_HOPOPTS`. The option is normally constructed using the `inet6_option_init()`, `inet6_option_append()`, and `inet6_option_alloc()` functions, described shortly.

Additional errors may be possible from `sendmsg()` if the specified option is in error.

6.3. Hop-by-Hop and Destination Options Processing

Building and parsing the Hop-by-Hop and Destination options is complicated for the reasons given earlier. We therefore define a set of functions to help the application. The function prototypes for these functions are all in the `<netinet/in.h>` header.

6.3.1. `inet6_option_space`

```
int inet6_option_space(int nbytes);
```

This function returns the number of bytes required to hold an option when it is stored as ancillary data, including the `cmsghdr` structure at the beginning, and any padding at the end (to make its size a multiple of 8 bytes). The argument is the size of the structure defining the option, which must include any pad bytes at the beginning (the value `y` in the alignment term "`xn + y`"), the type byte, the length byte, and the option data.

(Note: If multiple options are stored in a single ancillary data object, which is the recommended technique, this function overestimates the amount of space required by the size of `N-1` `cmsghdr` structures, where `N` is the number of options to be stored in the object. This is of little consequence, since it is assumed that most Hop-by-Hop option headers and Destination option headers carry only one option (p. 33 of [RFC-1883]).)

6.3.2. `inet6_option_init`

```
int inet6_option_init(void *bp, struct cmsghdr **cmsgpp, int type);
```

This function is called once per ancillary data object that will contain either Hop-by-Hop or Destination options. It returns 0 on success or -1 on an error.

`bp` is a pointer to previously allocated space that will contain the ancillary data object. It must be large enough to contain all the individual options to be added by later calls to `inet6_option_append()` and `inet6_option_alloc()`.

`cmsg` is a pointer to a pointer to a `cmsghdr` structure. `*cmsg` is initialized by this function to point to the `cmsghdr` structure constructed by this function in the buffer pointed to by `bp`.

type is either `IPV6_HOPOPTS` or `IPV6_DSTOPTS`. This type is stored in the `cmsg_type` member of the `cmsghdr` structure pointed to by `*cmsg`.

6.3.3. `inet6_option_append`

```
int inet6_option_append(struct cmsghdr *cmsg, const uint8_t *typep,
                       int multx, int plusy);
```

This function appends a Hop-by-Hop option or a Destination option into an ancillary data object that has been initialized by `inet6_option_init()`. This function returns 0 if it succeeds or -1 on an error.

`cmsg` is a pointer to the `cmsghdr` structure that must have been initialized by `inet6_option_init()`.

`typep` is a pointer to the 8-bit option type. It is assumed that this field is immediately followed by the 8-bit option data length field, which is then followed immediately by the option data. The caller initializes these three fields (the type-length-value, or TLV) before calling this function.

The option type must have a value from 2 to 255, inclusive. (0 and 1 are reserved for the `Pad1` and `PadN` options, respectively.)

The option data length must have a value between 0 and 255, inclusive, and is the length of the option data that follows.

`multx` is the value `x` in the alignment term "`xn + y`" described earlier. It must have a value of 1, 2, 4, or 8.

`plusy` is the value `y` in the alignment term "`xn + y`" described earlier. It must have a value between 0 and 7, inclusive.

6.3.4. `inet6_option_alloc`

```
uint8_t *inet6_option_alloc(struct cmsghdr *cmsg, int datalen,
                             int multx, int plusy);
```

This function appends a Hop-by-Hop option or a Destination option into an ancillary data object that has been initialized by `inet6_option_init()`. This function returns a pointer to the 8-bit option type field that starts the option on success, or NULL on an error.

The difference between this function and `inet6_option_append()` is that the latter copies the contents of a previously built option into the ancillary data object while the current function returns a pointer to the space in the data object where the option's TLV must then be built by the caller.

`cmsg` is a pointer to the `cmsghdr` structure that must have been initialized by `inet6_option_init()`.

`datalen` is the value of the option data length byte for this option. This value is required as an argument to allow the function to determine if padding must be appended at the end of the option. (The `inet6_option_append()` function does not need a data length argument since the option data length must already be stored by the caller.)

`multx` is the value `x` in the alignment term "`xn + y`" described earlier. It must have a value of 1, 2, 4, or 8.

`plusy` is the value `y` in the alignment term "`xn + y`" described earlier. It must have a value between 0 and 7, inclusive.

6.3.5. `inet6_option_next`

```
int inet6_option_next(const struct cmsghdr *cmsg, uint8_t
**tptrp);
```

This function processes the next Hop-by-Hop option or Destination option in an ancillary data object. If another option remains to be processed, the return value of the function is 0 and `*tptrp` points to the 8-bit option type field (which is followed by the 8-bit option data length, followed by the option data). If no more options remain to be processed, the return value is -1 and `*tptrp` is NULL. If an error occurs, the return value is -1 and `*tptrp` is not NULL.

`cmsg` is a pointer to `cmsghdr` structure of which `cmsg_level` equals `IPPROTO_IPV6` and `cmsg_type` equals either `IPV6_HOPOPTS` or `IPV6_DSTOPTS`.

`tptrp` is a pointer to a pointer to an 8-bit byte and `*tptrp` is used by the function to remember its place in the ancillary data object each time the function is called. The first time this function is called for a given ancillary data object, `*tptrp` must be set to NULL.

Each time this function returns success, **tptrp* points to the 8-bit option type field for the next option to be processed.

6.3.6. `inet6_option_find`

```
int inet6_option_find(const struct cmsghdr *cmsg, uint8_t *tptrp,
                    int type);
```

This function is similar to the previously described `inet6_option_next()` function, except this function lets the caller specify the option type to be searched for, instead of always returning the next option in the ancillary data object. *cmsg* is a pointer to `cmsghdr` structure of which `cmsg_level` equals `IPPROTO_IPV6` and `cmsg_type` equals either `IPV6_HOPOPTS` or `IPV6_DSTOPTS`.

tptrp is a pointer to a pointer to an 8-bit byte and **tptrp* is used by the function to remember its place in the ancillary data object each time the function is called. The first time this function is called for a given ancillary data object, **tptrp* must be set to `NULL`.

This function starts searching for an option of the specified type beginning after the value of **tptrp*. If an option of the specified type is located, this function returns 0 and **tptrp* points to the 8-bit option type field for the option of the specified type. If an option of the specified type is not located, the return value is -1 and **tptrp* is `NULL`. If an error occurs, the return value is -1 and **tptrp* is not `NULL`.

6.3.7. Options Examples

We now provide an example that builds two Hop-by-Hop options. First we define two options, called X and Y, taken from the example in Appendix A of [RFC-1883]. We assume that all options will have structure definitions similar to what is shown below.

```
/* option X and option Y are defined in [RFC-1883], pp. 33-34 */
#define IP6_X_OPT_TYPE      X    /* replace X with assigned value */
#define IP6_X_OPT_LEN      12
#define IP6_X_OPT_MULTX    8    /* 8n + 2 alignment */
#define IP6_X_OPT_OFFSETY  2

struct ip6_X_opt {
    uint8_t    ip6_X_opt_pad[IP6_X_OPT_OFFSETY];
    uint8_t    ip6_X_opt_type;
    uint8_t    ip6_X_opt_len;
    uint32_t   ip6_X_opt_val1;
    uint64_t   ip6_X_opt_val2;
};
```

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```

#define IP6_Y_OPT_TYPE      Y    /* replace Y with assigned value */
#define IP6_Y_OPT_LEN      7
#define IP6_Y_OPT_MULTX    4    /* 4n + 3 alignment */
#define IP6_Y_OPT_OFFSETY  3

struct ip6_Y_opt {
    uint8_t    ip6_Y_opt_pad[IP6_Y_OPT_OFFSETY];
    uint8_t    ip6_Y_opt_type;
    uint8_t    ip6_Y_opt_len;
    uint8_t    ip6_Y_opt_val1;
    uint16_t   ip6_Y_opt_val2;
    uint32_t   ip6_Y_opt_val3;
};

```

We now show the code fragment to build one ancillary data object containing both options.

```

struct msghdr  msg;
struct cmsghdr *cmsgptr;
struct ip6_X_opt  optX;
struct ip6_Y_opt  optY;

msg.msg_control = malloc(inet6_option_space(sizeof(optX) +
                                             sizeof(optY)));

inet6_option_init(msg.msg_control, &cmsgptr, IPV6_HOPOPTS);

optX.ip6_X_opt_type = IP6_X_OPT_TYPE;
optX.ip6_X_opt_len  = IP6_X_OPT_LEN;
optX.ip6_X_opt_val1 = <32-bit value>;
optX.ip6_X_opt_val2 = <64-bit value>;
inet6_option_append(cmsgptr, &optX.ip6_X_opt_type,
                    IP6_X_OPT_MULTX, IP6_X_OPT_OFFSETY);

optY.ip6_Y_opt_type = IP6_Y_OPT_TYPE;
optY.ip6_Y_opt_len  = IP6_Y_OPT_LEN;
optY.ip6_Y_opt_val1 = <8-bit value>;
optY.ip6_Y_opt_val2 = <16-bit value>;
optY.ip6_Y_opt_val3 = <32-bit value>;
inet6_option_append(cmsgptr, &optY.ip6_Y_opt_type,
                    IP6_Y_OPT_MULTX, IP6_Y_OPT_OFFSETY);

msg.msg_controllen = cmsgptr->cmsg_len;

```

The call to `inet6_option_init()` builds the `cmsghdr` structure in the control buffer.

```

+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|      msg_len = MSG_LEN(0) = 12      |
+-----+-----+-----+-----+-----+-----+-----+-----+
|      msg_level = IPPROTO_IPV6      |
+-----+-----+-----+-----+-----+-----+-----+-----+
|      msg_type = IPV6_HOPOPTS      |
+-----+-----+-----+-----+-----+-----+-----+-----+

```

Here we assume a 32-bit architecture where `sizeof(struct cmsghdr)` equals 12, with a desired alignment of 4-byte boundaries (that is, the `ALIGN()` macro shown in the sample implementations of the `MSGG_xxx()` macros rounds up to a multiple of 4).

The first call to `inet6_option_append()` appends the X option. Since this is the first option in the ancillary data object, 2 bytes are allocated for the Next Header byte and for the Hdr Ext Len byte. The former will be set by the kernel, depending on the type of header that follows this header, and the latter byte is set to 1. These 2 bytes form the 2 bytes of padding (`IP6_X_OPT_OFFSETY`) required at the beginning of this option.

```

+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|      msg_len = 28      |
+-----+-----+-----+-----+-----+-----+-----+-----+
|      msg_level = IPPROTO_IPV6      |
+-----+-----+-----+-----+-----+-----+-----+-----+
|      msg_type = IPV6_HOPOPTS      |
+-----+-----+-----+-----+-----+-----+-----+-----+
| Next Header | Hdr Ext Len=1 | Option Type=X | Opt Data Len=12 |
+-----+-----+-----+-----+-----+-----+-----+-----+
|                                     4-octet field                                     |
+-----+-----+-----+-----+-----+-----+-----+-----+
|                                     8-octet field                                     |
+-----+-----+-----+-----+-----+-----+-----+-----+

```

The `msg_len` member of the `cmsghdr` structure is incremented by 16, the size of the option.

The next call to `inet6_option_append()` appends the Y option to the ancillary data object.

```

+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsg_len = 44      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsg_level = IPPROTO_IPV6      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsg_type = IPV6_HOPOPTS      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|  Next Header  | Hdr Ext Len=3 | Option Type=X |Opt Data Len=12|
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|                                     4-octet field      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|                                     8-octet field      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
| PadN Option=1 |Opt Data Len=1 |          0          | Option Type=Y |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|Opt Data Len=7 | 1-octet field |          2-octet field      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|                                     4-octet field      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
| PadN Option=1 |Opt Data Len=2 |          0          |          0          |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+

```

16 bytes are appended by this function, so `cmsg_len` becomes 44. The `inet6_option_append()` function notices that the appended data requires 4 bytes of padding at the end, to make the size of the ancillary data object a multiple of 8, and appends the `PadN` option before returning. The `Hdr Ext Len` byte is incremented by 2 to become 3.

Alternately, the application could build two ancillary data objects, one per option, although this will probably be less efficient than combining the two options into a single ancillary data object (as just shown). The kernel must combine these into a single Hop-by-Hop extension header in the final IPv6 packet.

```

struct msghdr  msg;
struct cmsghdr *cmsgptr;
struct ip6_X_opt  optX;
struct ip6_Y_opt  optY;

msg.msg_control = malloc(inet6_option_space(sizeof(optX)) +
                        inet6_option_space(sizeof(optY)));

inet6_option_init(msg.msg_control, &cmsgptr, IPPROTO_HOPOPTS);

optX.ip6_X_opt_type = IP6_X_OPT_TYPE;

```



```
optX.ip6_X_opt_len  = IP6_X_OPT_LEN;
optX.ip6_X_opt_val1 = <32-bit value>;
optX.ip6_X_opt_val2 = <64-bit value>;
inet6_option_append(cmsgptr, &optX.ip6_X_opt_type,
                    IP6_X_OPT_MULTX, IP6_X_OPT_OFFSETY);
msg.msg_controllen = CMSG_SPACE(sizeof(optX));

inet6_option_init((u_char *)msg.msg_control + msg.msg_controllen,
                  &cmsgptr, IPPROTO_HOPOPTS);

optY.ip6_Y_opt_type = IP6_Y_OPT_TYPE;
optY.ip6_Y_opt_len  = IP6_Y_OPT_LEN;
optY.ip6_Y_opt_val1 = <8-bit value>;
optY.ip6_Y_opt_val2 = <16-bit value>;
optY.ip6_Y_opt_val3 = <32-bit value>;
inet6_option_append(cmsgptr, &optY.ip6_Y_opt_type,
                    IP6_Y_OPT_MULTX, IP6_Y_OPT_OFFSETY);
msg.msg_controllen += cmsgptr->cmsg_len;
```

Each call to `inet6_option_init()` builds a new `cmsg_hdr` structure, and the final result looks like the following:

```

+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsg_len = 28      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsg_level = IPPROTO_IPV6      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsg_type = IPV6_HOPOPTS      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|  Next Header  | Hdr Ext Len=1 | Option Type=X | Opt Data Len=12 |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|                                     4-octet field                                     |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|                                     8-octet field                                     |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsg_len = 28      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsg_level = IPPROTO_IPV6      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsg_type = IPV6_HOPOPTS      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|  Next Header  | Hdr Ext Len=1 | Pad1 Option=0 | Option Type=Y |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
| Opt Data Len=7 | 1-octet field |           2-octet field           |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|                                     4-octet field                                     |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
| PadN Option=1 | Opt Data Len=2 |           0           |           0           |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+

```

When the kernel combines these two options into a single Hop-by-Hop extension header, the first 3 bytes of the second ancillary data object (the Next Header byte, the Hdr Ext Len byte, and the Pad1 option) will be combined into a PadN option occupying 3 bytes.

The following code fragment is a redo of the first example shown (building two options in a single ancillary data object) but this time we use `inet6_option_alloc()`.

```

uint8_t  *typep;
struct msghdr  msg;
struct cmsghdr *cmsgptr;
struct ip6_X_opt  *optXp; /* now a pointer, not a struct */
struct ip6_Y_opt  *optYp; /* now a pointer, not a struct */

msg.msg_control = malloc(inet6_option_space(sizeof(*optXp) +
                                             sizeof(*optYp)));

```

```

inet6_option_init(msg.msg_control, &cmsgptr, IPV6_HOPOPTS);

typep = inet6_option_alloc(cmsgptr, IP6_X_OPT_LEN,
                           IP6_X_OPT_MULTX, IP6_X_OPT_OFFSETY);
optXp = (struct ip6_X_opt *) (typep - IP6_X_OPT_OFFSETY);
optXp->ip6_X_opt_type = IP6_X_OPT_TYPE;
optXp->ip6_X_opt_len = IP6_X_OPT_LEN;
optXp->ip6_X_opt_val1 = <32-bit value>;
optXp->ip6_X_opt_val2 = <64-bit value>;

typep = inet6_option_alloc(cmsgptr, IP6_Y_OPT_LEN,
                           IP6_Y_OPT_MULTX, IP6_Y_OPT_OFFSETY);
optYp = (struct ip6_Y_opt *) (typep - IP6_Y_OPT_OFFSETY);
optYp->ip6_Y_opt_type = IP6_Y_OPT_TYPE;
optYp->ip6_Y_opt_len = IP6_Y_OPT_LEN;
optYp->ip6_Y_opt_val1 = <8-bit value>;
optYp->ip6_Y_opt_val2 = <16-bit value>;
optYp->ip6_Y_opt_val3 = <32-bit value>;

msg.msg_controllen = cmsgptr->cmsg_len;

```

Notice that `inet6_option_alloc()` returns a pointer to the 8-bit option type field. If the program wants a pointer to an option structure that includes the padding at the front (as shown in our definitions of the `ip6_X_opt` and `ip6_Y_opt` structures), the y-offset at the beginning of the structure must be subtracted from the returned pointer.

The following code fragment shows the processing of Hop-by-Hop options using the `inet6_option_next()` function.

```

struct msghdr  msg;
struct cmsghdr *cmsgptr;

/* fill in msg */

/* call recvmsg() */

for (cmsgptr = CMSG_FIRSTHDR(&msg); cmsgptr != NULL;
     cmsgptr = CMSG_NXTHDR(&msg, cmsgptr)) {
    if (cmsgptr->cmsg_level == IPPROTO_IPV6 &&
        cmsgptr->cmsg_type == IPV6_HOPOPTS) {

        uint8_t *tpttr = NULL;

        while (inet6_option_next(cmsgptr, &tpttr) == 0) {
            if (*tpttr == IP6_X_OPT_TYPE) {
                struct ip6_X_opt *optXp;

```

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```

    optXp = (struct ip6_X_opt *) (tptr - IP6_X_OPT_OFFSETY);
    <do whatever with> optXp->ip6_X_opt_val1;
    <do whatever with> optXp->ip6_X_opt_val2;

    } else if (*tptr == IP6_Y_OPT_TYPE) {
        struct ip6_Y_opt *optYp;

        optYp = (struct ip6_Y_opt *) (tptr - IP6_Y_OPT_OFFSETY);
        <do whatever with> optYp->ip6_Y_opt_val1;
        <do whatever with> optYp->ip6_Y_opt_val2;
        <do whatever with> optYp->ip6_Y_opt_val3;
    }
}
if (tptr != NULL)
    <error encountered by inet6_option_next(>;
}
}

```

7. Destination Options

A variable number of Destination options can appear in one or more Destination option headers. As defined in [RFC-1883], a Destination options header appearing before a Routing header is processed by the first destination plus any subsequent destinations specified in the Routing header, while a Destination options header appearing after a Routing header is processed only by the final destination. As with the Hop-by-Hop options, each option in a Destination options header is TLV-encoded with a type, length, and value.

Today no Destination options are defined for IPv6 [RFC-1883], although proposals exist to use Destination options with mobility and anycasting.

7.1. Receiving Destination Options

To receive Destination options the application must enable the IPV6_DSTOPTS socket option:

```

int  on = 1;
setsockopt(fd, IPPROTO_IPV6, IPV6_DSTOPTS, &on, sizeof(on));

```

All the Destination options appearing before a Routing header are returned as one ancillary data object described by a cmsghdr structure and all the Destination options appearing after a Routing header are returned as another ancillary data object described by a cmsghdr structure. For these ancillary data objects, the cmsgh_level

member will be `IPPROTO_IPV6` and the `cmsg_type` member will be `IPV6_HOPOPTS`. These options are then processed by calling the `inet6_option_next()` and `inet6_option_find()` functions.

7.2. Sending Destination Options

To send one or more Destination options, the application just specifies them as ancillary data in a call to `sendmsg()`. No socket option need be set.

As described earlier, one set of Destination options can appear before a Routing header, and one set can appear after a Routing header. Each set can consist of one or more options.

Normally all the Destination options in a set are specified by a single ancillary data object, since each option is itself TLV-encoded. Multiple ancillary data objects, each containing one or more Destination options, can also be specified, in which case the kernel will combine all the Destination options in the set into a single Destination extension header. But it should be more efficient to use a single ancillary data object to describe all the Destination options in a set. The `cmsg_level` member is set to `IPPROTO_IPV6` and the `cmsg_type` member is set to `IPV6_DSTOPTS`. The option is normally constructed using the `inet6_option_init()`, `inet6_option_append()`, and `inet6_option_alloc()` functions.

Additional errors may be possible from `sendmsg()` if the specified option is in error.

8. Routing Header Option

Source routing in IPv6 is accomplished by specifying a Routing header as an extension header. There can be different types of Routing headers, but IPv6 currently defines only the Type 0 Routing header [RFC-1883]. This type supports up to 23 intermediate nodes. With this maximum number of intermediate nodes, a source, and a destination, there are 24 hops, each of which is defined as a strict or loose hop.

Source routing with IPv4 sockets API (the `IP_OPTIONS` socket option) requires the application to build the source route in the format that appears as the IPv4 header option, requiring intimate knowledge of the IPv4 options format. This IPv6 API, however, defines eight functions that the application calls to build and examine a Routing header. Four functions build a Routing header:

<code>inet6_rthdr_space()</code>	- return #bytes required for ancillary data
<code>inet6_rthdr_init()</code>	- initialize ancillary data for Routing header

```
inet6_rthdr_add()      - add IPv6 address & flags to Routing header
inet6_rthdr_lasthop() - specify the flags for the final hop
```

Four functions deal with a returned Routing header:

```
inet6_rthdr_reverse() - reverse a Routing header
inet6_rthdr_segments() - return #segments in a Routing header
inet6_rthdr_getaddr() - fetch one address from a Routing header
inet6_rthdr_getflags() - fetch one flag from a Routing header
```

The function prototypes for these functions are all in the `<netinet/in.h>` header.

To receive a Routing header the application must enable the `IPV6_RTHDR` socket option:

```
int  on = 1;
setsockopt(fd, IPPROTO_IPV6, IPV6_RTHDR, &on, sizeof(on));
```

To send a Routing header the application just specifies it as ancillary data in a call to `sendmsg()`.

A Routing header is passed between the application and the kernel as an ancillary data object. The `cmsg_level` member has a value of `IPPROTO_IPV6` and the `cmsg_type` member has a value of `IPV6_RTHDR`. The contents of the `cmsg_data[]` member is implementation dependent and should not be accessed directly by the application, but should be accessed using the eight functions that we are about to describe.

The following constants are defined in the `<netinet/in.h>` header:

```
#define IPV6_RTHDR_LOOSE      0 /* this hop need not be a neighbor */
#define IPV6_RTHDR_STRICT    1 /* this hop must be a neighbor */

#define IPV6_RTHDR_TYPE_0     0 /* IPv6 Routing header type 0 */
```

When a Routing header is specified, the destination address specified for `connect()`, `sendto()`, or `sendmsg()` is the final destination address of the datagram. The Routing header then contains the addresses of all the intermediate nodes.

8.1. `inet6_rthdr_space`

```
size_t inet6_rthdr_space(int type, int segments);
```

This function returns the number of bytes required to hold a Routing header of the specified type containing the specified number of

segments (addresses). For an IPv6 Type 0 Routing header, the number of segments must be between 1 and 23, inclusive. The return value includes the size of the cmsghdr structure that precedes the Routing header, and any required padding.

If the return value is 0, then either the type of the Routing header is not supported by this implementation or the number of segments is invalid for this type of Routing header.

(Note: This function returns the size but does not allocate the space required for the ancillary data. This allows an application to allocate a larger buffer, if other ancillary data objects are desired, since all the ancillary data objects must be specified to `sendmsg()` as a single `msg_control` buffer.)

8.2. `inet6_rthdr_init`

```
struct cmsghdr *inet6_rthdr_init(void *bp, int type);
```

This function initializes the buffer pointed to by `bp` to contain a cmsghdr structure followed by a Routing header of the specified type. The `cmsgh_len` member of the cmsghdr structure is initialized to the size of the structure plus the amount of space required by the Routing header. The `cmsgh_level` and `cmsgh_type` members are also initialized as required.

The caller must allocate the buffer and its size can be determined by calling `inet6_rthdr_space()`.

Upon success the return value is the pointer to the cmsghdr structure, and this is then used as the first argument to the next two functions. Upon an error the return value is NULL.

8.3. `inet6_rthdr_add`

```
int inet6_rthdr_add(struct cmsghdr *cmsg,
                   const struct in6_addr *addr, unsigned int flags);
```

This function adds the address pointed to by `addr` to the end of the Routing header being constructed and sets the type of this hop to the value of `flags`. For an IPv6 Type 0 Routing header, `flags` must be either `IPV6_RTHDR_LOOSE` or `IPV6_RTHDR_STRICT`.

If successful, the `cmsgh_len` member of the cmsghdr structure is updated to account for the new address in the Routing header and the return value of the function is 0. Upon an error the return value of the function is -1.

8.4. `inet6_rthdr_lasthop`

```
int inet6_rthdr_lasthop(struct cmsghdr *cmsg,
                        unsigned int flags);
```

This function specifies the Strict/Loose flag for the final hop of a Routing header. For an IPv6 Type 0 Routing header, flags must be either `IPV6_RTHDR_LOOSE` or `IPV6_RTHDR_STRICT`.

The return value of the function is 0 upon success, or -1 upon an error.

Notice that a Routing header specifying N intermediate nodes requires N+1 Strict/Loose flags. This requires N calls to `inet6_rthdr_add()` followed by one call to `inet6_rthdr_lasthop()`.

8.5. `inet6_rthdr_reverse`

```
int inet6_rthdr_reverse(const struct cmsghdr *in, struct cmsghdr *out);
```

This function takes a Routing header that was received as ancillary data (pointed to by the first argument) and writes a new Routing header that sends datagrams along the reverse of that route. Both arguments are allowed to point to the same buffer (that is, the reversal can occur in place).

The return value of the function is 0 on success, or -1 upon an error.

8.6. `inet6_rthdr_segments`

```
int inet6_rthdr_segments(const struct cmsghdr *cmsg);
```

This function returns the number of segments (addresses) contained in the Routing header described by `cmsg`. On success the return value is between 1 and 23, inclusive. The return value of the function is -1 upon an error.

8.7. `inet6_rthdr_getaddr`

```
struct in6_addr *inet6_rthdr_getaddr(struct cmsghdr *cmsg, int
index);
```

This function returns a pointer to the IPv6 address specified by `index` (which must have a value between 1 and the value returned by `inet6_rthdr_segments()`) in the Routing header described by `cmsg`. An application should first call `inet6_rthdr_segments()` to obtain the number of segments in the Routing header.

Upon an error the return value of the function is NULL.

8.8. inet6_rthdr_getflags

```
int inet6_rthdr_getflags(const struct cmsghdr *cmsg, int index);
```

This function returns the flags value specified by index (which must have a value between 0 and the value returned by `inet6_rthdr_segments()` in the Routing header described by cmsg. For an IPv6 Type 0 Routing header the return value will be either `IPV6_RTHDR_LOOSE` or `IPV6_RTHDR_STRICT`.

Upon an error the return value of the function is -1.

(Note: Addresses are indexed starting at 1, and flags starting at 0, to maintain consistency with the terminology and figures in [RFC-1883].)

8.9. Routing Header Example

As an example of these Routing header functions, we go through the function calls for the example on p. 18 of [RFC-1883]. The source is S, the destination is D, and the three intermediate nodes are I1, I2, and I3. f0, f1, f2, and f3 are the Strict/Loose flags for each hop.

		f0		f1		f2		f3	
	S	----->	I1	----->	I2	----->	I3	----->	D
src:	*	S		S		S		S	S
dst:	D	I1		I2		I3		D	D
A[1]:	I1	I2		I1		I1		I1	I1
A[2]:	I2	I3		I3		I2		I2	I2
A[3]:	I3	D		D		D		I3	I3
#seg:	3	3		2		1		0	3
check:	f0			f1		f2		f3	

src and dst are the source and destination IPv6 addresses in the IPv6 header. A[1], A[2], and A[3] are the three addresses in the Routing header. #seg is the Segments Left field in the Routing header. check indicates which bit of the Strict/Loose Bit Map (0 through 3, specified as f0 through f3) that node checks.

The six values in the column beneath node S are the values in the Routing header specified by the application using `sendmsg()`. The function calls by the sender would look like:

```

void *ptr;
struct msghdr msg;
struct cmsghdr *cmsgptr;
struct sockaddr_in6 I1, I2, I3, D;
unsigned int f0, f1, f2, f3;

ptr = malloc(inet6_rthdr_space(IPV6_RTHDR_TYPE_0, 3));
cmsgptr = inet6_rthdr_init(ptr, IPV6_RTHDR_TYPE_0);

inet6_rthdr_add(cmsgptr, &I1.sin6_addr, f0);
inet6_rthdr_add(cmsgptr, &I2.sin6_addr, f1);
inet6_rthdr_add(cmsgptr, &I3.sin6_addr, f2);
inet6_rthdr_lasthop(cmsgptr, f3);

msg.msg_control = ptr;
msg.msg_controllen = cmsgptr->cmsg_len;

/* finish filling in msg{}, msg_name = D */
/* call sendmsg() */

```

We also assume that the source address for the socket is not specified (i.e., the asterisk in the figure).

The four columns of six values that are then shown between the five nodes are the values of the fields in the packet while the packet is in transit between the two nodes. Notice that before the packet is sent by the source node S, the source address is chosen (replacing the asterisk), I1 becomes the destination address of the datagram, the two addresses A[2] and A[3] are "shifted up", and D is moved to A[3]. If f0 is IPV6_RTHDR_STRICT, then I1 must be a neighbor of S.

The columns of values that are shown beneath the destination node are the values returned by `recvmsg()`, assuming the application has enabled both the `IPV6_PKTINFO` and `IPV6_RTHDR` socket options. The source address is S (contained in the `sockaddr_in6` structure pointed to by the `msg_name` member), the destination address is D (returned as an ancillary data object in an `in6_pktinfo` structure), and the ancillary data object specifying the Routing header will contain three addresses (I1, I2, and I3) and four flags (f0, f1, f2, and f3). The number of segments in the Routing header is known from the `Hdr Ext Len` field in the Routing header (a value of 6, indicating 3 addresses).

The return value from `inet6_rthdr_segments()` will be 3 and `inet6_rthdr_getaddr(1)` will return I1, `inet6_rthdr_getaddr(2)` will return I2, and `inet6_rthdr_getaddr(3)` will return I3. The return

value from `inet6_rthdr_flags(0)` will be `f0`, `inet6_rthdr_flags(1)` will return `f1`, `inet6_rthdr_flags(2)` will return `f2`, and `inet6_rthdr_flags(3)` will return `f3`.

If the receiving application then calls `inet6_rthdr_reverse()`, the order of the three addresses will become `I3`, `I2`, and `I1`, and the order of the four Strict/Loose flags will become `f3`, `f2`, `f1`, and `f0`.

We can also show what an implementation might store in the ancillary data object as the Routing header is being built by the sending process. If we assume a 32-bit architecture where `sizeof(struct cmsghdr)` equals 12, with a desired alignment of 4-byte boundaries, then the call to `inet6_rthdr_space(3)` returns 68: 12 bytes for the `cmsghdr` structure and 56 bytes for the Routing header ($8 + 3 \cdot 16$).

The call to `inet6_rthdr_init()` initializes the ancillary data object to contain a Type 0 Routing header:

```

+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsg_len = 20      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsg_level = IPPROTO_IPV6      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsg_type = IPV6_RTHDR      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+
| Next Header | Hdr Ext Len=0 | Routing Type=0 | Seg Left=0 |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|   Reserved   |               Strict/Loose Bit Map               |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+

```

The first call to `inet6_rthdr_add()` adds `I1` to the list.

```

+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsg_len = 36      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsg_level = IPPROTO_IPV6      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsg_type = IPV6_RTHDR      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|  Next Header  | Hdr Ext Len=2 | Routing Type=0 | Seg Left=1 |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|  Reserved    |X|                Strict/Loose Bit Map      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|
+
|
+
|
+
|
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|
+
|
+
|
+
|
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+

```

Bit 0 of the Strict/Loose Bit Map contains the value f0, which we just mark as X. cmsg_len is incremented by 16, the Hdr Ext Len field is incremented by 2, and the Segments Left field is incremented by 1.

The next call to inet6_rthdr_add() adds I2 to the list.

```

+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsg_len = 52      |
+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsg_level = IPPROTO_IPV6      |
+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsg_type = IPV6_RTHDR      |
+-----+-----+-----+-----+-----+-----+-----+-----+
|  Next Header  | Hdr Ext Len=4 | Routing Type=0 | Seg Left=2 |
+-----+-----+-----+-----+-----+-----+-----+-----+
|  Reserved    |X|X|          Strict/Loose Bit Map          |
+-----+-----+-----+-----+-----+-----+-----+-----+
|
+
|
|                                     Address[1] = I1
|
+
|
+-----+-----+-----+-----+-----+-----+-----+-----+
|
+
|
|                                     Address[2] = I2
|
+
|
+-----+-----+-----+-----+-----+-----+-----+-----+

```

The next bit of the Strict/Loose Bit Map contains the value f1. cmsg_len is incremented by 16, the Hdr Ext Len field is incremented by 2, and the Segments Left field is incremented by 1.

The last call to inet6_rthdr_add() adds I3 to the list.

```

+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsg_len = 68      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsg_level = IPPROTO_IPV6      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsg_type = IPV6_RTHDR      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|  Next Header  | Hdr Ext Len=6 | Routing Type=0 | Seg Left=3 |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|  Reserved    |X|X|X|          Strict/Loose Bit Map          |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|
+
|
|                                     Address[1] = I1
|
+
|
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|
+
|
|                                     Address[2] = I2
|
+
|
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|
+
|
|                                     Address[3] = I3
|
+
|
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+

```

The next bit of the Strict/Loose Bit Map contains the value f2. cmsg_len is incremented by 16, the Hdr Ext Len field is incremented by 2, and the Segments Left field is incremented by 1.

Finally, the call to inet6_rthdr_lasthop() sets the next bit of the Strict/Loose Bit Map to the value specified by f3. All the lengths remain unchanged.

9. Ordering of Ancillary Data and IPv6 Extension Headers

Three IPv6 extension headers can be specified by the application and returned to the application using ancillary data with `sendmsg()` and `recvmsg()`: Hop-by-Hop options, Destination options, and the Routing header. When multiple ancillary data objects are transferred via `sendmsg()` or `recvmsg()` and these objects represent any of these three extension headers, their placement in the control buffer is directly tied to their location in the corresponding IPv6 datagram. This API imposes some ordering constraints when using multiple ancillary data objects with `sendmsg()`.

When multiple IPv6 Hop-by-Hop options having the same option type are specified, these options will be inserted into the Hop-by-Hop options header in the same order as they appear in the control buffer. But when multiple Hop-by-Hop options having different option types are specified, these options may be reordered by the kernel to reduce padding in the Hop-by-Hop options header. Hop-by-Hop options may appear anywhere in the control buffer and will always be collected by the kernel and placed into a single Hop-by-Hop options header that immediately follows the IPv6 header.

Similar rules apply to the Destination options: (1) those of the same type will appear in the same order as they are specified, and (2) those of differing types may be reordered. But the kernel will build up to two Destination options headers: one to precede the Routing header and one to follow the Routing header. If the application specifies a Routing header then all Destination options that appear in the control buffer before the Routing header will appear in a Destination options header before the Routing header and these options might be reordered, subject to the two rules that we just stated. Similarly all Destination options that appear in the control buffer after the Routing header will appear in a Destination options header after the Routing header, and these options might be reordered, subject to the two rules that we just stated.

As an example, assume that an application specifies control information to `sendmsg()` containing six ancillary data objects: the first containing two Hop-by-Hop options, the second containing one Destination option, the third containing two Destination options, the fourth containing a Routing header, the fifth containing a Hop-by-Hop option, and the sixth containing two Destination options. We also assume that all the Hop-by-Hop options are of different types, as are all the Destination options. We number these options 1-9, corresponding to their order in the control buffer, and show them on the left below.

In the middle we show the final arrangement of the options in the extension headers built by the kernel. On the right we show the four ancillary data objects returned to the receiving application.

Sender's Ancillary Data Objects	->	IPv6 Extension Headers	->	Receiver's Ancillary Data Objects
-----		-----		-----
HOPOPT-1,2 (first)		HOPHDR(J,7,1,2)		HOPOPT-7,1,2
DSTOPT-3		DSTHDR(4,5,3)		DSTOPT-4,5,3
DSTOPT-4,5		RTHDR(6)		RTHDR-6
RTHDR-6		DSTHDR(8,9)		DSTOPT-8,9
HOPOPT-7				
DSTOPT-8,9 (last)				

The sender's two Hop-by-Hop ancillary data objects are reordered, as are the first two Destination ancillary data objects. We also show a Jumbo Payload option (denoted as J) inserted by the kernel before the sender's three Hop-by-Hop options. The first three Destination options must appear in a Destination header before the Routing header, and the final two Destination options must appear in a Destination header after the Routing header.

If Destination options are specified in the control buffer after a Routing header, or if Destination options are specified without a Routing header, the kernel will place those Destination options after an authentication header and/or an encapsulating security payload header, if present.

10. IPv6-Specific Options with IPv4-Mapped IPv6 Addresses

The various socket options and ancillary data specifications defined in this document apply only to true IPv6 sockets. It is possible to create an IPv6 socket that actually sends and receives IPv4 packets, using IPv4-mapped IPv6 addresses, but the mapping of the options defined in this document to an IPv4 datagram is beyond the scope of this document.

In general, attempting to specify an IPv6-only option, such as the Hop-by-Hop options, Destination options, or Routing header on an IPv6 socket that is using IPv4-mapped IPv6 addresses, will probably result in an error. Some implementations, however, may provide access to the packet information (source/destination address, send/receive interface, and hop limit) on an IPv6 socket that is using IPv4-mapped IPv6 addresses.

11. rresvport_af

The `rresvport()` function is used by the `rcmd()` function, and this function is in turn called by many of the "r" commands such as `rlogin`. While new applications are not being written to use the `rcmd()` function, legacy applications such as `rlogin` will continue to use it and these will be ported to IPv6.

`rresvport()` creates an IPv4/TCP socket and binds a "reserved port" to the socket. Instead of defining an IPv6 version of this function we define a new function that takes an address family as its argument.

```
#include <unistd.h>
```

```
int rresvport_af(int *port, int family);
```

This function behaves the same as the existing `rresvport()` function, but instead of creating an IPv4/TCP socket, it can also create an IPv6/TCP socket. The family argument is either `AF_INET` or `AF_INET6`, and a new error return is `EAFNOSUPPORT` if the address family is not supported.

(Note: There is little consensus on which header defines the `rresvport()` and `rcmd()` function prototypes. 4.4BSD defines it in `<unistd.h>`, others in `<netdb.h>`, and others don't define the function prototypes at all.)

(Note: We define this function only, and do not define something like `rcmd_af()` or `rcmd6()`. The reason is that `rcmd()` calls `gethostbyname()`, which returns the type of address: `AF_INET` or `AF_INET6`. It should therefore be possible to modify `rcmd()` to support either IPv4 or IPv6, based on the address family returned by `gethostbyname()`.)

12. Future Items

Some additional items may require standardization, but no concrete proposals have been made for the API to perform these tasks. These may be addressed in a later document.

12.1. Flow Labels

Earlier revisions of this document specified a set of `inet6_flow_XXX()` functions to assign, share, and free IPv6 flow labels. Consensus, however, indicated that it was premature to specify this part of the API.

12.2. Path MTU Discovery and UDP

A standard method may be desirable for a UDP application to determine the "maximum send transport-message size" (Section 5.1 of [RFC-1981]) to a given destination. This would let the UDP application send smaller datagrams to the destination, avoiding fragmentation.

12.3. Neighbor Reachability and UDP

A standard method may be desirable for a UDP application to tell the kernel that it is making forward progress with a given peer (Section 7.3.1 of [RFC-1970]). This could save unneeded neighbor solicitations and neighbor advertisements.

13. Summary of New Definitions

The following list summarizes the constants and structure, definitions discussed in this memo, sorted by header.

```
<netinet/icmp6.h> ICMP6_DST_UNREACH
<netinet/icmp6.h> ICMP6_DST_UNREACH_ADDR
<netinet/icmp6.h> ICMP6_DST_UNREACH_ADMIN
<netinet/icmp6.h> ICMP6_DST_UNREACH_NOPORT
<netinet/icmp6.h> ICMP6_DST_UNREACH_NOROUTE
<netinet/icmp6.h> ICMP6_DST_UNREACH_NOTNEIGHBOR
<netinet/icmp6.h> ICMP6_ECHO_REPLY
<netinet/icmp6.h> ICMP6_ECHO_REQUEST
<netinet/icmp6.h> ICMP6_INFOMSG_MASK
<netinet/icmp6.h> ICMP6_MEMBERSHIP_QUERY
<netinet/icmp6.h> ICMP6_MEMBERSHIP_REDUCTION
<netinet/icmp6.h> ICMP6_MEMBERSHIP_REPORT
<netinet/icmp6.h> ICMP6_PACKET_TOO_BIG
<netinet/icmp6.h> ICMP6_PARAMPROB_HEADER
<netinet/icmp6.h> ICMP6_PARAMPROB_NEXTHEADER
<netinet/icmp6.h> ICMP6_PARAMPROB_OPTION
<netinet/icmp6.h> ICMP6_PARAM_PROB
<netinet/icmp6.h> ICMP6_TIME_EXCEEDED
<netinet/icmp6.h> ICMP6_TIME_EXCEED_REASSEMBLY
<netinet/icmp6.h> ICMP6_TIME_EXCEED_TRANSIT
<netinet/icmp6.h> ND_NA_FLAG_OVERRIDE
<netinet/icmp6.h> ND_NA_FLAG_ROUTER
<netinet/icmp6.h> ND_NA_FLAG_SOLICITED
<netinet/icmp6.h> ND_NEIGHBOR_ADVERT
<netinet/icmp6.h> ND_NEIGHBOR_SOLICIT
<netinet/icmp6.h> ND_OPT_MTU
<netinet/icmp6.h> ND_OPT_PI_FLAG_AUTO
<netinet/icmp6.h> ND_OPT_PI_FLAG_ONLINK
<netinet/icmp6.h> ND_OPT_PREFIX_INFORMATION
```

```

<netinet/icmp6.h> ND_OPT_REDIRECTED_HEADER
<netinet/icmp6.h> ND_OPT_SOURCE_LINKADDR
<netinet/icmp6.h> ND_OPT_TARGET_LINKADDR
<netinet/icmp6.h> ND_RA_FLAG_MANAGED
<netinet/icmp6.h> ND_RA_FLAG_OTHER
<netinet/icmp6.h> ND_REDIRECT
<netinet/icmp6.h> ND_ROUTER_ADVERT
<netinet/icmp6.h> ND_ROUTER_SOLICIT

<netinet/icmp6.h> struct icmp6_filter{};
<netinet/icmp6.h> struct icmp6_hdr{};
<netinet/icmp6.h> struct nd_neighbor_advert{};
<netinet/icmp6.h> struct nd_neighbor_solicit{};
<netinet/icmp6.h> struct nd_opt_hdr{};
<netinet/icmp6.h> struct nd_opt_mtu{};
<netinet/icmp6.h> struct nd_opt_prefix_info{};
<netinet/icmp6.h> struct nd_opt_rd_hdr{};
<netinet/icmp6.h> struct nd_redirect{};
<netinet/icmp6.h> struct nd_router_advert{};
<netinet/icmp6.h> struct nd_router_solicit{};

<netinet/in.h>      IPPROTO_AH
<netinet/in.h>      IPPROTO_DSTOPTS
<netinet/in.h>      IPPROTO_ESP
<netinet/in.h>      IPPROTO_FRAGMENT
<netinet/in.h>      IPPROTO_HOPOPTS
<netinet/in.h>      IPPROTO_ICMPV6
<netinet/in.h>      IPPROTO_IPV6
<netinet/in.h>      IPPROTO_NONE
<netinet/in.h>      IPPROTO_ROUTING
<netinet/in.h>      IPV6_DSTOPTS
<netinet/in.h>      IPV6_HOPLIMIT
<netinet/in.h>      IPV6_HOPOPTS
<netinet/in.h>      IPV6_NEXTHOP
<netinet/in.h>      IPV6_PKTINFO
<netinet/in.h>      IPV6_PKTOPTIONS
<netinet/in.h>      IPV6_RTHDR
<netinet/in.h>      IPV6_RTHDR_LOOSE
<netinet/in.h>      IPV6_RTHDR_STRICT
<netinet/in.h>      IPV6_RTHDR_TYPE_0
<netinet/in.h>      struct in6_pktinfo{};

<netinet/ip6.h>     IP6F_OFF_MASK
<netinet/ip6.h>     IP6F_RESERVED_MASK
<netinet/ip6.h>     IP6F_MORE_FRAG
<netinet/ip6.h>     struct ip6_dest{};
<netinet/ip6.h>     struct ip6_frag{};
<netinet/ip6.h>     struct ip6_hbh{};

```

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```

<netinet/ip6.h>  struct ip6_hdr{};
<netinet/ip6.h>  struct ip6_rthdr{};
<netinet/ip6.h>  struct ip6_rthdr0{};

<sys/socket.h>   struct cmsghdr{};
<sys/socket.h>   struct msghdr{};

```

The following list summarizes the function and macro prototypes discussed in this memo, sorted by header.

```

<netinet/icmp6.h> void ICMP6_FILTER_SETBLOCK(int,
                                                struct icmp6_filter *);
<netinet/icmp6.h> void ICMP6_FILTER_SETBLOCKALL(struct icmp6_filter *);
<netinet/icmp6.h> void ICMP6_FILTER_SETPASS(int, struct icmp6_filter *);
<netinet/icmp6.h> void ICMP6_FILTER_SETPASSALL(struct icmp6_filter *);
<netinet/icmp6.h> int  ICMP6_FILTER_WILLBLOCK(int,
                                                const struct icmp6_filter *);
<netinet/icmp6.h> int  ICMP6_FILTER_WILLPASS(int,
                                                const struct icmp6_filter *);

<netinet/in.h>     int IN6_ARE_ADDR_EQUAL(const struct in6_addr *,
                                                const struct in6_addr *);

<netinet/in.h>     uint8_t *inet6_option_alloc(struct cmsghdr *,
                                                int, int, int);
<netinet/in.h>     int inet6_option_append(struct cmsghdr *,
                                                const uint8_t *, int, int);
<netinet/in.h>     int inet6_option_find(const struct cmsghdr *,
                                                uint8_t *, int);
<netinet/in.h>     int inet6_option_init(void *, struct cmsghdr **, int);
<netinet/in.h>     int inet6_option_next(const struct cmsghdr *,
                                                uint8_t **);
<netinet/in.h>     int inet6_option_space(int);

<netinet/in.h>     int inet6_rthdr_add(struct cmsghdr *,
                                                const struct in6_addr *,
                                                unsigned int);
<netinet/in.h>     struct in6_addr inet6_rthdr_getaddr(struct cmsghdr *,
                                                int);
<netinet/in.h>     int inet6_rthdr_getflags(const struct cmsghdr *, int);
<netinet/in.h>     struct cmsghdr *inet6_rthdr_init(void *, int);
<netinet/in.h>     int inet6_rthdr_lasthop(struct cmsghdr *,
                                                unsigned int);
<netinet/in.h>     int inet6_rthdr_reverse(const struct cmsghdr *,
                                                struct cmsghdr *);
<netinet/in.h>     int inet6_rthdr_segments(const struct cmsghdr *);
<netinet/in.h>     size_t inet6_rthdr_space(int, int);

```

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```

<sys/socket.h>    unsigned char *CMSG_DATA(const struct cmsghdr *);
<sys/socket.h>    struct cmsghdr *CMSG_FIRSTHDR(const struct msghdr *);
<sys/socket.h>    unsigned int CMSG_LEN(unsigned int);
<sys/socket.h>    struct cmsghdr *CMSG_NXTHDR(const struct msghdr *mhdr,
                                             const struct cmsghdr *);
<sys/socket.h>    unsigned int CMSG_SPACE(unsigned int);

<unistd.h>        int rresvport_af(int *, int);

```

14. Security Considerations

The setting of certain Hop-by-Hop options and Destination options may be restricted to privileged processes. Similarly some Hop-by-Hop options and Destination options may not be returned to nonprivileged applications.

15. Change History

Changes from the June 1997 Edition (-03 draft)

- Added a note that defined constants for multibyte fields are in network byte order. This affects the `ip6f_offlg` member of the Fragment header (Section 2.1.2) and the `nd_na_flags_reserved` member of the `nd_neighbor_advert` structure (Section 2.2.2).
- Section 5: the `ipi6_ifindex` member of the `in6_pktinfo` structure should be "unsigned int" instead of "int", for consistency with the interface indexes in [RFC-2133].
- Section 6.3.7: the three calls to `inet6_option_space()` in the examples needed to be arguments to `malloc()`. The final one of these was missing the "6" in the name "`inet6_option_space`".
- Section 8.6: the function prototype for `inet6_rthdr_segments()` was missing the ending semicolon.

Changes from the March 1997 Edition (-02 draft)

- In May 1997 Draft 6.6 of Posix 1003.1g (called Posix.1g herein) passed ballot and will be forwarded to the IEEE Standards Board later in 1997 for final approval. Some changes made for this final Posix draft are incorporated into this Internet Draft, specifically the datatypes mentioned in Section 1 (and used throughout the text), and the `socklen_t` datatype used in Section 4.1 and 4.2.
- Section 1: Added the `intN_t` signed datatypes, changed the datatype `u_intN_t` to `uintN_t` (no underscore after the "u"), and

removed the datatype `u_intNm_t`, as per Draft 6.6 of Posix.1g.

- Name space issues for structure and constant names in Section 2: Many of the structure member names and constant names were changed so that the prefixes are the same. The following prefixes are used for structure members: `"ip6_"`, `"icmp6_"`, and `"nd_"`. All constants have the prefixes `"ICMP6_"` and `"ND_"`.
- New definitions: Section 2.1.2: contains definitions for the IPv6 extension headers, other than AH and ESP. Section 2.2.2: contains additional structures and constants for the neighbor discovery option header and redirected header.
- Section 2.2.2: the enum for the neighbor discovery option field was changed to be a set of `#define` constants.
- Changed the word "function" to "macro" for references to all the uppercase names in Sections 2.3 (`IN6_ARE_ADDR_EQUAL`), 3.2 (`ICMPV6_FILTER_xxx`), and 4.3 (`CMSG_xxx`).
- Added more protocols to the `/etc/protocols` file (Section 2.4) and changed the name of `"icmpv6"` to `"ipv6-icmp"`.
- Section 3: Made it more explicit that an application cannot read or write entire IPv6 packets, that all extension headers are passed as ancillary data. Added a sentence that the kernel fragments packets written to an IPv6 raw socket when necessary. Added a note that `IPPROTO_RAW` raw IPv6 sockets are not special.
- Section 3.1: Explicitly stated that the checksum option applies to both outgoing packets and received packets.
- Section 3.2: Changed the array name within the `icmp6_filter` structure from `"data"` to `"icmp6_filt"`. Changes the prefix for the filter macros from `"ICMPV6_"` to `"ICMP6_"`, for consistency with the names in Section 2.2. Changed the example from a ping program to a program that wants to receive only router advertisements.
- Section 4.1: Changed `msg_namelen` and `msg_controllen` from `size_t` to the Posix.1g `socklen_t` datatype. Updated the Note that follows.
- Section 4.2: Changed `cmsg_len` from `size_t` to the Posix.1g `socklen_t` datatype. Updated the Note that follows.

- Section 4.4: Added a Note that the second and third arguments to `getsockopt()` and `setsockopt()` are intentionally the same as the `cmsg_level` and `cmsg_type` members.
- Section 4.5: Reorganized the section into a description of the option, followed by the TCP semantics, and the UDP and raw socket semantics. Added a sentence on how to clear all the sticky options. Added a note that TCP need not save the options from the most recently received segment until the application says to do so. Added the statement that ancillary data is never passed with `sendmsg()` or `recvmsg()` on a TCP socket. Simplified the interaction of the sticky options with ancillary data for UDP or raw IP: none of the sticky options are sent if ancillary data is specified.
- Final paragraph of Section 5.1: `ipi6_index` should be `ipi6_ifindex`.
- Section 5.4: Added a note on the term "privileged".
- Section 5.5: Noted that the errors listed are examples, and the actual errors depend on the implementation.
- Removed Section 6 ("Flow Labels") as the consensus is that it is premature to try and specify an API for this feature. Access to the flow label field in the IPv6 header is still provided through the `sin6_flowinfo` member of the IPv6 socket address structure in [RFC-2133]. Added a subsection to Section 13 that this is a future item.

All remaining changes are identified by their section number in the previous draft. With the removal of Section 6, the section numbers are decremented by one.

- Section 7.3.7: the calls to `malloc()` in all three examples should be calls to `inet6_option_space()` instead. The two calls to `inet6_option_append()` in the third example should be calls to `inet6_option_alloc()`. The two calls to `CMSG_SPACE()` in the first and third examples should be calls to `CMSG_LEN()`. The second call to `CMSG_SPACE()` in the second example should be a call to `CMSG_LEN()`.
- Section 7.3.7: All the `opt_X_` and `opt_Y_` structure member names were changed to be `ip6_X_opt_` and `ip6_Y_opt_`. The two structure names `ipv6_opt_X` and `ipv6_opt_Y` were changed to `ip6_X_opt` and `ip6_Y_opt`. The constants beginning with `IPV6_OPT_X_` and `IPV6_OPT_Y_` were changed to begin with `IP6_X_OPT_` and `IP6_Y_OPT_`.

- Use the term "Routing header" throughout the draft, instead of "source routing". Changed the names of the eight `inet6_srcrt_XXX()` functions in Section 9 to `inet6_rthdr_XXX()`. Changed the name of the socket option from `IPV6_SRCRT` to `IPV6_RTHDR`, and the names of the three `IPV6_SRCRT_XXX` constants in Section 9 to `IPV6_RTHDR_XXX`.
- Added a paragraph to Section 9 on how to receive and send a Routing header.
- Changed `inet6_rthdr_add()` and `inet6_rthdr_reverse()` so that they return -1 upon an error, instead of an `Exxx` errno value.
- In the description of `inet6_rthdr_space()` in Section 9.1, added the qualifier "For an IPv6 Type 0 Routing header" to the restriction of between 1 and 23 segments.
- Refer to final function argument in Sections 9.7 and 9.8 as index, not offset.
- Updated Section 14 with new names from Section 2.
- Changed the References from "[n]" to "[RFC-abcd]".

Changes from the February 1997 Edition (-01 draft)

- Changed the name of the `ip6hdr` structure to `ip6_hdr` (Section 2.1) for consistency with the `icmp6hdr` structure. Also changed the name of the `ip6hdrctl` structure contained within the `ip6_hdr` structure to `ip6_hdrctl` (Section 2.1). Finally, changed the name of the `icmp6hdr` structure to `icmp6_hdr` (Section 2.2). All other occurrences of this structure name, within the Neighbor Discovery structures in Section 2.2.1, already contained the underscore.
- The "struct `nd_router_solicit`" and "struct `nd_router_advert`" should both begin with "nd6_". (Section 2.2.2).
- Changed the name of `in6_are_addr_equal` to `IN6_ARE_ADDR_EQUAL` (Section 2.3) for consistency with basic API address testing functions. The header defining this macro is `<netinet/in.h>`.
- `getprotobyname("ipv6")` now returns 41, not 0 (Section 2.4).
- The first occurrence of "struct `icmpv6_filter`" in Section 3.2 should be "struct `icmp6_filter`".
- Changed the name of the `CMSG_LENGTH()` macro to `CMSG_LEN()` (Section 4.3.5), since `LEN` is used throughout the `<netinet/*.h>`

headers.

- Corrected the argument name for the sample implementations of the CMSG_SPACE() and CMSG_LEN() macros to be "length" (Sections 4.3.4 and 4.3.5).
- Corrected the socket option mentioned in Section 5.1 to specify the interface for multicasting from IPV6_ADD_MEMBERSHIP to IPV6_MULTICAST_IF.
- There were numerous errors in the previous draft that specified <netinet/ip6.h> that should have been <netinet/in.h>. These have all been corrected and the locations of all definitions is now summarized in the new Section 14 ("Summary of New Definitions").

Changes from the October 1996 Edition (-00 draft)

- Numerous rationale added using the format (Note: ...).
- Added note that not all errors may be defined.
- Added note about ICMPv4, IGMPv4, and ARPv4 terminology.
- Changed the name of <netinet/ip6_icmp.h> to <netinet/icmp6.h>.
- Changed some names in Section 2.2.1: ICMPV6_PKT_TOOBIG to ICMPV6_PACKET_TOOBIG, ICMPV6_TIME_EXCEED to ICMPV6_TIME_EXCEEDED, ICMPV6_ECHORQST to ICMPV6_ECHOREQUEST, ICMPV6_ECHORPLY to ICMPV6_ECHOREPLY, ICMPV6_PARAMPROB_HDR to ICMPV6_PARAMPROB_HEADER, ICMPV6_PARAMPROB_NXT_HDR to ICMPV6_PARAMPROB_NEXTHEADER, and ICMPV6_PARAMPROB_OPTS to ICMPV6_PARAMPROB_OPTION.
- Prepend the prefix "icmp6_" to the three members of the icmp6_dataun union of the icmp6hdr structure (Section 2.2).
- Moved the neighbor discovery definitions into the <netinet/icmp6.h> header, instead of being in their own header (Section 2.2.1).
- Changed Section 2.3 ("Address Testing"). The basic macros are now in the basic API.
- Added the new Section 2.4 on "Protocols File".
- Added note to raw sockets description that something like BPF or DLPI must be used to read or write entire IPv6 packets.

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- Corrected example of `IPV6_CHECKSUM` socket option (Section 3.1). Also defined value of `-1` to disable.
- Noted that `<netinet/icmp6.h>` defines all the ICMPv6 filtering constants, macros, and structures (Section 3.2).
- Added note on magic number 10240 for amount of ancillary data (Section 4.1).
- Added possible padding to picture of ancillary data (Section 4.2).
- Defined `<sys/socket.h>` header for `CMSG_xxx()` functions (Section 4.2).
- Note that the data returned by `getsockopt(IPV6_PKTTOPTIONS)` for a TCP socket is just from the optional headers, if present, of the most recently received segment. Also note that control information is never returned by `recvmsg()` for a TCP socket.
- Changed header for struct `in6_pktinfo` from `<netinet.in.h>` to `<netinet/ip6.h>` (Section 5).
- Removed the old Sections 5.1 and 5.2, because the interface identification functions went into the basic API.
- Redid Section 5 to support the hop limit field.
- New Section 5.4 ("Next Hop Address").
- New Section 6 ("Flow Labels").
- Changed all of Sections 7 and 8 dealing with Hop-by-Hop and Destination options. We now define a set of `inet6_option_XXX()` functions.
- Changed header for `IPV6_SRCRT_xxx` constants from `<netinet.in.h>` to `<netinet/ip6.h>` (Section 9).
- Add `inet6_rthdr_lasthop()` function, and fix errors in description of Routing header (Section 9).
- Reworded some of the Routing header descriptions to conform to the terminology in [RFC-1883].
- Added the example from [RFC-1883] for the Routing header (Section 9.9).

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- Expanded the example in Section 10 to show multiple options per ancillary data object, and to show the receiver's ancillary data objects.
- New Section 11 ("IPv6-Specific Options with IPv4-Mapped IPv6 Addresses").
- New Section 12 ("rresvport_af").
- Redid old Section 10 ("Additional Items") into new Section 13 ("Future Items").

16. References

- [RFC-1883] Deering, S., and R. Hinden, "Internet Protocol, Version 6 (IPv6), Specification", RFC 1883, December 1995.
- [RFC-2133] Gilligan, R., Thomson, S., Bound, J., and W. Stevens, "Basic Socket Interface Extensions for IPv6", RFC 2133, April 1997.
- [RFC-1981] McCann, J., Deering, S., and J. Mogul, "Path MTU Discovery for IP version 6", RFC 1981, August 1996.
- [RFC-1970] Narten, T., Nordmark, E., and W. Simpson, "Neighbor Discovery for IP Version 6 (IPv6)", RFC 1970, August 1996.

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*RFC3542 “Advanced Sockets Application
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Advanced Sockets Application Program Interface (API) for IPv6

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Abstract

This document provides sockets Application Program Interface (API) to support "advanced" IPv6 applications, as a supplement to a separate specification, RFC 3493. The expected applications include Ping, Traceroute, routing daemons and the like, which typically use raw sockets to access IPv6 or ICMPv6 header fields. This document proposes some portable interfaces for applications that use raw sockets under IPv6. There are other features of IPv6 that some applications will need to access: interface identification (specifying the outgoing interface and determining the incoming interface), IPv6 extension headers, and path Maximum Transmission Unit (MTU) information. This document provides API access to these features too. Additionally, some extended interfaces to libraries for the "r" commands are defined. The extension will provide better backward compatibility to existing implementations that are not IPv6-capable.

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1. Introduction

A separate specification [RFC-3493] contains changes to the sockets API to support IP version 6. Those changes are for TCP and UDP-based applications. This document defines some of the "advanced" features of the sockets API that are required for applications to take advantage of additional features of IPv6.

Today, the portability of applications using IPv4 raw sockets is quite high, but this is mainly because most IPv4 implementations started from a common base (the Berkeley source code) or at least started with the Berkeley header files. This allows programs such as Ping and Traceroute, for example, to compile with minimal effort on many hosts that support the sockets API. With IPv6, however, there is no common source code base that implementors are starting from, and the possibility for divergence at this level between different implementations is high. To avoid a complete lack of portability amongst applications that use raw IPv6 sockets, some standardization is necessary.

There are also features from the basic IPv6 specification that are not addressed in [RFC-3493]: sending and receiving Routing headers, Hop-by-Hop options, and Destination options, specifying the outgoing interface, being told of the receiving interface, and control of path MTU information.

This document updates and replaces RFC 2292. This revision is based on implementation experience of RFC 2292, as well as some additional extensions that have been found to be useful through the IPv6 deployment. Note, however, that further work on this document may still be needed. Once the API specification becomes mature and is deployed among implementations, it may be formally standardized by a more appropriate body, such as has been done with the Basic API [RFC-3493].

This document can be divided into the following main sections.

1. Definitions of the basic constants and structures required for applications to use raw IPv6 sockets. This includes structure definitions for the IPv6 and ICMPv6 headers and all associated constants (e.g., values for the Next Header field).
2. Some basic semantic definitions for IPv6 raw sockets. For example, a raw ICMPv4 socket requires the application to calculate and store the ICMPv4 header checksum. But with IPv6 this would require the application to choose the source IPv6 address because the source address is part of the pseudo header that ICMPv6 now uses for its checksum computation. It should be defined that with a raw ICMPv6 socket the kernel always calculates and stores the ICMPv6 header checksum.
3. Packet information: how applications can obtain the received interface, destination address, and received hop limit, along with specifying these values on a per-packet basis. There are a class of applications that need this capability and the technique should be portable.

4. Access to the optional Routing header, Hop-by-Hop options, and Destination options extension headers.
5. Additional features required for improved IPv6 application portability.

The packet information along with access to the extension headers (Routing header, Hop-by-Hop options, and Destination options) are specified using the "ancillary data" fields that were added to the 4.3BSD Reno sockets API in 1990. The reason is that these ancillary data fields are part of the Posix standard [POSIX] and should therefore be adopted by most vendors.

This document does not address application access to either the authentication header or the encapsulating security payload header.

Many examples in this document omit error checking in favor of brevity and clarity.

We note that some of the functions and socket options defined in this document may have error returns that are not defined in this document. Some of these possible error returns will be recognized only as implementations proceed.

Datatypes in this document follow the Posix format: `intN_t` means a signed integer of exactly N bits (e.g., `int16_t`) and `uintN_t` means an unsigned integer of exactly N bits (e.g., `uint32_t`).

Note that we use the (unofficial) terminology ICMPv4, IGMPv4, and ARPv4 to avoid any confusion with the newer ICMPv6 protocol.

2. Common Structures and Definitions

Many advanced applications examine fields in the IPv6 header and set and examine fields in the various ICMPv6 headers. Common structure definitions for these protocol headers are required, along with common constant definitions for the structure members.

This API assumes that the fields in the protocol headers are left in the network byte order, which is big-endian for the Internet protocols. If not, then either these constants or the fields being tested must be converted at run-time, using something like `htons()` or `htonl()`.

Two new header files are defined: `<netinet/ip6.h>` and `<netinet/icmp6.h>`.

When an include file is specified, that include file is allowed to include other files that do the actual declaration or definition.

2.1. The ip6_hdr Structure

The following structure is defined as a result of including `<netinet/ip6.h>`. Note that this is a new header.

```
struct ip6_hdr {
    union {
        struct ip6_hdrctl {
            uint32_t ip6_un1_flow; /* 4 bits version, 8 bits TC, 20 bits
                                   flow-ID */
            uint16_t ip6_un1_plen; /* payload length */
            uint8_t  ip6_un1_nxt;  /* next header */
            uint8_t  ip6_un1_hlim; /* hop limit */
        } ip6_un1;
        uint8_t ip6_un2_vfc;      /* 4 bits version, top 4 bits
                                   tclass */
    } ip6_ctlun;
    struct in6_addr ip6_src;      /* source address */
    struct in6_addr ip6_dst;      /* destination address */
};

#define ip6_vfc    ip6_ctlun.ip6_un2_vfc
#define ip6_flow   ip6_ctlun.ip6_un1.ip6_un1_flow
#define ip6_plen   ip6_ctlun.ip6_un1.ip6_un1_plen
#define ip6_nxt    ip6_ctlun.ip6_un1.ip6_un1_nxt
#define ip6_hlim   ip6_ctlun.ip6_un1.ip6_un1_hlim
#define ip6_hops   ip6_ctlun.ip6_un1.ip6_un1_hlim
```

2.1.1. IPv6 Next Header Values

IPv6 defines many new values for the Next Header field. The following constants are defined as a result of including `<netinet/in.h>`.

```
#define IPPROTO_HOPOPTS  0 /* IPv6 Hop-by-Hop options */
#define IPPROTO_IPV6     41 /* IPv6 header */
#define IPPROTO_ROUTING  43 /* IPv6 Routing header */
#define IPPROTO_FRAGMENT 44 /* IPv6 fragment header */
#define IPPROTO_ESP       50 /* encapsulating security payload */
#define IPPROTO_AH        51 /* authentication header */
#define IPPROTO_ICMPV6   58 /* ICMPv6 */
#define IPPROTO_NONE     59 /* IPv6 no next header */
#define IPPROTO_DSTOPTS  60 /* IPv6 Destination options */
```

Berkeley-derived IPv4 implementations also define IPPROTO_IP to be 0. This should not be a problem since IPPROTO_IP is used only with IPv4 sockets and IPPROTO_HOPOPTS only with IPv6 sockets.

2.1.2. IPv6 Extension Headers

Six extension headers are defined for IPv6. We define structures for all except the Authentication header and Encapsulating Security Payload header, both of which are beyond the scope of this document. The following structures are defined as a result of including <netinet/ip6.h>.

```
/* Hop-by-Hop options header */
struct ip6_hbh {
    uint8_t ip6h_nxt;          /* next header */
    uint8_t ip6h_len;          /* length in units of 8 octets */
    /* followed by options */
};

/* Destination options header */
struct ip6_dest {
    uint8_t ip6d_nxt;          /* next header */
    uint8_t ip6d_len;          /* length in units of 8 octets */
    /* followed by options */
};

/* Routing header */
struct ip6_rthdr {
    uint8_t ip6r_nxt;          /* next header */
    uint8_t ip6r_len;          /* length in units of 8 octets */
    uint8_t ip6r_type;         /* routing type */
    uint8_t ip6r_segleft;      /* segments left */
    /* followed by routing type specific data */
};

/* Type 0 Routing header */
struct ip6_rthdr0 {
    uint8_t ip6r0_nxt;         /* next header */
    uint8_t ip6r0_len;         /* length in units of 8 octets */
    uint8_t ip6r0_type;        /* always zero */
    uint8_t ip6r0_segleft;     /* segments left */
    uint32_t ip6r0_reserved;   /* reserved field */
    /* followed by up to 127 struct in6_addr */
};
```

```

/* Fragment header */
struct ip6_frag {
    uint8_t  ip6f_nxt;        /* next header */
    uint8_t  ip6f_reserved;   /* reserved field */
    uint16_t ip6f_offlg;      /* offset, reserved, and flag */
    uint32_t ip6f_ident;      /* identification */
};

#if BYTE_ORDER == BIG_ENDIAN
#define IP6F_OFF_MASK        0xffff8 /* mask out offset from
                                     ip6f_offlg */
#define IP6F_RESERVED_MASK  0x0006 /* reserved bits in
                                     ip6f_offlg */
#define IP6F_MORE_FRAG      0x0001 /* more-fragments flag */
#else /* BYTE_ORDER == LITTLE_ENDIAN */
#define IP6F_OFF_MASK        0xf8ff /* mask out offset from
                                     ip6f_offlg */
#define IP6F_RESERVED_MASK  0x0600 /* reserved bits in
                                     ip6f_offlg */
#define IP6F_MORE_FRAG      0x0100 /* more-fragments flag */
#endif

```

2.1.3. IPv6 Options

Several options are defined for IPv6, and we define structures and macro definitions for some of them below. The following structures are defined as a result of including <netinet/ip6.h>.

```

/* IPv6 options */
struct ip6_opt {
    uint8_t ip6o_type;
    uint8_t ip6o_len;
};

/*
 * The high-order 3 bits of the option type define the behavior
 * when processing an unknown option and whether or not the option
 * content changes in flight.
 */
#define IP6OPT_TYPE(o) ((o) & 0xc0)
#define IP6OPT_TYPE_SKIP 0x00
#define IP6OPT_TYPE_DISCARD 0x40
#define IP6OPT_TYPE_FORCEICMP 0x80
#define IP6OPT_TYPE_ICMP 0xc0
#define IP6OPT_MUTABLE 0x20

#define IP6OPT_PAD1 0x00 /* 00 0 00000 */
#define IP6OPT_PADN 0x01 /* 00 0 00001 */

```

```

#define IP6OPT_JUMBO          0xc2 /* 11 0 00010 */
#define IP6OPT_NSAP_ADDR      0xc3 /* 11 0 00011 */
#define IP6OPT_TUNNEL_LIMIT   0x04 /* 00 0 00100 */
#define IP6OPT_ROUTER_ALERT   0x05 /* 00 0 00101 */

/* Jumbo Payload Option */
struct ip6_opt_jumbo {
    uint8_t ip6oj_type;
    uint8_t ip6oj_len;
    uint8_t ip6oj_jumbo_len[4];
};
#define IP6OPT_JUMBO_LEN      6

/* NSAP Address Option */
struct ip6_opt_nsap {
    uint8_t ip6on_type;
    uint8_t ip6on_len;
    uint8_t ip6on_src_nsap_len;
    uint8_t ip6on_dst_nsap_len;
    /* followed by source NSAP */
    /* followed by destination NSAP */
};

/* Tunnel Limit Option */
struct ip6_opt_tunnel {
    uint8_t ip6ot_type;
    uint8_t ip6ot_len;
    uint8_t ip6ot_encap_limit;
};

/* Router Alert Option */
struct ip6_opt_router {
    uint8_t ip6or_type;
    uint8_t ip6or_len;
    uint8_t ip6or_value[2];
};

/* Router alert values (in network byte order) */
#ifdef _BIG_ENDIAN
#define IP6_ALERT_MLD          0x0000
#define IP6_ALERT_RSVP        0x0001
#define IP6_ALERT_AN           0x0002
#else
#define IP6_ALERT_MLD          0x0000
#define IP6_ALERT_RSVP        0x0100
#define IP6_ALERT_AN           0x0200
#endif

```

2.2. The icmp6_hdr Structure

The ICMPv6 header is needed by numerous IPv6 applications including Ping, Traceroute, router discovery daemons, and neighbor discovery daemons. The following structure is defined as a result of including `<netinet/icmp6.h>`. Note that this is a new header.

```
struct icmp6_hdr {
    uint8_t      icmp6_type;    /* type field */
    uint8_t      icmp6_code;    /* code field */
    uint16_t     icmp6_cksum;   /* checksum field */
    union {
        uint32_t icmp6_un_data32[1]; /* type-specific field */
        uint16_t icmp6_un_data16[2]; /* type-specific field */
        uint8_t  icmp6_un_data8[4];  /* type-specific field */
    } icmp6_dataun;
};

#define icmp6_data32      icmp6_dataun.icmp6_un_data32
#define icmp6_data16      icmp6_dataun.icmp6_un_data16
#define icmp6_data8       icmp6_dataun.icmp6_un_data8
#define icmp6_pptr        icmp6_data32[0] /* parameter prob */
#define icmp6_mtu         icmp6_data32[0] /* packet too big */
#define icmp6_id          icmp6_data16[0] /* echo request/reply */
#define icmp6_seq         icmp6_data16[1] /* echo request/reply */
#define icmp6_maxdelay    icmp6_data16[0] /* mcast group
                                         membership */
```

2.2.1. ICMPv6 Type and Code Values

In addition to a common structure for the ICMPv6 header, common definitions are required for the ICMPv6 type and code fields. The following constants are also defined as a result of including `<netinet/icmp6.h>`.

```
#define ICMP6_DST_UNREACH          1
#define ICMP6_PACKET_TOO_BIG      2
#define ICMP6_TIME_EXCEEDED       3
#define ICMP6_PARAM_PROB          4

#define ICMP6_INFOMSG_MASK 0x80 /* all informational
                                messages */

#define ICMP6_ECHO_REQUEST         128
#define ICMP6_ECHO_REPLY          129

#define ICMP6_DST_UNREACH_NOROUTE 0 /* no route to
                                destination */
```



```

#define ICMP6_DST_UNREACH_ADMIN      1 /* communication with
                                         destination */
                                         /* admin. prohibited */
#define ICMP6_DST_UNREACH_BEYONDScope 2 /* beyond scope of source
                                         address */
#define ICMP6_DST_UNREACH_ADDR      3 /* address unreachable */
#define ICMP6_DST_UNREACH_NOPORT    4 /* bad port */

#define ICMP6_TIME_EXCEED_TRANSIT    0 /* Hop Limit == 0 in
                                         transit */
#define ICMP6_TIME_EXCEED_REASSEMBLY 1 /* Reassembly time out */

#define ICMP6_PARAMPROB_HEADER      0 /* erroneous header
                                         field */
#define ICMP6_PARAMPROB_NEXTHEADER  1 /* unrecognized
                                         Next Header */
#define ICMP6_PARAMPROB_OPTION      2 /* unrecognized
                                         IPv6 option */

```

The five ICMP message types defined by IPv6 neighbor discovery (133-137) are defined in the next section.

2.2.2. ICMPv6 Neighbor Discovery Definitions

The following structures and definitions are defined as a result of including <netinet/icmp6.h>.

```

#define ND_ROUTER_SOLICIT            133
#define ND_ROUTER_ADVERT             134
#define ND_NEIGHBOR_SOLICIT         135
#define ND_NEIGHBOR_ADVERT          136
#define ND_REDIRECT                  137

struct nd_router_solicit {           /* router solicitation */
    struct icmp6_hdr nd_rs_hdr;
    /* could be followed by options */
};

#define nd_rs_type                    nd_rs_hdr.icmp6_type
#define nd_rs_code                    nd_rs_hdr.icmp6_code
#define nd_rs_cksum                   nd_rs_hdr.icmp6_cksum
#define nd_rs_reserved                nd_rs_hdr.icmp6_data32[0]

```

```

struct nd_router_advert {          /* router advertisement */
    struct icmp6_hdr nd_ra_hdr;
    uint32_t nd_ra_reachable; /* reachable time */
    uint32_t nd_ra_retransmit; /* retransmit timer */
    /* could be followed by options */
};

#define nd_ra_type          nd_ra_hdr.icmp6_type
#define nd_ra_code          nd_ra_hdr.icmp6_code
#define nd_ra_cksum         nd_ra_hdr.icmp6_cksum
#define nd_ra_curhoplimit   nd_ra_hdr.icmp6_data8[0]
#define nd_ra_flags_reserved nd_ra_hdr.icmp6_data8[1]
#define ND_RA_FLAG_MANAGED  0x80
#define ND_RA_FLAG_OTHER    0x40
#define nd_ra_router_lifetime nd_ra_hdr.icmp6_data16[1]

struct nd_neighbor_solicit { /* neighbor solicitation */
    struct icmp6_hdr nd_ns_hdr;
    struct in6_addr nd_ns_target; /* target address */
    /* could be followed by options */
};

#define nd_ns_type          nd_ns_hdr.icmp6_type
#define nd_ns_code          nd_ns_hdr.icmp6_code
#define nd_ns_cksum         nd_ns_hdr.icmp6_cksum
#define nd_ns_reserved      nd_ns_hdr.icmp6_data32[0]

struct nd_neighbor_advert { /* neighbor advertisement */
    struct icmp6_hdr nd_na_hdr;
    struct in6_addr nd_na_target; /* target address */
    /* could be followed by options */
};

#define nd_na_type          nd_na_hdr.icmp6_type
#define nd_na_code          nd_na_hdr.icmp6_code
#define nd_na_cksum         nd_na_hdr.icmp6_cksum
#define nd_na_flags_reserved nd_na_hdr.icmp6_data32[0]
#if BYTE_ORDER == BIG_ENDIAN
#define ND_NA_FLAG_ROUTER    0x80000000
#define ND_NA_FLAG_SOLICITED 0x40000000
#define ND_NA_FLAG_OVERRIDE 0x20000000
#else /* BYTE_ORDER == LITTLE_ENDIAN */
#define ND_NA_FLAG_ROUTER    0x00000080
#define ND_NA_FLAG_SOLICITED 0x00000040
#define ND_NA_FLAG_OVERRIDE 0x00000020
#endif
#define nd_na_flags_reserved nd_na_hdr.icmp6_data32[0]

```

```

struct nd_redirect {          /* redirect */
    struct icmp6_hdr  nd_rd_hdr;
    struct in6_addr   nd_rd_target; /* target address */
    struct in6_addr   nd_rd_dst;    /* destination address */
    /* could be followed by options */
};

#define nd_rd_type          nd_rd_hdr.icmp6_type
#define nd_rd_code          nd_rd_hdr.icmp6_code
#define nd_rd_cksum         nd_rd_hdr.icmp6_cksum
#define nd_rd_reserved      nd_rd_hdr.icmp6_data32[0]

struct nd_opt_hdr {          /* Neighbor discovery option header */
    uint8_t  nd_opt_type;
    uint8_t  nd_opt_len;      /* in units of 8 octets */
    /* followed by option specific data */
};

#define ND_OPT_SOURCE_LINKADDR      1
#define ND_OPT_TARGET_LINKADDR      2
#define ND_OPT_PREFIX_INFORMATION   3
#define ND_OPT_REDIRECTED_HEADER    4
#define ND_OPT_MTU                   5

struct nd_opt_prefix_info {   /* prefix information */
    uint8_t  nd_opt_pi_type;
    uint8_t  nd_opt_pi_len;
    uint8_t  nd_opt_pi_prefix_len;
    uint8_t  nd_opt_pi_flags_reserved;
    uint32_t nd_opt_pi_valid_time;
    uint32_t nd_opt_pi_preferred_time;
    uint32_t nd_opt_pi_reserved2;
    struct in6_addr nd_opt_pi_prefix;
};

#define ND_OPT_PI_FLAG_ONLINK      0x80
#define ND_OPT_PI_FLAG_AUTO       0x40

struct nd_opt_rd_hdr {        /* redirected header */
    uint8_t  nd_opt_rh_type;
    uint8_t  nd_opt_rh_len;
    uint16_t nd_opt_rh_reserved1;
    uint32_t nd_opt_rh_reserved2;
    /* followed by IP header and data */
};

```

```

struct nd_opt_mtu {                /* MTU option */
    uint8_t    nd_opt_mtu_type;
    uint8_t    nd_opt_mtu_len;
    uint16_t   nd_opt_mtu_reserved;
    uint32_t   nd_opt_mtu_mtu;
};

```

We note that the `nd_na_flags_reserved` flags have the same byte ordering problems as we showed with `ip6f_offlg`.

2.2.3. Multicast Listener Discovery Definitions

The following structures and definitions are defined as a result of including `<netinet/icmp6.h>`.

```

#define MLD_LISTENER_QUERY          130
#define MLD_LISTENER_REPORT         131
#define MLD_LISTENER_REDUCTION      132

struct mld_hdr {
    struct icmp6_hdr  mld_icmp6_hdr;
    struct in6_addr   mld_addr; /* multicast address */
};
#define mld_type          mld_icmp6_hdr.icmp6_type
#define mld_code          mld_icmp6_hdr.icmp6_code
#define mld_cksum         mld_icmp6_hdr.icmp6_cksum
#define mld_maxdelay      mld_icmp6_hdr.icmp6_data16[0]
#define mld_reserved      mld_icmp6_hdr.icmp6_data16[1]

```

2.2.4. ICMPv6 Router Renumbering Definitions

The following structures and definitions are defined as a result of including `<netinet/icmp6.h>`.

```

#define ICMP6_ROUTER_RENUMBERING     138 /* router renumbering */

struct icmp6_router_renum { /* router renumbering header */
    struct icmp6_hdr  rr_hdr;
    uint8_t           rr_segnum;
    uint8_t           rr_flags;
    uint16_t          rr_maxdelay;
    uint32_t          rr_reserved;
};
#define rr_type          rr_hdr.icmp6_type
#define rr_code          rr_hdr.icmp6_code
#define rr_cksum         rr_hdr.icmp6_cksum
#define rr_segnum        rr_hdr.icmp6_data32[0]

```

```

/* Router renumbering flags */
#define ICMP6_RR_FLAGS_TEST      0x80
#define ICMP6_RR_FLAGS_REQRESULT 0x40
#define ICMP6_RR_FLAGS_FORCEAPPLY 0x20
#define ICMP6_RR_FLAGS_SPECSITE  0x10
#define ICMP6_RR_FLAGS_PREVDONE  0x08

struct rr_pco_match {    /* match prefix part */
    uint8_t      rpm_code;
    uint8_t      rpm_len;
    uint8_t      rpm_ordinal;
    uint8_t      rpm_matchlen;
    uint8_t      rpm_minlen;
    uint8_t      rpm_maxlen;
    uint16_t     rpm_reserved;
    struct in6_addr rpm_prefix;
};

/* PCO code values */
#define RPM_PCO_ADD      1
#define RPM_PCO_CHANGE   2
#define RPM_PCO_SETGLOBAL 3

struct rr_pco_use {    /* use prefix part */
    uint8_t      rpu_uselen;
    uint8_t      rpu_keeplen;
    uint8_t      rpu_ramask;
    uint8_t      rpu_raflags;
    uint32_t     rpu_vltime;
    uint32_t     rpu_pltime;
    uint32_t     rpu_flags;
    struct in6_addr rpu_prefix;
};
#define ICMP6_RR_PCOUSE_RAFLAGS_ONLINK  0x20
#define ICMP6_RR_PCOUSE_RAFLAGS_AUTO    0x10

#if BYTE_ORDER == BIG_ENDIAN
#define ICMP6_RR_PCOUSE_FLAGS_DECRVLTIME 0x80000000
#define ICMP6_RR_PCOUSE_FLAGS_DECRPLTIME 0x40000000
#elif BYTE_ORDER == LITTLE_ENDIAN
#define ICMP6_RR_PCOUSE_FLAGS_DECRVLTIME 0x80
#define ICMP6_RR_PCOUSE_FLAGS_DECRPLTIME 0x40
#endif
#endif

```

```

struct rr_result {      /* router renumbering result message */
    uint16_t            rrr_flags;
    uint8_t             rrr_ordinal;
    uint8_t             rrr_matchedlen;
    uint32_t            rrr_ifid;
    struct in6_addr      rrr_prefix;
};

#if BYTE_ORDER == BIG_ENDIAN
#define ICMP6_RR_RESULT_FLAGS_OOB        0x0002
#define ICMP6_RR_RESULT_FLAGS_FORBIDDEN  0x0001
#elif BYTE_ORDER == LITTLE_ENDIAN
#define ICMP6_RR_RESULT_FLAGS_OOB        0x0200
#define ICMP6_RR_RESULT_FLAGS_FORBIDDEN  0x0100
#endif

```

2.3. Address Testing Macros

The basic API ([RFC-3493]) defines some macros for testing an IPv6 address for certain properties. This API extends those definitions with additional address testing macros, defined as a result of including `<netinet/in.h>`.

```

int  IN6_ARE_ADDR_EQUAL(const struct in6_addr *,
                        const struct in6_addr *);

```

This macro returns non-zero if the addresses are equal; otherwise it returns zero.

2.4. Protocols File

Many hosts provide the file `/etc/protocols` that contains the names of the various IP protocols and their protocol number (e.g., the value of the protocol field in the IPv4 header for that protocol, such as 1 for ICMP). Some programs then call the function `getprotobyname()` to obtain the protocol value that is then specified as the third argument to the `socket()` function. For example, the Ping program contains code of the form

```

struct protoent  *proto;

proto = getprotobyname("icmp");

s = socket(AF_INET, SOCK_RAW, proto->p_proto);

```

Common names are required for the new IPv6 protocols in this file, to provide portability of applications that call the `getprotoXXX()` functions.

We define the following protocol names with the values shown. These are taken under <http://www.iana.org/numbers.html>.

hopopt	0	# hop-by-hop options for ipv6
ipv6	41	# ipv6
ipv6-route	43	# routing header for ipv6
ipv6-frag	44	# fragment header for ipv6
esp	50	# encapsulating security payload for ipv6
ah	51	# authentication header for ipv6
ipv6-icmp	58	# icmp for ipv6
ipv6-nonxt	59	# no next header for ipv6
ipv6-opts	60	# destination options for ipv6

3. IPv6 Raw Sockets

Raw sockets bypass the transport layer (TCP or UDP). With IPv4, raw sockets are used to access ICMPv4, IGMPv4, and to read and write IPv4 datagrams containing a protocol field that the kernel does not process. An example of the latter is a routing daemon for OSPF, since it uses IPv4 protocol field 89. With IPv6 raw sockets will be used for ICMPv6 and to read and write IPv6 datagrams containing a Next Header field that the kernel does not process. Examples of the latter are a routing daemon for OSPF for IPv6 and RSVP (protocol field 46).

All data sent via raw sockets must be in network byte order and all data received via raw sockets will be in network byte order. This differs from the IPv4 raw sockets, which did not specify a byte ordering and used the host's byte order for certain IP header fields.

Another difference from IPv4 raw sockets is that complete packets (that is, IPv6 packets with extension headers) cannot be sent or received using the IPv6 raw sockets API. Instead, ancillary data objects are used to transfer the extension headers and hoplimit information, as described in Section 6. Should an application need access to the complete IPv6 packet, some other technique, such as the datalink interfaces BPF or DLPI, must be used.

All fields except the flow label in the IPv6 header that an application might want to change (i.e., everything other than the version number) can be modified using ancillary data and/or socket options by the application for output. All fields except the flow label in a received IPv6 header (other than the version number and Next Header fields) and all extension headers that an application might want to know are also made available to the application as ancillary data on input. Hence there is no need for a socket option

similar to the IPv4 `IP_HDRINCL` socket option and on receipt the application will only receive the payload i.e., the data after the IPv6 header and all the extension headers.

This API does not define access to the flow label field, because today there is no standard usage of the field.

When writing to a raw socket the kernel will automatically fragment the packet if its size exceeds the path MTU, inserting the required fragment headers. On input the kernel reassembles received fragments, so the reader of a raw socket never sees any fragment headers.

When we say "an ICMPv6 raw socket" we mean a socket created by calling the socket function with the three arguments `AF_INET6`, `SOCK_RAW`, and `IPPROTO_ICMPV6`.

Most IPv4 implementations give special treatment to a raw socket created with a third argument to `socket()` of `IPPROTO_RAW`, whose value is normally 255, to have it mean that the application will send down complete packets including the IPv4 header. (Note: This feature was added to IPv4 in 1988 by Van Jacobson to support traceroute, allowing a complete IP header to be passed by the application, before the `IP_HDRINCL` socket option was added.) We note that `IPPROTO_RAW` has no special meaning to an IPv6 raw socket (and the IANA currently reserves the value of 255 when used as a next-header field).

3.1. Checksums

The kernel will calculate and insert the ICMPv6 checksum for ICMPv6 raw sockets, since this checksum is mandatory.

For other raw IPv6 sockets (that is, for raw IPv6 sockets created with a third argument other than `IPPROTO_ICMPV6`), the application must set the new `IPV6_CHECKSUM` socket option to have the kernel (1) compute and store a checksum for output, and (2) verify the received checksum on input, discarding the packet if the checksum is in error. This option prevents applications from having to perform source address selection on the packets they send. The checksum will incorporate the IPv6 pseudo-header, defined in Section 8.1 of [RFC-2460]. This new socket option also specifies an integer offset into the user data of where the checksum is located.

```
int offset = 2;
setsockopt(fd, IPPROTO_IPV6, IPV6_CHECKSUM, &offset,
           sizeof(offset));
```


By default, this socket option is disabled. Setting the offset to -1 also disables the option. By disabled we mean (1) the kernel will not calculate and store a checksum for outgoing packets, and (2) the kernel will not verify a checksum for received packets.

This option assumes the use of the 16-bit one's complement of the one's complement sum as the checksum algorithm and that the checksum field is aligned on a 16-bit boundary. Thus, specifying a positive odd value as offset is invalid, and `setsockopt()` will fail for such offset values.

An attempt to set `IPV6_CHECKSUM` for an ICMPv6 socket will fail. Also, an attempt to set or get `IPV6_CHECKSUM` for a non-raw IPv6 socket will fail.

(Note: Since the checksum is always calculated by the kernel for an ICMPv6 socket, applications are not able to generate ICMPv6 packets with incorrect checksums (presumably for testing purposes) using this API.)

3.2. ICMPv6 Type Filtering

ICMPv4 raw sockets receive most ICMPv4 messages received by the kernel. (We say "most" and not "all" because Berkeley-derived kernels never pass echo requests, timestamp requests, or address mask requests to a raw socket. Instead these three messages are processed entirely by the kernel.) But ICMPv6 is a superset of ICMPv4, also including the functionality of ICMPv4 and ARPv4. This means that an ICMPv6 raw socket can potentially receive many more messages than would be received with an ICMPv4 raw socket: ICMP messages similar to ICMPv4, along with neighbor solicitations, neighbor advertisements, and the three multicast listener discovery messages.

Most applications using an ICMPv6 raw socket care about only a small subset of the ICMPv6 message types. To transfer extraneous ICMPv6 messages from the kernel to user can incur a significant overhead. Therefore this API includes a method of filtering ICMPv6 messages by the ICMPv6 type field.

Each ICMPv6 raw socket has an associated filter whose datatype is defined as

```
struct icmp6_filter;
```

This structure, along with the macros and constants defined later in this section, are defined as a result of including the `<netinet/icmp6.h>`.

The current filter is fetched and stored using `getsockopt()` and `setsockopt()` with a level of `IPPROTO_ICMPV6` and an option name of `ICMP6_FILTER`.

Six macros operate on an `icmp6_filter` structure:

```
void ICMP6_FILTER_SETPASSALL (struct icmp6_filter *);
void ICMP6_FILTER_SETBLOCKALL(struct icmp6_filter *);

void ICMP6_FILTER_SETPASS ( int, struct icmp6_filter *);
void ICMP6_FILTER_SETBLOCK( int, struct icmp6_filter *);

int  ICMP6_FILTER_WILLPASS (int,
                             const struct icmp6_filter *);
int  ICMP6_FILTER_WILLBLOCK(int,
                             const struct icmp6_filter *);
```

The first argument to the last four macros (an integer) is an ICMPv6 message type, between 0 and 255. The pointer argument to all six macros is a pointer to a filter that is modified by the first four macros and is examined by the last two macros.

The first two macros, `SETPASSALL` and `SETBLOCKALL`, let us specify that all ICMPv6 messages are passed to the application or that all ICMPv6 messages are blocked from being passed to the application.

The next two macros, `SETPASS` and `SETBLOCK`, let us specify that messages of a given ICMPv6 type should be passed to the application or not passed to the application (blocked).

The final two macros, `WILLPASS` and `WILLBLOCK`, return true or false depending whether the specified message type is passed to the application or blocked from being passed to the application by the filter pointed to by the second argument.

When an ICMPv6 raw socket is created, it will by default pass all ICMPv6 message types to the application.

As an example, a program that wants to receive only router advertisements could execute the following:

```
struct icmp6_filter  myfilt;

fd = socket(AF_INET6, SOCK_RAW, IPPROTO_ICMPV6);

ICMP6_FILTER_SETBLOCKALL(&myfilt);
ICMP6_FILTER_SETPASS(ND_ROUTER_ADVERT, &myfilt);
setsockopt(fd, IPPROTO_ICMPV6, ICMP6_FILTER, &myfilt,
```

```
sizeof(myfilt));
```

The filter structure is declared and then initialized to block all messages types. The filter structure is then changed to allow router advertisement messages to be passed to the application and the filter is installed using `setsockopt()`.

In order to clear an installed filter the application can issue a `setsockopt` for `ICMP6_FILTER` with a zero length. When no such filter has been installed, `getsockopt()` will return the kernel default filter.

The `icmp6_filter` structure is similar to the `fd_set` datatype used with the `select()` function in the sockets API. The `icmp6_filter` structure is an opaque datatype and the application should not care how it is implemented. All the application does with this datatype is allocate a variable of this type, pass a pointer to a variable of this type to `getsockopt()` and `setsockopt()`, and operate on a variable of this type using the six macros that we just defined.

Nevertheless, it is worth showing a simple implementation of this datatype and the six macros.

```
struct icmp6_filter {
    uint32_t icmp6_filt[8]; /* 8*32 = 256 bits */
};

#define ICMP6_FILTER_WILLPASS(type, filterp) \
    (((filterp)->icmp6_filt[(type) >> 5]) & \
     (1 << ((type) & 31))) != 0
#define ICMP6_FILTER_WILLBLOCK(type, filterp) \
    (((filterp)->icmp6_filt[(type) >> 5]) & \
     (1 << ((type) & 31))) == 0
#define ICMP6_FILTER_SETPASS(type, filterp) \
    (((filterp)->icmp6_filt[(type) >> 5]) |= \
     (1 << ((type) & 31)))
#define ICMP6_FILTER_SETBLOCK(type, filterp) \
    (((filterp)->icmp6_filt[(type) >> 5]) &= \
     ~(1 << ((type) & 31)))
#define ICMP6_FILTER_SETPASSALL(filterp) \
    memset((filterp), 0xFF, sizeof(struct icmp6_filter))
#define ICMP6_FILTER_SETBLOCKALL(filterp) \
    memset((filterp), 0, sizeof(struct icmp6_filter))
```

(Note: These sample definitions have two limitations that an implementation may want to change. The first four macros evaluate their first argument two times. The second two macros require the inclusion of the `<string.h>` header for the `memset()` function.)

3.3. ICMPv6 Verification of Received Packets

The protocol stack will verify the ICMPv6 checksum and discard any packets with invalid checksums.

An implementation might perform additional validity checks on the ICMPv6 message content and discard malformed packets. However, a portable application must not assume that such validity checks have been performed.

The protocol stack should not automatically discard packets if the ICMP type is unknown to the stack. For extensibility reasons received ICMP packets with any type (informational or error) must be passed to the applications (subject to ICMP6_FILTER filtering on the type value and the checksum verification).

4. Access to IPv6 and Extension Headers

Applications need to be able to control IPv6 header and extension header content when sending as well as being able to receive the content of these headers. This is done by defining socket option types which can be used both with `setsockopt` and with ancillary data. Ancillary data is discussed in Appendix A. The following optional information can be exchanged between the application and the kernel:

1. The send/receive interface and source/destination address,
2. The hop limit,
3. Next hop address,
4. The traffic class,
5. Routing header,
6. Hop-by-Hop options header, and
7. Destination options header.

First, to receive any of this optional information (other than the next hop address, which can only be set) on a UDP or raw socket, the application must call `setsockopt()` to turn on the corresponding flag:

```
int on = 1;

setsockopt(fd, IPPROTO_IPV6, IPV6_RECVPKTINFO, &on, sizeof(on));
setsockopt(fd, IPPROTO_IPV6, IPV6_RECVHOPLIMIT, &on, sizeof(on));
setsockopt(fd, IPPROTO_IPV6, IPV6_RECVRTHDR, &on, sizeof(on));
setsockopt(fd, IPPROTO_IPV6, IPV6_RECVHOPOPTS, &on, sizeof(on));
setsockopt(fd, IPPROTO_IPV6, IPV6_RECVDSTOPTS, &on, sizeof(on));
setsockopt(fd, IPPROTO_IPV6, IPV6_RECVTCLASS, &on, sizeof(on));
```

When any of these options are enabled, the corresponding data is returned as control information by `recvmsg()`, as one or more ancillary data objects.

This document does not define how to receive the optional information on a TCP socket. See Section 4.1 for more details.

Two different mechanisms exist for sending this optional information:

1. Using `setsockopt` to specify the option content for a socket. These are known "sticky" options since they affect all transmitted packets on the socket until either a new `setsockopt` is done or the options are overridden using ancillary data.
2. Using ancillary data to specify the option content for a single datagram. This only applies to datagram and raw sockets; not to TCP sockets.

The three socket option parameters and the three `cmsghdr` fields that describe the options/ancillary data objects are summarized as:

opt_level/ cmsg_level	optname/ cmsg_type	optval/ cmsg_data[]
-----	-----	-----
IPPROTO_IPV6	IPV6_PKTINFO	in6_pktinfo structure
IPPROTO_IPV6	IPV6_HOPLIMIT	int
IPPROTO_IPV6	IPV6_NEXTHOP	socket address structure
IPPROTO_IPV6	IPV6_RTHDR	ip6_rthdr structure
IPPROTO_IPV6	IPV6_HOPOPTS	ip6_hbh structure
IPPROTO_IPV6	IPV6_DSTOPTS	ip6_dest structure
IPPROTO_IPV6	IPV6_RTHDRDSTOPTS	ip6_dest structure
IPPROTO_IPV6	IPV6_TCLASS	int

(Note: `IPV6_HOPLIMIT` can be used as ancillary data items only)

All these options are described in detail in Section 6, 7, 8 and 9. All the constants beginning with `IPV6_` are defined as a result of including `<netinet/in.h>`.

Note: We intentionally use the same constant for the `cmsg_level` member as is used as the second argument to `getsockopt()` and `setsockopt()` (what is called the "level"), and the same constant for the `cmsg_type` member as is used as the third argument to `getsockopt()` and `setsockopt()` (what is called the "option name").

Issuing `getsockopt()` for the above options will return the sticky option value i.e., the value set with `setsockopt()`. If no sticky option value has been set `getsockopt()` will return the following values:

- For the `IPV6_PKTINFO` option, it will return an `in6_pktinfo` structure with `ip6_addr` being `in6addr_any` and `ip6_ifindex` being zero.
- For the `IPV6_TCLASS` option, it will return the kernel default value.
- For other options, it will indicate the lack of the option value with `optlen` being zero.

The application does not explicitly need to access the data structures for the Routing header, Hop-by-Hop options header, and Destination options header, since the API to these features is through a set of `inet6_rth_XXX()` and `inet6_opt_XXX()` functions that we define in Section 7 and Section 10. Those functions simplify the interface to these features instead of requiring the application to know the intimate details of the extension header formats.

When specifying extension headers, this API assumes the header ordering and the number of occurrences of each header as described in [RFC-2460]. More details about the ordering issue will be discussed in Section 12.

4.1. TCP Implications

It is not possible to use ancillary data to transmit the above options for TCP since there is not a one-to-one mapping between send operations and the TCP segments being transmitted. Instead an application can use `setsockopt` to specify them as sticky options. When the application uses `setsockopt` to specify the above options it is expected that TCP will start using the new information when sending segments. However, TCP may or may not use the new information when retransmitting segments that were originally sent when the old sticky options were in effect.

It is unclear how a TCP application can use received information (such as extension headers) due to the lack of mapping between received TCP segments and receive operations. In particular, the received information could not be used for access control purposes like on UDP and raw sockets.

This specification therefore does not define how to get the received information on TCP sockets. The result of the IPV6_RECVxxx options on a TCP socket is undefined as well.

4.2. UDP and Raw Socket Implications

The receive behavior for UDP and raw sockets is quite straightforward. After the application has enabled an IPV6_RECVxxx socket option it will receive ancillary data items for every `recvmsg()` call containing the requested information. However, if the information is not present in the packet the ancillary data item will not be included. For example, if the application enables IPV6_RECVRTHDR and a received datagram does not contain a Routing header there will not be an IPV6_RTHDR ancillary data item. Note that due to buffering in the socket implementation there might be some packets queued when an IPV6_RECVxxx option is enabled and they might not have the ancillary data information.

For sending the application has the choice between using sticky options and ancillary data. The application can also use both having the sticky options specify the "default" and using ancillary data to override the default options.

When an ancillary data item is specified in a call to `sendmsg()`, the item will override an existing sticky option of the same name (if previously specified). For example, if the application has set IPV6_RTHDR using a sticky option and later passes IPV6_RTHDR as ancillary data this will override the IPV6_RTHDR sticky option and the routing header of the outgoing packet will be from the ancillary data item, not from the sticky option. Note, however, that other sticky options than IPV6_RTHDR will not be affected by the IPV6_RTHDR ancillary data item; the overriding mechanism only works for the same type of sticky options and ancillary data items.

(Note: the overriding rule is different from the one in RFC 2292. In RFC 2292, an ancillary data item overrode all sticky options previously defined. This was reasonable, because sticky options could only be specified as a set by a single socket option. However, in this API, each option is separated so that it can be specified as a single sticky option. Additionally, there are much more ancillary data items and sticky options than in RFC 2292, including ancillary-only one. Thus, it should be natural for application programmers to separate the overriding rule as well.)

An application can also temporarily disable a particular sticky option by specifying a corresponding ancillary data item that could disable the sticky option when being used as an argument for a socket option. For example, if the application has set IPV6_HOPOPTS as a

sticky option and later passes `IPV6_HOPOPTS` with a zero length as an ancillary data item, the packet will not have a Hop-by-Hop options header.

5. Extensions to Socket Ancillary Data

This specification uses ancillary data as defined in Posix with some compatible extensions, which are described in the following subsections. Section 20 will provide a detailed overview of ancillary data and related structures and macros, including the extensions.

5.1. `CMSG_NXTHDR`

```
struct cmsghdr *CMSG_NXTHDR(const struct msghdr *mhdr,  
                             const struct cmsghdr *cmsg);
```

`CMSG_NXTHDR()` returns a pointer to the `cmsghdr` structure describing the next ancillary data object. `Mhdr` is a pointer to a `msghdr` structure and `cmsg` is a pointer to a `cmsghdr` structure. If there is not another ancillary data object, the return value is `NULL`.

The following behavior of this macro is new to this API: if the value of the `cmsg` pointer is `NULL`, a pointer to the `cmsghdr` structure describing the first ancillary data object is returned. That is, `CMSG_NXTHDR(mhdr, NULL)` is equivalent to `CMSG_FIRSTHDR(mhdr)`. If there are no ancillary data objects, the return value is `NULL`.

5.2. `CMSG_SPACE`

```
socklen_t CMSG_SPACE(socklen_t length);
```

This macro is new with this API. Given the length of an ancillary data object, `CMSG_SPACE()` returns an upper bound on the space required by the object and its `cmsghdr` structure, including any padding needed to satisfy alignment requirements. This macro can be used, for example, when allocating space dynamically for the ancillary data. This macro should not be used to initialize the `cmsg_len` member of a `cmsghdr` structure; instead use the `CMSG_LEN()` macro.

5.3. CMSG_LEN

```
socklen_t CMSG_LEN(socklen_t length);
```

This macro is new with this API. Given the length of an ancillary data object, `CMSG_LEN()` returns the value to store in the `cmsg_len` member of the `cmsg_hdr` structure, taking into account any padding needed to satisfy alignment requirements.

Note the difference between `CMSG_SPACE()` and `CMSG_LEN()`, shown also in the figure in Section 20.2: the former accounts for any required padding at the end of the ancillary data object and the latter is the actual length to store in the `cmsg_len` member of the ancillary data object.

6. Packet Information

There are five pieces of information that an application can specify for an outgoing packet using ancillary data:

1. the source IPv6 address,
2. the outgoing interface index,
3. the outgoing hop limit,
4. the next hop address, and
5. the outgoing traffic class value.

Four similar pieces of information can be returned for a received packet as ancillary data:

1. the destination IPv6 address,
2. the arriving interface index,
3. the arriving hop limit, and
4. the arriving traffic class value.

The first two pieces of information are contained in an `in6_pktinfo` structure that is set with `setsockopt()` or sent as ancillary data with `sendmsg()` and received as ancillary data with `recvmsg()`. This structure is defined as a result of including `<netinet/in.h>`.

```
struct in6_pktinfo {
    struct in6_addr ipi6_addr;    /* src/dst IPv6 address */
    unsigned int    ipi6_ifindex; /* send/recv interface index */
};
```

In the socket option and `cmsg_hdr` level will be `IPPROTO_IPV6`, the type will be `IPV6_PKTINFO`, and the first byte of the option value and `cmsg_data[]` will be the first byte of the `in6_pktinfo` structure. An application can clear any sticky `IPV6_PKTINFO` option by doing a

"regular" `setsockopt` with `ipi6_addr` being `in6addr_any` and `ipi6_ifindex` being zero.

This information is returned as ancillary data by `recvmsg()` only if the application has enabled the `IPV6_RECVPKTINFO` socket option:

```
int on = 1;
setsockopt(fd, IPPROTO_IPV6, IPV6_RECVPKTINFO, &on, sizeof(on));
```

(Note: The hop limit is not contained in the `in6_pktinfo` structure for the following reason. Some UDP servers want to respond to client requests by sending their reply out the same interface on which the request was received and with the source IPv6 address of the reply equal to the destination IPv6 address of the request. To do this the application can enable just the `IPV6_RECVPKTINFO` socket option and then use the received control information from `recvmsg()` as the outgoing control information for `sendmsg()`. The application need not examine or modify the `in6_pktinfo` structure at all. But if the hop limit were contained in this structure, the application would have to parse the received control information and change the hop limit member, since the received hop limit is not the desired value for an outgoing packet.)

6.1. Specifying/Receiving the Interface

Interfaces on an IPv6 node are identified by a small positive integer, as described in Section 4 of [RFC-3493]. That document also describes a function to map an interface name to its interface index, a function to map an interface index to its interface name, and a function to return all the interface names and indexes. Notice from this document that no interface is ever assigned an index of 0.

When specifying the outgoing interface, if the `ipi6_ifindex` value is 0, the kernel will choose the outgoing interface.

The ordering among various options that can specify the outgoing interface, including `IPV6_PKTINFO`, is defined in Section 6.7.

When the `IPV6_RECVPKTINFO` socket option is enabled, the received interface index is always returned as the `ipi6_ifindex` member of the `in6_pktinfo` structure.

6.2. Specifying/Receiving Source/Destination Address

The source IPv6 address can be specified by calling `bind()` before each output operation, but supplying the source address together with the data requires less overhead (i.e., fewer system calls) and requires less state to be stored and protected in a multithreaded application.

When specifying the source IPv6 address as ancillary data, if the `ipi6_addr` member of the `in6_pktinfo` structure is the unspecified address (`IN6ADDR_ANY_INIT` or `in6addr_any`), then (a) if an address is currently bound to the socket, it is used as the source address, or (b) if no address is currently bound to the socket, the kernel will choose the source address. If the `ipi6_addr` member is not the unspecified address, but the socket has already bound a source address, then the `ipi6_addr` value overrides the already-bound source address for this output operation only.

The kernel must verify that the requested source address is indeed a unicast address assigned to the node. When the address is a scoped one, there may be ambiguity about its scope zone. This is particularly the case for link-local addresses. In such a case, the kernel must first determine the appropriate scope zone based on the zone of the destination address or the outgoing interface (if known), then qualify the address. This also means that it is not feasible to specify the source address for a non-binding socket by the `IPV6_PKTINFO` sticky option, unless the outgoing interface is also specified. The application should simply use `bind()` for such purposes.

`IPV6_PKTINFO` can also be used as a sticky option for specifying the socket's default source address. However, the `ipi6_addr` member must be the unspecified address for TCP sockets, because it is not possible to dynamically change the source address of a TCP connection. When the `IPV6_PKTINFO` option is specified for a TCP socket with a non-unspecified address, the call will fail. This restriction should be applied even before the socket binds a specific address.

When the `in6_pktinfo` structure is returned as ancillary data by `recvmsg()`, the `ipi6_addr` member contains the destination IPv6 address from the received packet.

6.3. Specifying/Receiving the Hop Limit

The outgoing hop limit is normally specified with either the `IPV6_UNICAST_HOPS` socket option or the `IPV6_MULTICAST_HOPS` socket option, both of which are described in [RFC-3493]. Specifying the

hop limit as ancillary data lets the application override either the kernel's default or a previously specified value, for either a unicast destination or a multicast destination, for a single output operation. Returning the received hop limit is useful for IPv6 applications that need to verify that the received hop limit is 255 (e.g., that the packet has not been forwarded).

The received hop limit is returned as ancillary data by `recvmsg()` only if the application has enabled the `IPV6_RECVHOPLIMIT` socket option:

```
int on = 1;
setsockopt(fd, IPPROTO_IPV6, IPV6_RECVHOPLIMIT, &on, sizeof(on));
```

In the `cmsg_hdr` structure containing this ancillary data, the `cmsg_level` member will be `IPPROTO_IPV6`, the `cmsg_type` member will be `IPV6_HOPLIMIT`, and the first byte of `cmsg_data[]` will be the first byte of the integer hop limit.

Nothing special need be done to specify the outgoing hop limit: just specify the control information as ancillary data for `sendmsg()`. As specified in [RFC-3493], the interpretation of the integer hop limit value is

```
x < -1:      return an error of EINVAL
x == -1:     use kernel default
0 <= x <= 255: use x
x >= 256:    return an error of EINVAL
```

This API defines `IPV6_HOPLIMIT` as an ancillary-only option, that is, the option name cannot be used as a socket option. This is because [RFC-3493] has more fine-grained socket options; `IPV6_UNICAST_HOPS` and `IPV6_MULTICAST_HOPS`.

6.4. Specifying the Next Hop Address

The `IPV6_NEXTHOP` ancillary data object specifies the next hop for the datagram as a socket address structure. In the `cmsg_hdr` structure containing this ancillary data, the `cmsg_level` member will be `IPPROTO_IPV6`, the `cmsg_type` member will be `IPV6_NEXTHOP`, and the first byte of `cmsg_data[]` will be the first byte of the socket address structure.

This is a privileged option. (Note: It is implementation defined and beyond the scope of this document to define what "privileged" means. Unix systems use this term to mean the process must have an effective user ID of 0.)

This API only defines the case where the socket address contains an IPv6 address (i.e., the `sa_family` member is `AF_INET6`). And, in this case, the node identified by that address must be a neighbor of the sending host. If that address equals the destination IPv6 address of the datagram, then this is equivalent to the existing `SO_DONTROUTE` socket option.

This option does not have any meaning for multicast destinations. In such a case, the specified next hop will be ignored.

When the outgoing interface is specified by `IPV6_PKTINFO` as well, the next hop specified by this option must be reachable via the specified interface.

In order to clear a sticky `IPV6_NEXTHOP` option the application must issue a `setsockopt` for `IPV6_NEXTHOP` with a zero length.

6.5. Specifying/Receiving the Traffic Class value

The outgoing traffic class is normally set to 0. Specifying the traffic class as ancillary data lets the application override either the kernel's default or a previously specified value, for either a unicast destination or a multicast destination, for a single output operation. Returning the received traffic class is useful for programs such as a diffserv debugging tool and for user level ECN (explicit congestion notification) implementation.

The received traffic class is returned as ancillary data by `recvmsg()` only if the application has enabled the `IPV6_RECVTCLASS` socket option:

```
int on = 1;
setsockopt(fd, IPPROTO_IPV6, IPV6_RECVTCLASS, &on, sizeof(on));
```

In the `cmsg_hdr` structure containing this ancillary data, the `cmsg_level` member will be `IPPROTO_IPV6`, the `cmsg_type` member will be `IPV6_TCLASS`, and the first byte of `cmsg_data[]` will be the first byte of the integer traffic class.

To specify the outgoing traffic class value, just specify the control information as ancillary data for `sendmsg()` or using `setsockopt()`. Just like the hop limit value, the interpretation of the integer traffic class value is

```
x < -1:      return an error of EINVAL
x == -1:     use kernel default
0 <= x <= 255: use x
x >= 256:    return an error of EINVAL
```

In order to clear a sticky `IPV6_TCLASS` option the application can specify `-1` as the value.

There are cases where the kernel needs to control the traffic class value and conflicts with the user-specified value on the outgoing traffic. An example is an implementation of ECN in the kernel, setting 2 bits of the traffic class value. In such cases, the kernel should override the user-specified value. On the incoming traffic, the kernel may mask some of the bits in the traffic class field.

6.6. Additional Errors with `sendmsg()` and `setsockopt()`

With the `IPV6_PKTINFO` socket option there are no additional errors possible with the call to `recvmsg()`. But when specifying the outgoing interface or the source address, additional errors are possible from `sendmsg()` or `setsockopt()`. Note that some implementations might only be able to return this type of errors for `setsockopt()`. The following are examples, but some of these may not be provided by some implementations, and some implementations may define additional errors:

<code>ENXIO</code>	The interface specified by <code>ip6_ifindex</code> does not exist.
<code>ENETDOWN</code>	The interface specified by <code>ip6_ifindex</code> is not enabled for IPv6 use.
<code>EADDRNOTAVAIL</code>	<code>ip6_ifindex</code> specifies an interface but the address <code>ip6_addr</code> is not available for use on that interface.
<code>EHOSTUNREACH</code>	No route to the destination exists over the interface specified by <code>ip6_ifindex</code> .

6.7. Summary of Outgoing Interface Selection

This document and [RFC-3493] specify various methods that affect the selection of the packet's outgoing interface. This subsection summarizes the ordering among those in order to ensure deterministic behavior.

For a given outgoing packet on a given socket, the outgoing interface is determined in the following order:

1. if an interface is specified in an `IPV6_PKTINFO` ancillary data item, the interface is used.
2. otherwise, if an interface is specified in an `IPV6_PKTINFO` sticky option, the interface is used.

3. otherwise, if the destination address is a multicast address and the `IPV6_MULTICAST_IF` socket option is specified for the socket, the interface is used.
4. otherwise, if an `IPV6_NEXTHOP` ancillary data item is specified, the interface to the next hop is used.
5. otherwise, if an `IPV6_NEXTHOP` sticky option is specified, the interface to the next hop is used.
6. otherwise, the outgoing interface should be determined in an implementation dependent manner.

The ordering above particularly means if the application specifies an interface by the `IPV6_MULTICAST_IF` socket option (described in [RFC-3493]) as well as specifying a different interface by the `IPV6_PKTINFO` sticky option, the latter will override the former for every multicast packet on the corresponding socket. The reason for the ordering comes from expectation that the source address is specified as well and that the pair of the address and the outgoing interface should be preferred.

In any case, the kernel must also verify that the source and destination addresses do not break their scope zones with regard to the outgoing interface.

7. Routing Header Option

Source routing in IPv6 is accomplished by specifying a Routing header as an extension header. There can be different types of Routing headers, but IPv6 currently defines only the Type 0 Routing header [RFC-2460]. This type supports up to 127 intermediate nodes (limited by the length field in the extension header). With this maximum number of intermediate nodes, a source, and a destination, there are 128 hops.

Source routing with the IPv4 sockets API (the `IP_OPTIONS` socket option) requires the application to build the source route in the format that appears as the IPv4 header option, requiring intimate knowledge of the IPv4 options format. This IPv6 API, however, defines six functions that the application calls to build and examine a Routing header, and the ability to use sticky options or ancillary data to communicate this information between the application and the kernel using the `IPV6_RTHDR` option.

Three functions build a Routing header:

```
inet6_rth_space()    - return #bytes required for Routing header
inet6_rth_init()     - initialize buffer data for Routing header
inet6_rth_add()      - add one IPv6 address to the Routing header
```

Three functions deal with a returned Routing header:

```
inet6_rth_reverse()  - reverse a Routing header
inet6_rth_segments() - return #segments in a Routing header
inet6_rth_getaddr()  - fetch one address from a Routing header
```

The function prototypes for these functions are defined as a result of including `<netinet/in.h>`.

To receive a Routing header the application must enable the `IPV6_RECVRTHDR` socket option:

```
int  on = 1;
setsockopt(fd, IPPROTO_IPV6, IPV6_RECVRTHDR, &on, sizeof(on));
```

Each received Routing header is returned as one ancillary data object described by a `cmsghdr` structure with `cmsg_type` set to `IPV6_RTHDR`. When multiple Routing headers are received, multiple ancillary data objects (with `cmsg_type` set to `IPV6_RTHDR`) will be returned to the application.

To send a Routing header the application specifies it either as ancillary data in a call to `sendmsg()` or using `setsockopt()`. For the sending side, this API assumes the number of occurrences of the Routing header as described in [RFC-2460]. That is, applications can only specify at most one outgoing Routing header.

The application can remove any sticky Routing header by calling `setsockopt()` for `IPV6_RTHDR` with a zero option length.

When using ancillary data a Routing header is passed between the application and the kernel as follows: The `cmsg_level` member has a value of `IPPROTO_IPV6` and the `cmsg_type` member has a value of `IPV6_RTHDR`. The contents of the `cmsg_data[]` member is implementation dependent and should not be accessed directly by the application, but should be accessed using the six functions that we are about to describe.

The following constant is defined as a result of including the `<netinet/in.h>`:

```
#define IPV6_RTHDR_TYPE_0    0 /* IPv6 Routing header type 0 */
```


When a Routing header is specified, the destination address specified for `connect()`, `sendto()`, or `sendmsg()` is the final destination address of the datagram. The Routing header then contains the addresses of all the intermediate nodes.

7.1. `inet6_rth_space`

```
socklen_t inet6_rth_space(int type, int segments);
```

This function returns the number of bytes required to hold a Routing header of the specified type containing the specified number of segments (addresses). For an IPv6 Type 0 Routing header, the number of segments must be between 0 and 127, inclusive. The return value is just the space for the Routing header. When the application uses ancillary data it must pass the returned length to `CMSG_SPACE()` to determine how much memory is needed for the ancillary data object (including the `cmsghdr` structure).

If the return value is 0, then either the type of the Routing header is not supported by this implementation or the number of segments is invalid for this type of Routing header.

(Note: This function returns the size but does not allocate the space required for the ancillary data. This allows an application to allocate a larger buffer, if other ancillary data objects are desired, since all the ancillary data objects must be specified to `sendmsg()` as a single `msg_control` buffer.)

7.2. `inet6_rth_init`

```
void *inet6_rth_init(void *bp, socklen_t bp_len, int type,  
                    int segments);
```

This function initializes the buffer pointed to by `bp` to contain a Routing header of the specified type and sets `ip6r_len` based on the `segments` parameter. `bp_len` is only used to verify that the buffer is large enough. The `ip6r_segleft` field is set to zero; `inet6_rth_add()` will increment it.

When the application uses ancillary data the application must initialize any `cmsghdr` fields.

The caller must allocate the buffer and its size can be determined by calling `inet6_rth_space()`.

Upon success the return value is the pointer to the buffer (`bp`), and this is then used as the first argument to the `inet6_rth_add()` function. Upon an error the return value is `NULL`.

7.3. `inet6_rth_add`

```
int inet6_rth_add(void *bp, const struct in6_addr *addr);
```

This function adds the IPv6 address pointed to by `addr` to the end of the Routing header being constructed.

If successful, the `segleft` member of the Routing Header is updated to account for the new address in the Routing header and the return value of the function is 0. Upon an error the return value of the function is -1.

7.4. `inet6_rth_reverse`

```
int inet6_rth_reverse(const void *in, void *out);
```

This function takes a Routing header extension header (pointed to by the first argument) and writes a new Routing header that sends datagrams along the reverse of that route. The function reverses the order of the addresses and sets the `segleft` member in the new Routing header to the number of segments. Both arguments are allowed to point to the same buffer (that is, the reversal can occur in place).

The return value of the function is 0 on success, or -1 upon an error.

7.5. `inet6_rth_segments`

```
int inet6_rth_segments(const void *bp);
```

This function returns the number of segments (addresses) contained in the Routing header described by `bp`. On success the return value is zero or greater. The return value of the function is -1 upon an error.

7.6. `inet6_rth_getaddr`

```
struct in6_addr *inet6_rth_getaddr(const void *bp, int index);
```

This function returns a pointer to the IPv6 address specified by `index` (which must have a value between 0 and one less than the value returned by `inet6_rth_segments()`) in the Routing header described by `bp`. An application should first call `inet6_rth_segments()` to obtain the number of segments in the Routing header.

Upon an error the return value of the function is `NULL`.

8. Hop-By-Hop Options

A variable number of Hop-by-Hop options can appear in a single Hop-by-Hop options header. Each option in the header is TLV-encoded with a type, length, and value. This IPv6 API defines seven functions that the application calls to build and examine a Hop-by-Hop options header, and the ability to use sticky options or ancillary data to communicate this information between the application and the kernel. This uses the IPV6_HOPOPTS for a Hop-by-Hop options header.

Today several Hop-by-Hop options are defined for IPv6. Two pad options, Pad1 and PadN, are for alignment purposes and are automatically inserted by the `inet6_opt_XXX()` routines and ignored by the `inet6_opt_XXX()` routines on the receive side. This section of the API is therefore defined for other (and future) Hop-by-Hop options that an application may need to specify and receive.

Four functions build an options header:

```
inet6_opt_init()      - initialize buffer data for options header
inet6_opt_append()    - add one TLV option to the options header
inet6_opt_finish()    - finish adding TLV options to the options
                        header
inet6_opt_set_val()    - add one component of the option content to
                        the option
```

Three functions deal with a returned options header:

```
inet6_opt_next()      - extract the next option from the options
                        header
inet6_opt_find()       - extract an option of a specified type from
                        the header
inet6_opt_get_val()    - retrieve one component of the option
                        content
```

Individual Hop-by-Hop options (and Destination options, which are described in Section 9 and are very similar to the Hop-by-Hop options) may have specific alignment requirements. For example, the 4-byte Jumbo Payload length should appear on a 4-byte boundary, and IPv6 addresses are normally aligned on an 8-byte boundary. These requirements and the terminology used with these options are discussed in Section 4.2 and Appendix B of [RFC-2460]. The alignment of first byte of each option is specified by two values, called *x* and *y*, written as "*xn + y*". This states that the option must appear at an integer multiple of *x* bytes from the beginning of the options header (*x* can have the values 1, 2, 4, or 8), plus *y* bytes (*y* can have a value between 0 and 7, inclusive). The Pad1 and PadN options are inserted as needed to maintain the required alignment. The

functions below need to know the alignment of the end of the option (which is always in the form "xn," where x can have the values 1, 2, 4, or 8) and the total size of the data portion of the option. These are passed as the "align" and "len" arguments to `inet6_opt_append()`.

Multiple Hop-by-Hop options must be specified by the application by placing them in a single extension header.

Finally, we note that use of some Hop-by-Hop options or some Destination options, might require special privilege. That is, normal applications (without special privilege) might be forbidden from setting certain options in outgoing packets, and might never see certain options in received packets.

8.1. Receiving Hop-by-Hop Options

To receive a Hop-by-Hop options header the application must enable the `IPV6_RECVHOPOPTS` socket option:

```
int on = 1;
setsockopt(fd, IPPROTO_IPV6, IPV6_RECVHOPOPTS, &on, sizeof(on));
```

When using ancillary data a Hop-by-hop options header is passed between the application and the kernel as follows: The `cmsg_level` member will be `IPPROTO_IPV6` and the `cmsg_type` member will be `IPV6_HOPOPTS`. These options are then processed by calling the `inet6_opt_next()`, `inet6_opt_find()`, and `inet6_opt_get_val()` functions, described in Section 10.

8.2. Sending Hop-by-Hop Options

To send a Hop-by-Hop options header, the application specifies the header either as ancillary data in a call to `sendmsg()` or using `setsockopt()`.

The application can remove any sticky Hop-by-Hop options header by calling `setsockopt()` for `IPV6_HOPOPTS` with a zero option length.

All the Hop-by-Hop options must be specified by a single ancillary data object. The `cmsg_level` member is set to `IPPROTO_IPV6` and the `cmsg_type` member is set to `IPV6_HOPOPTS`. The option is normally constructed using the `inet6_opt_init()`, `inet6_opt_append()`, `inet6_opt_finish()`, and `inet6_opt_set_val()` functions, described in Section 10.

Additional errors may be possible from `sendmsg()` and `setsockopt()` if the specified option is in error.

9. Destination Options

A variable number of Destination options can appear in one or more Destination options headers. As defined in [RFC-2460], a Destination options header appearing before a Routing header is processed by the first destination plus any subsequent destinations specified in the Routing header, while a Destination options header that is not followed by a Routing header is processed only by the final destination. As with the Hop-by-Hop options, each option in a Destination options header is TLV-encoded with a type, length, and value.

9.1. Receiving Destination Options

To receive Destination options header the application must enable the `IPV6_RECVDSTOPTS` socket option:

```
int on = 1;
setsockopt(fd, IPPROTO_IPV6, IPV6_RECVDSTOPTS, &on, sizeof(on));
```

Each Destination options header is returned as one ancillary data object described by a `cmsghdr` structure with `cmsg_level` set to `IPPROTO_IPV6` and `cmsg_type` set to `IPV6_DSTOPTS`.

These options are then processed by calling the `inet6_opt_next()`, `inet6_opt_find()`, and `inet6_opt_get_value()` functions.

9.2. Sending Destination Options

To send a Destination options header, the application specifies it either as ancillary data in a call to `sendmsg()` or using `setsockopt()`.

The application can remove any sticky Destination options header by calling `setsockopt()` for `IPV6_RTHDRDSTOPTS/IPV6_DSTOPTS` with a zero option length.

This API assumes the ordering about extension headers as described in [RFC-2460]. Thus, one set of Destination options can only appear before a Routing header, and one set can only appear after a Routing header (or in a packet with no Routing header). Each set can consist of one or more options but each set is a single extension header.

Today all destination options that an application may want to specify can be put after (or without) a Routing header. Thus, applications should usually need `IPV6_DSTOPTS` only and should avoid using `IPV6_RTHDRDSTOPTS` whenever possible.

When using ancillary data a Destination options header is passed between the application and the kernel as follows: The set preceding a Routing header are specified with the `cmsg_level` member set to `IPPROTO_IPV6` and the `cmsg_type` member set to `IPV6_RTHDRDSTOPTS`. Any `setsockopt` or ancillary data for `IPV6_RTHDRDSTOPTS` is silently ignored when sending packets unless a Routing header is also specified. Note that the "Routing header" here means the one specified by this API. Even when the kernel inserts a routing header in its internal routine (e.g., in a mobile IPv6 stack), the Destination options header specified by `IPV6_RTHDRDSTOPTS` will still be ignored unless the application explicitly specifies its own Routing header.

The set of Destination options after a Routing header, which are also used when no Routing header is present, are specified with the `cmsg_level` member is set to `IPPROTO_IPV6` and the `cmsg_type` member is set to `IPV6_DSTOPTS`.

The Destination options are normally constructed using the `inet6_opt_init()`, `inet6_opt_append()`, `inet6_opt_finish()`, and `inet6_opt_set_val()` functions, described in Section 10.

Additional errors may be possible from `sendmsg()` and `setsockopt()` if the specified option is in error.

10. Hop-by-Hop and Destination Options Processing

Building and parsing the Hop-by-Hop and Destination options is complicated for the reasons given earlier. We therefore define a set of functions to help the application. These functions assume the formatting rules specified in Appendix B in [RFC-2460] i.e., that the largest field is placed last in the option.

The function prototypes for these functions are defined as a result of including `<netinet/in.h>`.

The first 3 functions (`init`, `append`, and `finish`) are used both to calculate the needed buffer size for the options, and to actually encode the options once the application has allocated a buffer for the header. In order to only calculate the size the application must pass a `NULL` `extbuf` and a zero `extlen` to those functions.

10.1. `inet6_opt_init`

```
int inet6_opt_init(void *extbuf, socklen_t extlen);
```

This function returns the number of bytes needed for the empty extension header i.e., without any options. If `extbuf` is not NULL it also initializes the extension header to have the correct length field. In that case if the `extlen` value is not a positive (i.e., non-zero) multiple of 8 the function fails and returns -1.

(Note: since the return value on success is based on a "constant" parameter, i.e., the empty extension header, an implementation may return a constant value. However, this specification does not require the value be constant, and leaves it as implementation dependent. The application should not assume a particular constant value as a successful return value of this function.)

10.2. `inet6_opt_append`

```
int inet6_opt_append(void *extbuf, socklen_t extlen, int offset,
                    uint8_t type, socklen_t len, uint_t align,
                    void **databufp);
```

Offset should be the length returned by `inet6_opt_init()` or a previous `inet6_opt_append()`. This function returns the updated total length taking into account adding an option with length 'len' and alignment 'align'. If `extbuf` is not NULL then, in addition to returning the length, the function inserts any needed pad option, initializes the option (setting the type and length fields) and returns a pointer to the location for the option content in `databufp`. If the option does not fit in the extension header buffer the function returns -1.

Type is the 8-bit option type. Len is the length of the option data (i.e., excluding the option type and option length fields).

Once `inet6_opt_append()` has been called the application can use the `databuf` directly, or use `inet6_opt_set_val()` to specify the content of the option.

The option type must have a value from 2 to 255, inclusive. (0 and 1 are reserved for the Pad1 and PadN options, respectively.)

The option data length must have a value between 0 and 255, inclusive, and is the length of the option data that follows.

The align parameter must have a value of 1, 2, 4, or 8. The align value can not exceed the value of len.

10.3. `inet6_opt_finish`

```
int inet6_opt_finish(void *extbuf, socklen_t extlen, int offset);
```

Offset should be the length returned by `inet6_opt_init()` or `inet6_opt_append()`. This function returns the updated total length taking into account the final padding of the extension header to make it a multiple of 8 bytes. If `extbuf` is not NULL the function also initializes the option by inserting a Pad1 or PadN option of the proper length.

If the necessary pad does not fit in the extension header buffer the function returns -1.

10.4. `inet6_opt_set_val`

```
int inet6_opt_set_val(void *databuf, int offset, void *val,  
                      socklen_t vallen);
```

Databuf should be a pointer returned by `inet6_opt_append()`. This function inserts data items of various sizes in the data portion of the option. Val should point to the data to be inserted. Offset specifies where in the data portion of the option the value should be inserted; the first byte after the option type and length is accessed by specifying an offset of zero.

The caller should ensure that each field is aligned on its natural boundaries as described in Appendix B of [RFC-2460], but the function must not rely on the caller's behavior. Even when the alignment requirement is not satisfied, `inet6_opt_set_val` should just copy the data as required.

The function returns the offset for the next field (i.e., `offset + vallen`) which can be used when composing option content with multiple fields.

10.5. `inet6_opt_next`

```
int inet6_opt_next(void *extbuf, socklen_t extlen, int offset,  
                  uint8_t *typep, socklen_t *lenp,  
                  void **databufp);
```

This function parses received option extension headers returning the next option. Extbuf and extlen specifies the extension header. Offset should either be zero (for the first option) or the length returned by a previous call to `inet6_opt_next()` or `inet6_opt_find()`. It specifies the position where to continue scanning the extension buffer. The next option is returned by updating `typep`, `lenp`, and

databufp. Typep stores the option type, lenp stores the length of the option data (i.e., excluding the option type and option length fields), and databufp points the data field of the option. This function returns the updated "previous" length computed by advancing past the option that was returned. This returned "previous" length can then be passed to subsequent calls to `inet6_opt_next()`. This function does not return any PAD1 or PADN options. When there are no more options or if the option extension header is malformed the return value is -1.

10.6. `inet6_opt_find`

```
int inet6_opt_find(void *extbuf, socklen_t extlen, int offset,
                  uint8_t type, socklen_t *lenp,
                  void **databufp);
```

This function is similar to the previously described `inet6_opt_next()` function, except this function lets the caller specify the option type to be searched for, instead of always returning the next option in the extension header.

If an option of the specified type is located, the function returns the updated "previous" total length computed by advancing past the option that was returned and past any options that didn't match the type. This returned "previous" length can then be passed to subsequent calls to `inet6_opt_find()` for finding the next occurrence of the same option type.

If an option of the specified type is not located, the return value is -1. If the option extension header is malformed, the return value is -1.

10.7. `inet6_opt_get_val`

```
int inet6_opt_get_val(void *databuf, int offset, void *val,
                     socklen_t vallen);
```

Databuf should be a pointer returned by `inet6_opt_next()` or `inet6_opt_find()`. This function extracts data items of various sizes in the data portion of the option. Val should point to the destination for the extracted data. Offset specifies from where in the data portion of the option the value should be extracted; the first byte after the option type and length is accessed by specifying an offset of zero.

It is expected that each field is aligned on its natural boundaries as described in Appendix B of [RFC-2460], but the function must not rely on the alignment.

The function returns the offset for the next field (i.e., offset + vallen) which can be used when extracting option content with multiple fields.

11. Additional Advanced API Functions

11.1. Sending with the Minimum MTU

Unicast applications should usually let the kernel perform path MTU discovery [RFC-1981], as long as the kernel supports it, and should not care about the path MTU. Some applications, however, might not want to incur the overhead of path MTU discovery, especially if the applications only send a single datagram to a destination. A potential example is a DNS server.

[RFC-1981] describes how path MTU discovery works for multicast destinations. From practice in using IPv4 multicast, however, many careless applications that send large multicast packets on the wire have caused implosion of ICMPv4 error messages. The situation can be worse when there is a filtering node that blocks the ICMPv4 messages. Though the filtering issue applies to unicast as well, the impact is much larger in the multicast cases.

Thus, applications sending multicast traffic should explicitly enable path MTU discovery only when they understand that the benefit of possibly larger MTU usage outweighs the possible impact of MTU discovery for active sources across the delivery tree(s). This default behavior is based on the today's practice with IPv4 multicast and path MTU discovery. The behavior may change in the future once it is found that path MTU discovery effectively works with actual multicast applications and network configurations.

This specification defines a mechanism to avoid path MTU discovery by sending at the minimum IPv6 MTU [RFC-2460]. If the packet is larger than the minimum MTU and this feature has been enabled the IP layer will fragment to the minimum MTU. To control the policy about path MTU discovery, applications can use the `IPV6_USE_MIN_MTU` socket option.

As described above, the default policy should depend on whether the destination is unicast or multicast. For unicast destinations path MTU discovery should be performed by default. For multicast destinations path MTU discovery should be disabled by default. This option thus takes the following three types of integer arguments:

- 1: perform path MTU discovery for unicast destinations but do not perform it for multicast destinations. Packets to multicast destinations are therefore sent with the minimum MTU.

0: always perform path MTU discovery.

1: always disable path MTU discovery and send packets at the minimum MTU.

The default value of this option is -1. Values other than -1, 0, and 1 are invalid, and an error EINVAL will be returned for those values.

As an example, if a unicast application intentionally wants to disable path MTU discovery, it will add the following lines:

```
int on = 1;
setsockopt(fd, IPPROTO_IPV6, IPV6_USE_MIN_MTU, &on, sizeof(on));
```

Note that this API intentionally excludes the case where the application wants to perform path MTU discovery for multicast but to disable it for unicast. This is because such usage is not feasible considering a scale of performance issues around whether to do path MTU discovery or not. When path MTU discovery makes sense to a destination but not to a different destination, regardless of whether the destination is unicast or multicast, applications either need to toggle the option between sending such packets on the same socket, or use different sockets for the two classes of destinations.

This option can also be sent as ancillary data. In the cmsghdr structure containing this ancillary data, the cmsg_level member will be IPPROTO_IPV6, the cmsg_type member will be IPV6_USE_MIN_MTU, and the first byte of cmsg_data[] will be the first byte of the integer.

11.2. Sending without Fragmentation

In order to provide for easy porting of existing UDP and raw socket applications IPv6 implementations will, when originating packets, automatically insert a fragment header in the packet if the packet is too big for the path MTU.

Some applications might not want this behavior. An example is traceroute which might want to discover the actual path MTU.

This specification defines a mechanism to turn off the automatic inserting of a fragment header for UDP and raw sockets. This can be enabled using the IPV6_DONTFRAG socket option.

```
int on = 1;
setsockopt(fd, IPPROTO_IPV6, IPV6_DONTFRAG, &on, sizeof(on));
```

By default, this socket option is disabled. Setting the value to 0 also disables the option i.e., reverts to the default behavior of automatic inserting. This option can also be sent as ancillary data. In the `cmsghdr` structure containing this ancillary data, the `cmsg_level` member will be `IPPROTO_IPV6`, the `cmsg_type` member will be `IPV6_DONTFRAG`, and the first byte of `cmsg_data[]` will be the first byte of the integer. This API only specifies the use of this option for UDP and raw sockets, and does not define the usage for TCP sockets.

When the data size is larger than the MTU of the outgoing interface, the packet will be discarded. Applications can know the result by enabling the `IPV6_RECVPATHMTU` option described below and receiving the corresponding ancillary data items. An additional error `EMSGSIZE` may also be returned in some implementations. Note, however, that some other implementations might not be able to return this additional error when sending a message.

11.3. Path MTU Discovery and UDP

UDP and raw socket applications need to be able to determine the "maximum send transport-message size" (Section 5.1 of [RFC-1981]) to a given destination so that those applications can participate in path MTU discovery. This lets those applications send smaller datagrams to the destination, avoiding fragmentation.

This is accomplished using a new ancillary data item (`IPV6_PATHMTU`) which is delivered to `recvmsg()` without any actual data. The application can enable the receipt of `IPV6_PATHMTU` ancillary data items by setting the `IPV6_RECVPATHMTU` socket option.

```
int on = 1;
setsockopt(fd, IPPROTO_IPV6, IPV6_RECVPATHMTU, &on, sizeof(on));
```

By default, this socket option is disabled. Setting the value to 0 also disables the option. This API only specifies the use of this option for UDP and raw sockets, and does not define the usage for TCP sockets.

When the application is sending packets too big for the path MTU `recvmsg()` will return zero (indicating no data) but there will be a `cmsghdr` with `cmsg_type` set to `IPV6_PATHMTU`, and `cmsg_len` will indicate that `cmsg_data` is `sizeof(struct ip6_mtuinfo)` bytes long. This can happen when the sending node receives a corresponding ICMPv6 packet too big error, or when the packet is sent from a socket with the `IPV6_DONTFRAG` option being on and the packet size is larger than the MTU of the outgoing interface. This indication is considered as an ancillary data item for a separate (empty) message. Thus, when

there are buffered messages (i.e., messages that the application has not received yet) on the socket the application will first receive the buffered messages and then receive the indication.

The first byte of `cmsg_data[]` will point to a struct `ip6_mtuinfo` carrying the path MTU to use together with the IPv6 destination address.

```
struct ip6_mtuinfo {
    struct sockaddr_in6 ip6m_addr; /* dst address including
                                   zone ID */
    uint32_t             ip6m_mtu; /* path MTU in host byte order */
};
```

This `cmsghdr` will be passed to every socket that sets the `IPV6_RECVPATHMTU` socket option, even if the socket is non-connected. Note that this also means an application that sets the option may receive an `IPV6_MTU` ancillary data item for each ICMP too big error the node receives, including such ICMP errors caused by other applications on the node. Thus, an application that wants to perform the path MTU discovery by itself needs to keep history of destinations that it has actually sent to and to compare the address returned in the `ip6_mtuinfo` structure to the history. An implementation may choose not to delivery data to a connected socket that has a foreign address that is different than the address specified in the `ip6m_addr` structure.

When an application sends a packet with a routing header, the final destination stored in the `ip6m_addr` member does not necessarily contain complete information of the entire path.

11.4. Determining the Current Path MTU

Some applications might need to determine the current path MTU e.g., applications using `IPV6_RECVPATHMTU` might want to pick a good starting value.

This specification defines a get-only socket option to retrieve the current path MTU value for the destination of a given connected socket. If the IP layer does not have a cached path MTU value it will return the interface MTU for the interface that will be used when sending to the destination address.

This information is retrieved using the `IPV6_PATHMTU` socket option. This option takes a pointer to the `ip6_mtuinfo` structure as the fourth argument, and the size of the structure should be passed as a value-result parameter in the fifth argument.

```
struct ip6_mtuinfo mtuinfo;
socklen_t infolen = sizeof(mtuinfo);

getsockopt(fd, IPPROTO_IPV6, IPV6_PATHMTU, &mtuinfo, &infolen);
```

When the call succeeds, the path MTU value is stored in the `ip6_mtu` member of the `ip6_mtuinfo` structure. Since the socket is connected, the `ip6m_addr` member is meaningless and should not be referred to by the application.

This option can only be used for a connected socket, because a non-connected socket does not have the information of the destination and there is no way to pass the destination via `getsockopt()`. When `getsockopt()` for this option is issued on a non-connected socket, the call will fail. Despite this limitation, this option is still useful from a practical point of view, because applications that care about the path MTU tend to send a lot of packets to a single destination and to connect the socket to the destination for performance reasons. If the application needs to get the MTU value in a more generic way, it should use a more generic interface, such as routing sockets [TCPIPILLUST].

12. Ordering of Ancillary Data and IPv6 Extension Headers

Three IPv6 extension headers can be specified by the application and returned to the application using ancillary data with `sendmsg()` and `recvmsg()`: the Routing header, Hop-by-Hop options header, and Destination options header. When multiple ancillary data objects are transferred via `recvmsg()` and these objects represent any of these three extension headers, their placement in the control buffer is directly tied to their location in the corresponding IPv6 datagram. For example, when the application has enabled the `IPV6_RECVRTHDR` and `IPV6_RECVDSOPTS` options and later receives an IPv6 packet with extension headers in the following order:

- The IPv6 header
- A Hop-by-Hop options header
- A Destination options header (1)
- A Routing header
- An Authentication header
- A Destination options header (2)
- A UDP header and UDP data

then the application will receive three ancillary data objects in the following order:

- an object with `cmsg_type` set to `IPV6_DSTOPTS`, which represents the destination options header (1)
- an object with `cmsg_type` set to `IPV6_RTHDR`, which represents the Routing header
- an object with `cmsg_type` set to `IPV6_DSTOPTS`, which represents the destination options header (2)

This example follows the header ordering described in [RFC-2460], but the receiving side of this specification does not assume the ordering. Applications may receive any numbers of objects in any order according to the ordering of the received IPv6 datagram.

For the sending side, however, this API imposes some ordering constraints according to [RFC-2460]. Applications using this API cannot make a packet with extension headers that do not follow the ordering. Note, however, that this does not mean applications must always follow the restriction. This is just a limitation in this API in order to give application programmers a guideline to construct headers in a practical manner. Should an application need to make an outgoing packet in an arbitrary order about the extension headers, some other technique, such as the datalink interfaces BPF or DLPI, must be used.

The followings are more details about the constraints:

- Each `IPV6_xxx` ancillary data object for a particular type of extension header can be specified at most once in a single control buffer.
- `IPV6_xxx` ancillary data objects can appear in any order in a control buffer, because there is no ambiguity of the ordering.
- Each set of `IPV6_xxx` ancillary data objects and sticky options will be put in the outgoing packet along with the header ordering described in [RFC-2460].
- An ancillary data object or a sticky option of `IPV6_RTHDRDSTOPTS` will affect the outgoing packet only when a Routing header is specified as an ancillary data object or a sticky option. Otherwise, the specified value for `IPV6_RTHDRDSTOPTS` will be ignored.

For example, when an application sends a UDP datagram with a control data buffer containing ancillary data objects in the following order:

- an object with `cmsg_type` set to `IPV6_DSTOPTS`
- an object with `cmsg_type` set to `IPV6_RTHDRDSTOPTS`
- an object with `cmsg_type` set to `IPV6_HOPOPTS`

and the sending socket does not have any sticky options, then the outgoing packet would be constructed as follows:

- The IPv6 header
- A Hop-by-Hop options header
- A Destination options header
- A UDP header and UDP data

where the destination options header corresponds to the ancillary data object with the type `IPV6_DSTOPTS`.

Note that the constraints above do not necessarily mean that the outgoing packet sent on the wire always follows the header ordering specified in this API document. The kernel may insert additional headers that break the ordering as a result. For example, if the kernel supports Mobile IPv6, an additional destination options header may be inserted before an authentication header, even without a routing header.

This API does not provide access to any other extension headers than the supported three types of headers. In particular, no information is provided about the IP security headers on an incoming packet, nor can be specified for an outgoing packet. This API is for applications that do not care about the existence of IP security headers.

13. IPv6-Specific Options with IPv4-Mapped IPv6 Addresses

The various socket options and ancillary data specifications defined in this document apply only to true IPv6 sockets. It is possible to create an IPv6 socket that actually sends and receives IPv4 packets, using IPv4-mapped IPv6 addresses, but the mapping of the options defined in this document to an IPv4 datagram is beyond the scope of this document.

In general, attempting to specify an IPv6-only option, such as the Hop-by-Hop options, Destination options, or Routing header on an IPv6 socket that is using IPv4-mapped IPv6 addresses, will probably result in an error. Some implementations, however, may provide access to

the packet information (source/destination address, send/receive interface, and hop limit) on an IPv6 socket that is using IPv4-mapped IPv6 addresses.

14. Extended interfaces for rresvport, rcmd and rexec

Library functions that support the "r" commands hide the creation of a socket and the name resolution procedure from an application. When the libraries return an AF_INET6 socket to an application that do not support the address family, the application may encounter an unexpected result when, e.g., calling getpeername() for the socket. In order to support AF_INET6 sockets for the "r" commands while keeping backward compatibility, this section defines some extensions to the libraries.

14.1. rresvport_af

The rresvport() function is used by the rcmd() function, and this function is in turn called by many of the "r" commands such as rlogin. While new applications are not being written to use the rcmd() function, legacy applications such as rlogin will continue to use it and these will be ported to IPv6.

rresvport() creates an IPv4/TCP socket and binds a "reserved port" to the socket. Instead of defining an IPv6 version of this function we define a new function that takes an address family as its argument.

```
#include <unistd.h>
```

```
int rresvport_af(int *port, int family);
```

This function behaves the same as the existing rresvport() function, but instead of creating an AF_INET TCP socket, it can also create an AF_INET6 TCP socket. The family argument is either AF_INET or AF_INET6, and a new error return is EAFNOSUPPORT if the address family is not supported.

(Note: There is little consensus on which header defines the rresvport() and rcmd() function prototypes. 4.4BSD defines it in <unistd.h>, others in <netdb.h>, and others don't define the function prototypes at all.)

14.2. rcmd_af

The existing rcmd() function can not transparently use AF_INET6 sockets since an application would not be prepared to handle AF_INET6 addresses returned by e.g., getpeername() on the file descriptor created by rcmd(). Thus a new function is needed.

```
int rcmd_af(char **ahost, unsigned short rport,
            const char *locuser, const char *remuser,
            const char *cmd, int *fd2p, int af)
```

This function behaves the same as the existing `rcmd()` function, but instead of creating an `AF_INET` TCP socket, it can also create an `AF_INET6` TCP socket. The family argument is `AF_INET`, `AF_INET6`, or `AF_UNSPEC`. When either `AF_INET` or `AF_INET6` is specified, this function will create a socket of the specified address family. When `AF_UNSPEC` is specified, it will try all possible address families until a connection can be established, and will return the associated socket of the connection. A new error `EAFNOSUPPORT` will be returned if the address family is not supported.

14.3. `rexec_af`

The existing `rexec()` function can not transparently use `AF_INET6` sockets since an application would not be prepared to handle `AF_INET6` addresses returned by e.g., `getpeername()` on the file descriptor created by `rexec()`. Thus a new function is needed.

```
int rexec_af(char **ahost, unsigned short rport, const char *name,
            const char *pass, const char *cmd, int *fd2p, int af)
```

This function behaves the same as the existing `rexec()` function, but instead of creating an `AF_INET` TCP socket, it can also create an `AF_INET6` TCP socket. The family argument is `AF_INET`, `AF_INET6`, or `AF_UNSPEC`. When either `AF_INET` or `AF_INET6` is specified, this function will create a socket of the specified address family. When `AF_UNSPEC` is specified, it will try all possible address families until a connection can be established, and will return the associated socket of the connection. A new error `EAFNOSUPPORT` will be returned if the address family is not supported.

15. Summary of New Definitions

The following list summarizes the constants and structure, definitions discussed in this memo, sorted by header.

```
<netinet/icmp6.h> ICMP6_DST_UNREACH
<netinet/icmp6.h> ICMP6_DST_UNREACH_ADDR
<netinet/icmp6.h> ICMP6_DST_UNREACH_ADMIN
<netinet/icmp6.h> ICMP6_DST_UNREACH_BEYONDSCOPE
<netinet/icmp6.h> ICMP6_DST_UNREACH_NOPORT
<netinet/icmp6.h> ICMP6_DST_UNREACH_NOROUTE
<netinet/icmp6.h> ICMP6_ECHO_REPLY
<netinet/icmp6.h> ICMP6_ECHO_REQUEST
<netinet/icmp6.h> ICMP6_INFOMSG_MASK
```

```

<netinet/icmp6.h> ICMP6_PACKET_TOO_BIG
<netinet/icmp6.h> ICMP6_PARAMPROB_HEADER
<netinet/icmp6.h> ICMP6_PARAMPROB_NEXTHHEADER
<netinet/icmp6.h> ICMP6_PARAMPROB_OPTION
<netinet/icmp6.h> ICMP6_PARAM_PROB
<netinet/icmp6.h> ICMP6_ROUTER_RENUMBERING
<netinet/icmp6.h> ICMP6_RR_FLAGS_FORCEAPPLY
<netinet/icmp6.h> ICMP6_RR_FLAGS_PREVDONE
<netinet/icmp6.h> ICMP6_RR_FLAGS_REQRESULT
<netinet/icmp6.h> ICMP6_RR_FLAGS_SPECSITE
<netinet/icmp6.h> ICMP6_RR_FLAGS_TEST
<netinet/icmp6.h> ICMP6_RR_PCOUSE_FLAGS_DECRPLTIME
<netinet/icmp6.h> ICMP6_RR_PCOUSE_FLAGS_DECRVLTIME
<netinet/icmp6.h> ICMP6_RR_PCOUSE_RAFLAGS_AUTO
<netinet/icmp6.h> ICMP6_RR_PCOUSE_RAFLAGS_ONLINK
<netinet/icmp6.h> ICMP6_RR_RESULT_FLAGS_FORBIDDEN
<netinet/icmp6.h> ICMP6_RR_RESULT_FLAGS_OOB
<netinet/icmp6.h> ICMP6_TIME_EXCEEDED
<netinet/icmp6.h> ICMP6_TIME_EXCEED_REASSEMBLY
<netinet/icmp6.h> ICMP6_TIME_EXCEED_TRANSIT
<netinet/icmp6.h> MLD_LISTENER_QUERY
<netinet/icmp6.h> MLD_LISTENER_REDUCTION
<netinet/icmp6.h> MLD_LISTENER_REPORT
<netinet/icmp6.h> ND_NA_FLAG_OVERRIDE
<netinet/icmp6.h> ND_NA_FLAG_ROUTER
<netinet/icmp6.h> ND_NA_FLAG_SOLICITED
<netinet/icmp6.h> ND_NEIGHBOR_ADVERT
<netinet/icmp6.h> ND_NEIGHBOR_SOLICIT
<netinet/icmp6.h> ND_OPT_MTU
<netinet/icmp6.h> ND_OPT_PI_FLAG_AUTO
<netinet/icmp6.h> ND_OPT_PI_FLAG_ONLINK
<netinet/icmp6.h> ND_OPT_PREFIX_INFORMATION
<netinet/icmp6.h> ND_OPT_REDIRECTED_HEADER
<netinet/icmp6.h> ND_OPT_SOURCE_LINKADDR
<netinet/icmp6.h> ND_OPT_TARGET_LINKADDR
<netinet/icmp6.h> ND_RA_FLAG_MANAGED
<netinet/icmp6.h> ND_RA_FLAG_OTHER
<netinet/icmp6.h> ND_REDIRECT
<netinet/icmp6.h> ND_ROUTER_ADVERT
<netinet/icmp6.h> ND_ROUTER_SOLICIT

<netinet/icmp6.h> struct icmp6_filter{};
<netinet/icmp6.h> struct icmp6_hdr{};
<netinet/icmp6.h> struct icmp6_router_renum{};
<netinet/icmp6.h> struct mld_hdr{};
<netinet/icmp6.h> struct nd_neighbor_advert{};
<netinet/icmp6.h> struct nd_neighbor_solicit{};
<netinet/icmp6.h> struct nd_opt_hdr{};

```

```

<netinet/icmp6.h> struct nd_opt_mtu{};
<netinet/icmp6.h> struct nd_opt_prefix_info{};
<netinet/icmp6.h> struct nd_opt_rd_hdr{};
<netinet/icmp6.h> struct nd_redirect{};
<netinet/icmp6.h> struct nd_router_advert{};
<netinet/icmp6.h> struct nd_router_solicit{};
<netinet/icmp6.h> struct rr_pco_match{};
<netinet/icmp6.h> struct rr_pco_use{};
<netinet/icmp6.h> struct rr_result{};

<netinet/in.h>      IPPROTO_AH
<netinet/in.h>      IPPROTO_DSTOPTS
<netinet/in.h>      IPPROTO_ESP
<netinet/in.h>      IPPROTO_FRAGMENT
<netinet/in.h>      IPPROTO_HOPOPTS
<netinet/in.h>      IPPROTO_ICMPV6
<netinet/in.h>      IPPROTO_IPV6
<netinet/in.h>      IPPROTO_NONE
<netinet/in.h>      IPPROTO_ROUTING
<netinet/in.h>      IPV6_CHECKSUM
<netinet/in.h>      IPV6_DONTFRAG
<netinet/in.h>      IPV6_DSTOPTS
<netinet/in.h>      IPV6_HOPLIMIT
<netinet/in.h>      IPV6_HOPOPTS

<netinet/in.h>      IPV6_NEXTHOP
<netinet/in.h>      IPV6_PATHMTU
<netinet/in.h>      IPV6_PKTINFO
<netinet/in.h>      IPV6_RECVDSTOPTS
<netinet/in.h>      IPV6_RECVHOPLIMIT
<netinet/in.h>      IPV6_RECVHOPOPTS
<netinet/in.h>      IPV6_RECVPKTINFO
<netinet/in.h>      IPV6_RECVRTHDR
<netinet/in.h>      IPV6_RECVTCLASS
<netinet/in.h>      IPV6_RTHDR
<netinet/in.h>      IPV6_RTHDRDSTOPTS
<netinet/in.h>      IPV6_RTHDR_TYPE_0
<netinet/in.h>      IPV6_RECVPATHMTU
<netinet/in.h>      IPV6_TCLASS
<netinet/in.h>      IPV6_USE_MIN_MTU
<netinet/in.h>      struct in6_pktinfo{};
<netinet/in.h>      struct ip6_mtuinfo{};

<netinet/ip6.h>     IP6F_MORE_FRAG
<netinet/ip6.h>     IP6F_OFF_MASK
<netinet/ip6.h>     IP6F_RESERVED_MASK
<netinet/ip6.h>     IP6OPT_JUMBO
<netinet/ip6.h>     IP6OPT_JUMBO_LEN

```

```

<netinet/ip6.h>    IP6OPT_MUTABLE
<netinet/ip6.h>    IP6OPT_NSAP_ADDR
<netinet/ip6.h>    IP6OPT_PAD1
<netinet/ip6.h>    IP6OPT_PADN
<netinet/ip6.h>    IP6OPT_ROUTER_ALERT
<netinet/ip6.h>    IP6OPT_TUNNEL_LIMIT
<netinet/ip6.h>    IP6OPT_TYPE_DISCARD
<netinet/ip6.h>    IP6OPT_TYPE_FORCEICMP
<netinet/ip6.h>    IP6OPT_TYPE_ICMP
<netinet/ip6.h>    IP6OPT_TYPE_SKIP
<netinet/ip6.h>    IP6_ALERT_AN
<netinet/ip6.h>    IP6_ALERT_MLD
<netinet/ip6.h>    IP6_ALERT_RSVP
<netinet/ip6.h>    struct ip6_dest{};
<netinet/ip6.h>    struct ip6_frag{};
<netinet/ip6.h>    struct ip6_hbh{};
<netinet/ip6.h>    struct ip6_hdr{};
<netinet/ip6.h>    struct ip6_opt{};
<netinet/ip6.h>    struct ip6_opt_jumbo{};
<netinet/ip6.h>    struct ip6_opt_nsap{};
<netinet/ip6.h>    struct ip6_opt_router{};
<netinet/ip6.h>    struct ip6_opt_tunnel{};
<netinet/ip6.h>    struct ip6_rthdr{};
<netinet/ip6.h>    struct ip6_rthdr0{};

```

The following list summarizes the function and macro prototypes discussed in this memo, sorted by header.

```

<netinet/icmp6.h> void ICMP6_FILTER_SETBLOCK(int, struct
                                icmp6_filter *);
<netinet/icmp6.h> void
    ICMP6_FILTER_SETBLOCKALL(struct icmp6_filter *);
<netinet/icmp6.h> void
    ICMP6_FILTER_SETPASS(int,
                                struct icmp6_filter *);
<netinet/icmp6.h> void
    ICMP6_FILTER_SETPASSALL(struct icmp6_filter *);
<netinet/icmp6.h> int  ICMP6_FILTER_WILLBLOCK(int,
                                const struct icmp6_filter *);
<netinet/icmp6.h> int  ICMP6_FILTER_WILLPASS(int,
                                const struct icmp6_filter *);

<netinet/in.h>     int IN6_ARE_ADDR_EQUAL(const struct in6_addr *,
                                const struct in6_addr *);

<netinet/in.h>     int inet6_opt_append(void *, socklen_t, int,
                                uint8_t, socklen_t, uint_t,
                                void **);

```

```

<netinet/in.h>    int inet6_opt_get_val(void *, int, void *,
                    socklen_t);
<netinet/in.h>    int inet6_opt_find(void *, socklen_t,
                    int, uint8_t ,
                    socklen_t *, void **);
<netinet/in.h>    int inet6_opt_finish(void *, socklen_t, int);
<netinet/in.h>    int inet6_opt_init(void *, socklen_t);
<netinet/in.h>    int inet6_opt_next(void *, socklen_t,
                    int, uint8_t *,
                    socklen_t *, void **);
<netinet/in.h>    int inet6_opt_set_val(void *, int,
                    void *, socklen_t);

<netinet/in.h>    int inet6_rth_add(void *,
                    const struct in6_addr *);
<netinet/in.h>    struct in6_addr inet6_rth_getaddr(const void *,
                    int);
<netinet/in.h>    void *inet6_rth_init(void *, socklen_t,
                    int, int);
<netinet/in.h>    int inet6_rth_reverse(const void *, void *);
<netinet/in.h>    int inet6_rth_segments(const void *);
<netinet/in.h>    socklen_t inet6_rth_space(int, int);

<netinet/ip6.h>   int  IP6OPT_TYPE(uint8_t);

<sys/socket.h>    socklen_t CMSG_LEN(socklen_t);
<sys/socket.h>    socklen_t CMSG_SPACE(socklen_t);

<unistd.h>        int rresvport_af(int *, int);
<unistd.h>        int rcmd_af(char **, unsigned short,
                    const char *, const char *,
                    const char *, int *, int);
<unistd.h>        int rexec_af(char **, unsigned short,
                    const char *, const char *,
                    const char *, int *, int);

```

16. Security Considerations

The setting of certain Hop-by-Hop options and Destination options may be restricted to privileged processes. Similarly some Hop-by-Hop options and Destination options may not be returned to non-privileged applications.

The ability to specify an arbitrary source address using IPV6_PKTINFO must be prevented; at least for non-privileged processes.

17. Changes from RFC 2292

Significant changes that affect the compatibility to RFC 2292:

- Removed the IPV6_PKTOPTIONS socket option by allowing sticky options to be set with individual setsockopt() calls.
- Removed the ability to be able to specify Hop-by-Hop and Destination options using multiple ancillary data items. The application, using the inet6_opt_xxx() routines (see below), is responsible for formatting the whole extension header.
- Removed the support for the loose/strict Routing header since that has been removed from the IPv6 specification.
- Loosened the constraints for jumbo payload option that this option was always hidden from applications.
- Disabled the use of the IPV6_HOPLIMIT sticky option.
- Removed ip6r0_addr field from the ip6_rthdr structure.
- Intentionally unspecified how to get received packet's information on TCP sockets.

New features:

- Added IPV6_RTHDRDSTOPTS to specify a Destination Options header before the Routing header.
- Added separate IPV6_RECVxxx options to enable the receipt of the corresponding ancillary data items.
- Added inet6_rth_xxx() and inet6_opt_xxx() functions to deal with routing or IPv6 options headers.
- Added extensions of libraries for the "r" commands.
- Introduced additional IPv6 option definitions such as IP6OPT_PAD1.
- Added MLD and router renumbering definitions.
- Added MTU-related socket options and ancillary data items.
- Added options and ancillary data items to manipulate the traffic class field.

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- Changed the name of ICMPv6 unreachable code 2 to be "beyond scope of source address." ICMP6_DST_UNREACH_NOTNEIGHBOR was removed with this change.

Clarifications:

- Added clarifications on extension headers ordering; for the sending side, assume the recommended ordering described in RFC 2460. For the receiving side, do not assume any ordering and pass all headers to the application in the received order.
- Added a summary about the interface selection rule.
- Clarified the ordering between IPV6_MULTICAST_IF and the IPV6_PKTINFO sticky option for multicast packets.
- Clarified how sticky options and the ICMPv6 filter are turned off and that getsockopt() of a sticky option returns what was set with setsockopt().
- Clarified that IPV6_NEXTHOP should be ignored for a multicast destination, that it should not contradict with the specified outgoing interface, and that the next hop should be a sockaddr_in6 structure.
- Clarified corner cases of IPV6_CHECKSUM.
- Aligned with the POSIX standard.

Editorial changes:

- Replaced MUST with must (since this is an informational document).
- Revised abstract to be more clear and concise, particularly concentrating on differences from RFC 2292.
- Made the URL of assigned numbers less specific so that it would be more robust for future changes.
- Updated the reference to the basic API.
- Added a reference to the latest POSIX standard.
- Moved general specifications of ancillary data and CMSG macros to the appendix.

18. References

- [RFC-1981] McCann, J., Deering, S. and J. Mogul, "Path MTU Discovery for IP version 6", RFC 1981, August 1996.
- [RFC-2460] Deering, S. and R. Hinden, "Internet Protocol, Version 6 (IPv6) Specification", RFC 2460, December 1998.
- [RFC-3493] Gilligan, R., Thomson, S., Bound, J., McCann, J. and W. Stevens, "Basic Socket Interface Extensions for IPv6", RFC 3493, March 2003.
- [POSIX] IEEE Std. 1003.1-2001 Standard for Information Technology – Portable Operating System Interface (POSIX). Open group Technical Standard: Base Specifications, Issue 6, December 2001. ISO/IEC 9945:2002. <http://www.opengroup.org/austin>
- [TCPIPILLUST] Wright, G., Stevens, W., "TCP/IP Illustrated, Volume 2: The Implementation", Addison Wesley, 1994.

19. Acknowledgments

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20. Appendix A: Ancillary Data Overview

4.2BSD allowed file descriptors to be transferred between separate processes across a UNIX domain socket using the `sendmsg()` and `recvmsg()` functions. Two members of the `msghdr` structure, `msg_accrights` and `msg_accrightslen`, were used to send and receive the descriptors. When the OSI protocols were added to 4.3BSD Reno in 1990 the names of these two fields in the `msghdr` structure were changed to `msg_control` and `msg_controllen`, because they were used by the OSI protocols for "control information", although the comments in the source code call this "ancillary data".

Other than the OSI protocols, the use of ancillary data has been rare. In 4.4BSD, for example, the only use of ancillary data with IPv4 is to return the destination address of a received UDP datagram if the `IP_RECVSTADDR` socket option is set. With Unix domain sockets ancillary data is still used to send and receive descriptors.

Nevertheless the ancillary data fields of the `msghdr` structure provide a clean way to pass information in addition to the data that is being read or written. The inclusion of the `msg_control` and `msg_controllen` members of the `msghdr` structure along with the `cmsghdr` structure that is pointed to by the `msg_control` member is required by the Posix sockets API standard.

20.1. The `msghdr` Structure

The `msghdr` structure is used by the `recvmsg()` and `sendmsg()` functions. Its Posix definition is:

```
struct msghdr {
    void      *msg_name;          /* ptr to socket address
                                   structure */
    socklen_t  msg_namelen;       /* size of socket address
                                   structure */
    struct iovec *msg_iov;        /* scatter/gather array */
    int        msg_iovlen;       /* # elements in msg_iov */
    void      *msg_control;       /* ancillary data */
    socklen_t  msg_controllen;    /* ancillary data buffer length */
    int        msg_flags;        /* flags on received message */
};
```

The structure is declared as a result of including `<sys/socket.h>`.

(Note: Before Posix the two "void *" pointers were typically "char *", and the two `socklen_t` members were typically integers. Earlier drafts of Posix had the two `socklen_t` members as `size_t`, but it then changed these to `socklen_t` to simplify binary portability for 64-bit

implementations and to align Posix with X/Open's Networking Services, Issue 5. The change in `msg_control` to a "void *" pointer affects any code that increments this pointer.)

Most Berkeley-derived implementations limit the amount of ancillary data in a call to `sendmsg()` to no more than 108 bytes (an mbuf). This API requires a minimum of 10240 bytes of ancillary data, but it is recommended that the amount be limited only by the buffer space reserved by the socket (which can be modified by the `SO_SNDBUF` socket option). (Note: This magic number 10240 was picked as a value that should always be large enough. 108 bytes is clearly too small as the maximum size of a Routing header is 2048 bytes.)

20.2. The `cmsghdr` Structure

The `cmsghdr` structure describes ancillary data objects transferred by `recvmsg()` and `sendmsg()`. Its Posix definition is:

```
struct cmsghdr {
    socklen_t  cmsg_len; /* #bytes, including this header */
    int        cmsg_level; /* originating protocol */
    int        cmsg_type; /* protocol-specific type */
                /* followed by unsigned char cmsg_data[]; */
};
```

This structure is declared as a result of including `<sys/socket.h>`.

(Note: Before Posix the `cmsg_len` member was an integer, and not a `socklen_t`. See the Note in the previous section for why `socklen_t` is used here.)

As shown in this definition, normally there is no member with the name `cmsg_data[]`. Instead, the data portion is accessed using the `MSG_xxx()` macros, as described in Section 20.3. Nevertheless, it is common to refer to the `cmsg_data[]` member.

When ancillary data is sent or received, any number of ancillary data objects can be specified by the `msg_control` and `msg_controllen` members of the `msghdr` structure, because each object is preceded by a `cmsghdr` structure defining the object's length (the `cmsg_len` member). Historically Berkeley-derived implementations have passed only one object at a time, but this API allows multiple objects to be passed in a single call to `sendmsg()` or `recvmsg()`. The following example shows two ancillary data objects in a control buffer.

```

|<----- msg_controllen ----->|
|OR|
|<----- msg_controllen ----->|
|<----- ancillary data object ----->|<----- ancillary data object ----->|
|<----- min CMSG_SPACE() ----->|<----- min CMSG_SPACE() ----->|
|<----- cmsg_len ----->|<----- cmsg_len ----->|
|<----- CMSG_LEN() ----->|<----- CMSG_LEN() ----->|
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|cmsg_|cmsg_|cmsg_|XX|  cmsg_|  XX|cmsg_|cmsg_|cmsg_|XX|  cmsg_|  XX|
|len_|level|type|XX|  data[]|XX|len_|level|type|XX|  data[]|XX|
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
^
|
msg_control
points here

```

The fields shown as "XX" are possible padding, between the cmsghdr structure and the data, and between the data and the next cmsghdr structure, if required by the implementation. While sending an application may or may not include padding at the end of last ancillary data in msg_controllen and implementations must accept both as valid. On receiving a portable application must provide space for padding at the end of the last ancillary data as implementations may copy out the padding at the end of the control message buffer and include it in the received msg_controllen. When recvmsg() is called if msg_controllen is too small for all the ancillary data items including any trailing padding after the last item an implementation may set MSG_CTRUNC.

20.3. Ancillary Data Object Macros

To aid in the manipulation of ancillary data objects, three macros from 4.4BSD are defined by Posix: CMSG_DATA(), CMSG_NXTHDR(), and CMSG_FIRSTHDR(). Before describing these macros, we show the following example of how they might be used with a call to recvmsg().

```

struct msghdr  msg;
struct cmsghdr *cmsgptr;

/* fill in msg */

/* call recvmsg() */

```

```

for (cmsgptr = CMSG_FIRSTHDR(&msg); cmsgptr != NULL;
    cmsgptr = CMSG_NXTHDR(&msg, cmsgptr)) {
    if (cmsgptr->cmsg_len == 0) {
        /* Error handling */
        break;
    }
    if (cmsgptr->cmsg_level == ... &&
        cmsgptr->cmsg_type == ... ) {
        u_char *ptr;

        ptr = CMSG_DATA(cmsgptr);
        /* process data pointed to by ptr */
    }
}

```

We now describe the three Posix macros, followed by two more that are new with this API: `CMSG_SPACE()` and `CMSG_LEN()`. All these macros are defined as a result of including `<sys/socket.h>`.

20.3.1. CMSG_FIRSTHDR

```
struct cmsghdr *CMSG_FIRSTHDR(const struct msghdr *mhdr);
```

`CMSG_FIRSTHDR()` returns a pointer to the first `cmsghdr` structure in the `msghdr` structure pointed to by `mhdr`. The macro returns `NULL` if there is no ancillary data pointed to by the `msghdr` structure (that is, if either `msg_control` is `NULL` or if `msg_controllen` is less than the size of a `cmsghdr` structure).

One possible implementation could be

```

#define CMSG_FIRSTHDR(mhdr) \
    ( (mhdr)->msg_controllen >= sizeof(struct cmsghdr) ? \
      (struct cmsghdr *) (mhdr)->msg_control : \
      (struct cmsghdr *) NULL )

```

(Note: Most existing implementations do not test the value of `msg_controllen`, and just return the value of `msg_control`. The value of `msg_controllen` must be tested, because if the application asks `recvmsg()` to return ancillary data, by setting `msg_control` to point to the application's buffer and setting `msg_controllen` to the length of this buffer, the kernel indicates that no ancillary data is available by setting `msg_controllen` to 0 on return. It is also easier to put this test into this macro, than making the application perform the test.)

20.3.2. CMSG_NXTHDR

As described in Section 5.1, CMSG_NXTHDR has been extended to handle a NULL 2nd argument to mean "get the first header". This provides an alternative way of coding the processing loop shown earlier:

```
struct msghdr msg;
struct cmsghdr *cmsgptr = NULL;

/* fill in msg */

/* call recvmsg() */

while ((cmsgptr = CMSG_NXTHDR(&msg, cmsgptr)) != NULL) {
    if (cmsgptr->cmsg_len == 0) {
        /* Error handling */
        break;
    }
    if (cmsgptr->cmsg_level == ... &&
        cmsgptr->cmsg_type == ... ) {
        u_char *ptr;

        ptr = CMSG_DATA(cmsgptr);
        /* process data pointed to by ptr */
    }
}
```

One possible implementation could be:

```
#define CMSG_NXTHDR(mhdr, cmsg) \
    (((cmsg) == NULL) ? CMSG_FIRSTHDR(mhdr) : \
     (((u_char *) (cmsg) + ALIGN_H((cmsg)->cmsg_len) \
      + ALIGN_D(sizeof(struct cmsghdr)) > \
       (u_char *) ((mhdr)->msg_control) + (mhdr)->msg_controllen) ? \
      (struct cmsghdr *) NULL : \
      (struct cmsghdr *) ((u_char *) (cmsg) + \
                          ALIGN_H((cmsg)->cmsg_len))))
```

The macros ALIGN_H() and ALIGN_D(), which are implementation dependent, round their arguments up to the next even multiple of whatever alignment is required for the start of the cmsghdr structure and the data, respectively. (This is probably a multiple of 4 or 8 bytes.) They are often the same macro in implementations platforms where alignment requirement for header and data is chosen to be identical.

20.3.3. CMSG_DATA

```
unsigned char *CMSG_DATA(const struct cmsghdr *cmsg);
```

CMSG_DATA() returns a pointer to the data (what is called the `cmsg_data[]` member, even though such a member is not defined in the structure) following a `cmsghdr` structure.

One possible implementation could be:

```
#define CMSG_DATA(cmsg) ( (u_char *) (cmsg) + \
                          ALIGN_D(sizeof(struct cmsghdr)) )
```

20.3.4. CMSG_SPACE

CMSG_SPACE is new with this API (see Section 5.2). It is used to determine how much space needs to be allocated for an ancillary data item.

One possible implementation could be:

```
#define CMSG_SPACE(length) ( ALIGN_D(sizeof(struct cmsghdr)) + \
                             ALIGN_H(length) )
```

20.3.5. CMSG_LEN

CMSG_LEN is new with this API (see Section 5.3). It returns the value to store in the `cmsg_len` member of the `cmsghdr` structure, taking into account any padding needed to satisfy alignment requirements.

One possible implementation could be:

```
#define CMSG_LEN(length) ( ALIGN_D(sizeof(struct cmsghdr)) + \
                           length )
```

21. Appendix B: Examples Using the `inet6_rth_XXX()` Functions

Here we show an example for both sending Routing headers and processing and reversing a received Routing header.

21.1. Sending a Routing Header

As an example of these Routing header functions defined in this document, we go through the function calls for the example on p. 17 of [RFC-2460]. The source is S, the destination is D, and the three intermediate nodes are I1, I2, and I3.

	S	----->	I1	----->	I2	----->	I3	----->	D
src:	*		S		S		S		S
dst:	D		I1		I2		I3		D
A[1]:	I1		I2		I1		I1		I1
A[2]:	I2		I3		I3		I2		I2
A[3]:	I3		D		D		D		I3
#seg:	3		3		2		1		0

src and dst are the source and destination IPv6 addresses in the IPv6 header. A[1], A[2], and A[3] are the three addresses in the Routing header. #seg is the Segments Left field in the Routing header.

The six values in the column beneath node S are the values in the Routing header specified by the sending application using `sendmsg()` of `setsockopt()`. The function calls by the sender would look like:

```
void *extptr;
socklen_t extlen;
struct msghdr msg;
struct cmsghdr *cmsgptr;
int cmsglen;
struct sockaddr_in6 I1, I2, I3, D;

extlen = inet6_rth_space(IPV6_RTHDR_TYPE_0, 3);
cmsglen = CMSG_SPACE(extlen);
cmsgptr = malloc(cmsglen);
cmsgptr->cmsg_len = CMSG_LEN(extlen);
cmsgptr->cmsg_level = IPPROTO_IPV6;
cmsgptr->cmsg_type = IPV6_RTHDR;

extptr = CMSG_DATA(cmsgptr);
extptr = inet6_rth_init(extptr, extlen, IPV6_RTHDR_TYPE_0, 3);

inet6_rth_add(extptr, &I1.sin6_addr);
inet6_rth_add(extptr, &I2.sin6_addr);
inet6_rth_add(extptr, &I3.sin6_addr);

msg.msg_control = cmsgptr;
msg.msg_controllen = cmsglen;

/* finish filling in msg{}, msg_name = D */
/* call sendmsg() */
```

We also assume that the source address for the socket is not specified (i.e., the asterisk in the figure).

The four columns of six values that are then shown between the five nodes are the values of the fields in the packet while the packet is in transit between the two nodes. Notice that before the packet is sent by the source node S, the source address is chosen (replacing the asterisk), I1 becomes the destination address of the datagram, the two addresses A[2] and A[3] are "shifted up", and D is moved to A[3].

The columns of values that are shown beneath the destination node are the values returned by `recvmsg()`, assuming the application has enabled both the `IPV6_RECVPKTINFO` and `IPV6_RECVRTHDR` socket options. The source address is S (contained in the `sockaddr_in6` structure pointed to by the `msg_name` member), the destination address is D (returned as an ancillary data object in an `in6_pktinfo` structure), and the ancillary data object specifying the Routing header will contain three addresses (I1, I2, and I3). The number of segments in the Routing header is known from the Hdr Ext Len field in the Routing header (a value of 6, indicating 3 addresses).

The return value from `inet6_rth_segments()` will be 3 and `inet6_rth_getaddr(0)` will return I1, `inet6_rth_getaddr(1)` will return I2, and `inet6_rth_getaddr(2)` will return I3,

If the receiving application then calls `inet6_rth_reverse()`, the order of the three addresses will become I3, I2, and I1.

We can also show what an implementation might store in the ancillary data object as the Routing header is being built by the sending process. If we assume a 32-bit architecture where `sizeof(struct cmsghdr)` equals 12, with a desired alignment of 4-byte boundaries, then the call to `inet6_rth_space(3)` returns 68: 12 bytes for the `cmsghdr` structure and 56 bytes for the Routing header (8 + 3*16).

The call to `inet6_rth_init()` initializes the ancillary data object to contain a Type 0 Routing header:

```
+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsgh_len = 20      |
+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsgh_level = IPPROTO_IPV6      |
+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsgh_type = IPV6_RTHDR      |
+-----+-----+-----+-----+-----+-----+-----+-----+
| Next Header | Hdr Ext Len=6 | Routing Type=0 | Seg Left=0 |
+-----+-----+-----+-----+-----+-----+-----+-----+
|                                     Reserved                                     |
+-----+-----+-----+-----+-----+-----+-----+-----+
```

The first call to `inet6_rth_add()` adds `I1` to the list.

```

+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsg_len = 36      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsg_level = IPPROTO_IPV6      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsg_type = IPV6_RTHDR      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|  Next Header  | Hdr Ext Len=6 | Routing Type=0 | Seg Left=1  |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|                                     Reserved                                     |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|                                     |
+                                     +
|                                     |
+                                     +
|                                     |
+                                     +
|                                     |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|                                     Address[1] = I1                                     |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+

```

`cmsg_len` is incremented by 16, and the Segments Left field is incremented by 1.

The next call to `inet6_rth_add()` adds I2 to the list.

```

+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsg_len = 52      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsg_level = IPPROTO_IPV6      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsg_type = IPV6_RTHDR      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|  Next Header  |  Hdr Ext Len=6  |  Routing Type=0  |  Seg Left=2  |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|                                     Reserved                                     |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|
+
|                                     Address[1] = I1                                     +
|
+
|
+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|
+
|                                     Address[2] = I2                                     +
|
+
|
+-----+-----+-----+-----+-----+-----+-----+-----+-----+

```

`cmsg_len` is incremented by 16, and the Segments Left field is incremented by 1.

The last call to `inet6_rth_add()` adds I3 to the list.

```

+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsg_len = 68      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsg_level = IPPROTO_IPV6      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|      cmsg_type = IPV6_RTHDR      |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+
| Next Header | Hdr Ext Len=6 | Routing Type=0 | Seg Left=3 |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|                               Reserved                               |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|
+
|                               Address[1] = I1                               +
|
+
+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|
+
|                               Address[2] = I2                               +
|
+
+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|
+
|                               Address[3] = I3                               +
|
+
+-----+-----+-----+-----+-----+-----+-----+-----+-----+

```

`cmsg_len` is incremented by 16, and the Segments Left field is incremented by 1.

21.2. Receiving Routing Headers

This example assumes that the application has enabled `IPV6_RECVRTHDR` socket option. The application prints and reverses a source route and uses that to echo the received data.

```

    struct sockaddr_in6    addr;
    struct msghdr          msg;
    struct iovec           iov;
    struct cmsghdr         *cmsgptr;
    socklen_t             cmsgspace;
    void                  *extptr;
    int                   extlen;

    int                   segments;
    int                   i;
    char                  databuf[8192];

    segments = 100;          /* Enough */
    extlen = inet6_rth_space(IPV6_RTHDR_TYPE_0, segments);
    cmsgspace = CMSG_SPACE(extlen);
    cmsgptr = malloc(cmsgspace);
    if (cmsgptr == NULL) {
        perror("malloc");
        exit(1);
    }
    extptr = CMSG_DATA(cmsgptr);

    msg.msg_control = cmsgptr;
    msg.msg_controllen = cmsgspace;
    msg.msg_name = (struct sockaddr *)&addr;
    msg.msg_namelen = sizeof (addr);
    msg.msg_iov = &iov;
    msg.msg_iovlen = 1;
    iov.iov_base = databuf;
    iov.iov_len = sizeof (databuf);
    msg.msg_flags = 0;
    if (recvmsg(s, &msg, 0) == -1) {
        perror("recvmsg");
        return;
    }
    if (msg.msg_controllen != 0 &&
        cmsgptr->cmsg_level == IPPROTO_IPV6 &&
        cmsgptr->cmsg_type == IPV6_RTHDR) {
        struct in6_addr *in6;
        char asciiname[INET6_ADDRSTRLEN];
        struct ip6_rthdr *rthdr;

        rthdr = (struct ip6_rthdr *)extptr;
        segments = inet6_rth_segments(extptr);
        printf("route (%d segments, %d left): ",
            segments, rthdr->ip6r_segleft);
        for (i = 0; i < segments; i++) {
            in6 = inet6_rth_getaddr(extptr, i);

```

```

        if (in6 == NULL)
            printf("<NULL> ");
        else
            printf("%s ", inet_ntop(AF_INET6,
                (void *)in6->s6_addr,
                asciiname, INET6_ADDRSTRLEN));
    }
    if (inet6_rth_reverse(extptr, extptr) == -1) {
        printf("reverse failed");
        return;
    }
}
iov.iov_base = databuf;
iov.iov_len = strlen(databuf);
if (sendmsg(s, &msg, 0) == -1)
    perror("sendmsg");
if (cmsgptr != NULL)
    free(cmsgptr);

```

Note: The above example is a simple illustration. It skips some error checks, including those involving the MSG_TRUNC and MSG_CTRUNC flags. It also leaves some type mismatches in favor of brevity.

22. Appendix C: Examples Using the inet6_opt_XXX() Functions

This shows how Hop-by-Hop and Destination options can be both built as well as parsed using the inet6_opt_XXX() functions. These examples assume that there are defined values for OPT_X and OPT_Y.

Note: The example is a simple illustration. It skips some error checks and leaves some type mismatches in favor of brevity.

22.1. Building Options

We now provide an example that builds two Hop-by-Hop options using the example in Appendix B of [RFC-2460].

```

void *extbuf;
socklen_t extlen;
int currentlen;
void *databuf;
int offset;
uint8_t value1;
uint16_t value2;
uint32_t value4;
uint64_t value8;

/* Estimate the length */

```

```
currentlen = inet6_opt_init(NULL, 0);
if (currentlen == -1)
    return (-1);
currentlen = inet6_opt_append(NULL, 0, currentlen, OPT_X,
                              12, 8, NULL);
if (currentlen == -1)
    return (-1);
currentlen = inet6_opt_append(NULL, 0, currentlen, OPT_Y,
                              7, 4, NULL);
if (currentlen == -1)
    return (-1);
currentlen = inet6_opt_finish(NULL, 0, currentlen);
if (currentlen == -1)
    return (-1);
extlen = currentlen;

extbuf = malloc(extlen);
if (extbuf == NULL) {
    perror("malloc");
    return (-1);
}
currentlen = inet6_opt_init(extbuf, extlen);
if (currentlen == -1)
    return (-1);

currentlen = inet6_opt_append(extbuf, extlen, currentlen,
                              OPT_X, 12, 8, &databuf);
if (currentlen == -1)
    return (-1);
/* Insert value 0x12345678 for 4-octet field */
offset = 0;
value4 = 0x12345678;
offset = inet6_opt_set_val(databuf, offset,
                           &value4, sizeof (value4));
/* Insert value 0x0102030405060708 for 8-octet field */
value8 = 0x0102030405060708;
offset = inet6_opt_set_val(databuf, offset,
                           &value8, sizeof (value8));

currentlen = inet6_opt_append(extbuf, extlen, currentlen,
                              OPT_Y, 7, 4, &databuf);
if (currentlen == -1)
    return (-1);
/* Insert value 0x01 for 1-octet field */
offset = 0;
value1 = 0x01;
offset = inet6_opt_set_val(databuf, offset,
                           &value1, sizeof (value1));
```

```

/* Insert value 0x1331 for 2-octet field */
value2 = 0x1331;
offset = inet6_opt_set_val(databuf, offset,
                           &value2, sizeof (value2));
/* Insert value 0x01020304 for 4-octet field */
value4 = 0x01020304;
offset = inet6_opt_set_val(databuf, offset,
                           &value4, sizeof (value4));

currentlen = inet6_opt_finish(extbuf, extlen, currentlen);
if (currentlen == -1)
    return (-1);
/* extbuf and extlen are now completely formatted */

```

22.2. Parsing Received Options

This example parses and prints the content of the two options in the previous example.

```

int
print_opt(void *extbuf, socklen_t extlen)
{
    struct ip6_dest *ext;
    int currentlen;
    uint8_t type;
    socklen_t len;
    void *databuf;
    int offset;
    uint8_t value1;
    uint16_t value2;
    uint32_t value4;
    uint64_t value8;

    ext = (struct ip6_dest *)extbuf;
    printf("nxt %u, len %u (bytes %d)\n", ext->ip6d_nxt,
          ext->ip6d_len, (ext->ip6d_len + 1) * 8);

    currentlen = 0;
    while (1) {
        currentlen = inet6_opt_next(extbuf, extlen,
                                    currentlen, &type,
                                    &len, &databuf);

        if (currentlen == -1)
            break;
        printf("Received opt %u len %u\n",
              type, len);
        switch (type) {
            case OPT_X:

```



```
        offset = 0;
        offset =
            inet6_opt_get_val(databuf, offset,
                              &value4,
                              sizeof (value4));
        printf("X 4-byte field %x\n", value4);
        offset =
            inet6_opt_get_val(databuf, offset,
                              &value8,
                              sizeof (value8));
        printf("X 8-byte field %llx\n", value8);
        break;
    case OPT_Y:
        offset = 0;
        offset =
            inet6_opt_get_val(databuf, offset,
                              &value1,
                              sizeof (value1));
        printf("Y 1-byte field %x\n", value1);
        offset =
            inet6_opt_get_val(databuf, offset,
                              &value2,
                              sizeof (value2));
        printf("Y 2-byte field %x\n", value2);
        offset =
            inet6_opt_get_val(databuf, offset,
                              &value4,
                              sizeof (value4));
        printf("Y 4-byte field %x\n", value4);
        break;
    default:
        printf("Unknown option %u\n", type);
        break;
    }
}
return (0);
}
```

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IPv4-Mapped Address API Considered Harmful

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Abstract

The IPv6 Addressing Architecture [Hinden, 1998] defines the "IPv4-mapped IPv6 address." This representation is used in the IPv6 basic API [Gilligan, 1999] to denote IPv4 addresses using AF_INET6 sockets. The use of IPv4-mapped addresses on AF_INET6 sockets degrades portability, complicates IPv6 systems, and is likely to create security problems. This document discusses each issue in turn. Finally, it proposes to resolve these problems by recommending deprecation of this mechanism.

1. Drawbacks due to IPv4 mapped address support

1.1. Degraded portability

RFC2553 section 3.7 specifies the behavior of IPv4-mapped addresses with an AF_INET6 socket. However, the description fails to specify important details that are necessary for good portability. Specifically, the

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specification needs to define:

- (1) The interaction between multiple `bind(2)` attempts to the same port, with different addresses. What happens when an application does and does not call `setsockopt(..., SO_REUSEPORT, ...)` in order to `bind(2)` to the same port on `AF_INET` and `AF_INET6`? What happens when an application calls `bind(2)` on `AF_INET` socket, and an application calls `bind(2)` on an `AF_INET6` socket with IPv4-mapped address? Note that there are many more issues here that need specification.
- (2) The selection/interaction of port numbers between `AF_INET` and `AF_INET6` sockets on `bind(2)` and/or `connect(2)` system calls. This is related to (1).
- (3) The treatment of socket options (`setsockopt(2)` and `getsockopt(2)`) with IPv4-mapped addresses on `AF_INET6` sockets. What happens when an application calls `setsockopt(2)` for IPv4 options or IPv6 options on an `AF_INET6` socket that is not yet bound (and, therefore, the host does not know if IPv4 or IPv6 communication will be used)? What happens when an application calls `setsockopt(2)` for IPv4 options or IPv6 options on an `AF_INET6` socket that is bound to IPv4-mapped addresses?
- (4) The delivery of multicast packets to `AF_INET` and `AF_INET6` sockets. What happens when an application binds to the IPv6 unspecified address `:::` with a certain port – does it receive IPv4 multicast traffic as well? What will be the relationship between `IP_MULTICAST_IF` and `IPV6_MULTICAST_IF` socket options? What happens when an application calls `sendto(2)` to an IPv4-mapped address for an IPv4 multicast address? How will the source address will be selected?

Due to these ambiguities, developers of applications that use IPv4-mapped addresses on `AF_INET6` sockets might encounter portability problems.

1.2. Increased implementation complexity

Implementation of IPv4-mapped addresses has a real and significant cost, both in the system software (e.g., network stack, kernel, and system libraries) and in the application software (ALL of which must now correctly handle IPv4-mapped addresses). The combined man-time for developers, testers, document writers, and support staff is a real and potentially tangible added cost of this particular feature. Because applications are affected, the number of implementations for which this cost will apply has the potential to be huge.

Implementation of IPv4-mapped addresses increases the complexity of all IPv6 implementations, both in the system software and in the application software. Increased complexity is bad for software engineering reasons beyond the scope of this document. Technology market forces and Internet history have demonstrated that simpler protocols and simpler

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systems have a tendency to be more successful than complex alternatives.

If the community wishes to see IPv6 achieve successful deployment, it is important that the resource costs and complexity costs associated with IPv6 be as low as possible. Where opportunities exist to decrease these costs, the community should seriously consider doing so in order to nurture deployment.

1.3. Access control complexity

RFC2553 section 3.7 adds extra complexity to address-based access controls. It is likely that there will be many errors introduced by of this.

Due to RFC2553 section 3.7, AF_INET6 sockets will accept IPv4 packets. On an IPv4/v6 dual stack node, if there is no AF_INET listening socket, most users would believe that there will be no access from IPv4 peers. However, if an AF_INET6 listening socket is present, IPv4 peers will be able to access the service. This is likely to confuse users and result in configuration errors that can be exploited by malicious parties. (It is violating the security principle of least surprise)

AF_INET6 sockets will accept IPv4 packets even (and especially) if the application is not expecting them. Every application that uses AF_INET6 sockets MUST correctly handle reception of IPv4 packets. Failure of a developer to consider every relevant case might lead to a security problem. This is likely to be overlooked by developers – especially those new to IPv6 development (as most are). This is likely to result in applications with flaws that can be exploited by malicious parties. (Again, this is violating the security principle of least surprise)

Systems that support IPv4 communications on AF_INET6 sockets using IPv4-mapped addresses have a greater potential to have security problems than they would if they did not have this feature.

2. Recommended solution

- o Deprecate RFC2553 section 3.7. By doing so, IPv6 implementations will be greatly simplified, both in the system software and in all IPv6 application software.

3. Alternative solution

- o Expand RFC2553 section 3.7 to fully define the behavior of AF_INET6 sockets using IPv4-mapped addresses.
- o Change the default value for IPV6_V6ONLY socket option defined in [Gilligan, 2002] to "on." With this approach, systems must still implement the complex interactions between AF_INET and AF_INET6 socket, which can lead to security problems. Also, once a application

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turns the socket option off, it MUST correctly handle all cases where an IPv4-mapped address might be used or it may have security problems.

4. Implementation tips to application developers

- o In EVERY application, check for IPv4-mapped addresses wherever addresses enter code paths under your control (i.e., are returned from system calls, or from library calls, or are input from the user or a file), and handle them in an appropriate manner. This approach is difficult in reality, and there is no way to determine whether it has been followed fully.
- o Do not intentionally use RFC2553 section 3.7 (IPv4 traffic on AF_INET6 socket). Implement server applications by using separate AF_INET and AF_INET6 listening sockets. Explicitly set the IPV6_V6ONLY socket option to on, whenever the socket option is available on the system.

NOTE: Due to the lack of standard behavior in bind(2) semantics, this may not be possible on some systems. Some IPv6 stack does not permit bind(2) to 0.0.0.0, after bind(2) to ::. Also, there is no standard on how IPv4 traffic will be routed when both 0.0.0.0 and :: listening sockets are available on the same port.

- o Implement programs in a protocol-independent manner using getaddrinfo(3) and getnameinfo(3), instead of hard-coding AF_INET6. RFC2553 section 3.7 leads people to port IPv4 application to IPv6 by replacing AF_INET into AF_INET6. However, by hard-coding AF_INET6 into the program, developers are failing to correct their dependencies on particular protocol families. As a consequence, any future protocol support will again require the application to be modified. Applications that hard-code AF_INET6 require IPv6-capable systems and will fail on a system that only has IPv4 support. It is critical to implement programs in a protocol-independent manner if you want to ship a single program (binary/source) that runs on IPv4-only, IPv6-only, as well as IPv4/v6 dual stack systems.

5. Security considerations

This document discusses security issues with the use of IPv4-mapped address. A recommended and alternate solution is provided.

6. Change History

None yet.

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IPv4-Mapped Addresses on the Wire Considered Harmful

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Abstract

The IPv6 Addressing Architecture [Hinden, 1998] defines the "IPv4-mapped IPv6 address." These addresses are used in the IPv6 basic API [Gilligan, 1999] to denote IPv4 addresses using AF_INET6 sockets. These addresses are used in protocol proposals such as SIIT [Nordmark, 2000] to denote IPv6 communication using AF_INET6 sockets. Therefore, IPv4-mapped addresses have two different meanings, and they are not distinguishable from the user-land applications.

This draft discusses security threats due to this ambiguity of IPv4-mapped address. It also discusses threats due to the additional complexities introduced by IPv4-mapped addresses. Finally, it proposes to resolve these problems by forbidding protocols from using IPv4-mapped addresses for IPv6 communications.

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1. Dual meaning of IPv4-mapped address

Basic Socket Interface Extensions for IPv6 [Gilligan, 1999] defines the use of IPv4-mapped address with `AF_INET6` sockets. IPv4-mapped addresses are used to represent IPv4 addresses using the IPv6 API (e.g., on `AF_INET6` sockets). The API is designed with IPv4/v6 dual stack nodes in mind. When an IPv4 packet reaches an IPv4/v6 dual stack node, the node's IPv4 layer will process it, then pass it to the transport layer. When the transport layer finds an `AF_INET6` listening socket, it will pass the packet to the listening socket as if it was from the corresponding IPv4-mapped address. In this document, we will refer to this as the "basic API behavior."

Some of the IPv6 translation protocols, such as SIIT [Nordmark, 2000] , use IPv4-mapped addresses actual IPv6 packets on the wire. These protocols are designed for use with IPv6-only nodes. When an IPv6 packet containing these addresses reaches a node, the node's IPv6 layer will process it, then pass it to the transport layer. When the transport layer finds an `AF_INET6` listening socket, it will pass the packet to the listening socket with the IPv4-mapped address intact. In this document, we will refer to this as the "SIIT behavior."

2. Threats due to the use of IPv4-mapped address on wire

When an application using the `AF_INET6` API receives an IPv4-mapped addresses (for example, returned by `getpeername(2)` or `recvfrom(2)`), it cannot detect if the packet received by the node actually used IPv4 (basic API behavior) or IPv6 (SIIT behavior).

This ambiguity creates an opportunity that a malicious party can exploit in order to deceive victim nodes. For example:

- o If an attacker transmits an IPv6 packet with `::ffff:127.0.0.1` in the IPv6 source address field, he might be able to bypass a node's access controls by deceiving applications into believing that the packet is from the node itself (e.g., the IPv4 loopback address, `127.0.0.1`). The same attack might be performed using the node's IPv4 interface address instead.
- o If an attacker transmits an IPv6 packet with IPv4-mapped addresses in the IPv6 destination address field corresponding to IPv4 addresses inside a site's security perimeter (e.g., `::ffff:10.1.1.1`), he might be able to bypass IPv4 packet filtering rules and traverse a site's firewall.
- o If an attacker transmits an IPv6 packet with IPv4-mapped addresses in the IPv6 source and destination fields to a protocol that swaps IPv6 source and destination addresses, he might be able to use a node as a proxy for certain types of attacks. For example, this might be used to construct broadcast multiplication and proxy TCP port scan attacks.

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3. Recommended solution

Forbid the use of IPv4-mapped address on wire.

The IPv6 node requirements:

- o IPv6 nodes MUST NOT generate packets that contain IPv4-mapped addresses in any network layer field. Specifically, the IPv6 header, routing header, options headers, and any other chained headers MUST NOT contain IPv4-mapped addresses.
- o IPv6 nodes SHOULD NOT generate packets that contain IPv4-mapped addresses in any field. (As a particular exception, it MAY be acceptable for fields referring to third-party nodes to contain IPv4-mapped addresses. Implementors must ensure that, where this is allowed, it is done with great care.)
- o IPv6 nodes MUST silently discard packets that contain IPv4-mapped address in IPv6 header fields, or IPv6 extension header fields.

The IPv6 router requirements:

- o IPv6 routers MUST NOT forward packets that contain IPv4-mapped addresses in any field the router processes. Specifically, the IPv6 header, routing header, and the hop-by-hop options headers parsed by the router MUST NOT contain IPv4-mapped addresses.
- o IPv6 routers MUST NOT advertise any prefixes into a routing protocol that are within the IPv4-mapped address space. Further, IPv6 routers MUST appropriately discard and/or ignore any received prefixes within the IPv4-mapped address space.

Standards requirements:

- o The IPv6 address architecture document [Hinden, 1998] MUST explicitly state that IPv4-mapped addresses are exclusively for uses local to a node as specified in the basic API [Gilligan, 1999] and MUST never appear in the wire.
- o Any document that suggests the use of IPv4-mapped addresses in packets on the wire SHOULD be modified to remove such usage. This will remove the threat due to the use of IPv4-mapped address on wire.

An alternate solution is to deprecate IPv4-mapped addresses from the basic API. Due to the wide deployment of applications that use IPv6 basic API, further study of this option's feasibility is required. This solution is not mutually exclusive with the recommended solution.

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4. Suggested implementation tips

4.1. System (e.g., kernel and library) developers

- o Drop any IPv6 native packet with IPv4-mapped addresses in any of IPv6 header fields as well as IPv6 extension header fields. (N.B., this will make the system incompatible with the current version of SIIT [Nordmark, 2000])
- o Drop any IPv6 DNS response that contains IPv4-mapped addresses.

5. Security considerations

This document discusses security issues with the use of IPv4-mapped address. A recommended and alternate solution is provided.

6. Change History

00 -> 01

Craig Metz joins the team. Updates based on feedback given at v6ops interim meeting fall 2002. Move API issues to a separate draft.

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Author's addresses

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IPv4-mapped Addr. on Wire Considered Harmful

Oct 2002

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Possible Abuse Against IPv6 Transition Technologies

Draft-itojun-ipv6-transition-abuse-01.txt

Internet Engineering Task Force
INTERNET-DRAFT
Expires: January 10, 2001

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July 10, 2000

Possible abuse against IPv6 transition technologies
draft-itojun-ipv6-transition-abuse-01.txt

Status of this Memo

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The internet-draft will expire in 6 months. The date of expiration will be January 10, 2001.

Abstract

The document talks about possible abuse of IPv6 transition technologies, which may lead to denial-of-service (DoS) attacks and other problems. IPv6 transition technologies, namely IPv6 over IPv4 tunnelling specifications and some others, have room for abuse by malicious parties. Detailed descriptions and possible workarounds are supplied.

1. Abuse of IPv4 compatible address

1.1. Problem

To implement automatic tunnelling described in RFC1933 [Gilligan, 1996], IPv4 compatible addresses (like ::123.4.5.6) are used. From IPv6 stack point of view, an IPv4 compatible address is considered to be a normal unicast address. If an IPv6 packet has IPv4 compatible addresses in the header, the packet will be encapsulated automatically into an IPv4 packet, with IPv4 address taken from lowermost 4 bytes of the IPv4 compatible addresses. Since there is no good way to check if embedded

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IPv4 address is sane, improper IPv4 packet can be generated as a result. Malicious party can abuse it, by injecting IPv6 packets to an IPv4/v6 dual stack node with certain IPv6 source address, to cause transmission of unexpected IPv4 packets. Consider the following scenario:

- o You have an IPv6 transport-capable DNS server, running on top of IPv4/v6 dual stack node. The node is on IPv4 subnet 10.1.1.0/24.
- o Malicious party transmits an IPv6 UDP packet to port 53 (DNS), with source address ::10.1.1.255. It does not make difference if it is encapsulated into an IPv4 packet, or is transmitted as a native IPv6 packet.
- o IPv6 transport-capable DNS server will transmit an IPv6 packet as a reply, copying the original source address into the destination address. Note that the IPv6 DNS server will treat IPv6 compatible address as normal IPv6 unicast address.
- o The reply packet will automatically be encapsulated into IPv4 packet, based on RFC1933 automatic tunnelling. As a result, IPv4 packet toward 10.1.1.255 will be transmitted. This is the subnet broadcast address for your IPv4 subnet, and will (improperly) reach every node on the IPv4 subnet.

1.2. Possible solutions

For the following sections, possible solutions are presented in the order of preference (the author recommends to implement solutions that appear earlier). Note that some of the following are partial solution to the problem. Some of the solutions may overlap, or be able to coexist, with other solutions. Solutions marked with (*) are already incorporated into [Gilligan, 2000] which is an updated version of RFC1933. Note that, however, solutions incorporated into [Gilligan, 2000] do not make a complete protection against malicious parties.

- o Disable automatic tunnelling support.
- o Reject IPv6 packets with IPv4 compatible address in IPv6 header fields. Note that we may need to check extension headers as well.
- o Perform ingress filter against IPv6 packet and tunnelled IPv6 packet. Ingress filter should let the packets with IPv4 compatible source address through, only if the source address embeds an IPv4 address belongs to the organization. The approach is a partial solution for avoiding possible transmission of malicious packet, from the organization to the outside. (*)
- o Whenever possible, check if the addresses on the packet meet the topology you have. For example, if the IPv4 address block for your site is 43.0.0.0/8, and you have a packet from IPv4-wise outside with encapsulated IPv6 source matches ::43.0.0.0/104, it is likely that someone is doing something nasty. This may not be possible to make

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the filter complete, so consider it as a partial solution. (*)

- o Require use of IPv4 IPsec, namely authentication header [Kent, 1998] , for encapsulated packet. Even with IPv4 IPsec, reject the packet if the IPv6 compatible address in the IPv6 header does not embed the IPv4 address in the IPv4 header. We cannot blindly trust the inner IPv6 packet based on the existence of IPv4 IPsec association, since the inner IPv6 packet may be originated by other nodes and forwarded by the authenticated peer. The solution may be impractical, since it only solves very small part of the problem with too many requirements.
- o Reject inbound/outgoing IPv6 packets, if it has certain IPv4 compatible address in IPv6 header fields. Note that we may need to check extension headers as well. The author recommends to check any IPv4 compatible address that is mapped from/to IPv4 address not suitable as IPv4 peer. They include 0.0.0.0/8, 127.0.0.0/8, 224.0.0.0/4, 255.255.255.255/32, and subnet broadcast addresses. Since the check can never be perfect (we cannot check for subnet broadcast address in remote site, for example) the direction is not recommend. (*)

2. Abuse of 6to4 address

6to4 [Carpenter, 2000] is another proposal for IPv6-over-IPv4 packet encapsulation, and is very similar to RFC1933 automatic tunneling mentioned in the previous section. 6to4 address embeds IPv4 address in the middle (2nd byte to 5th byte). If an IPv6 packet has a 6to4 address as destination address, it will be encapsulated into IPv4 packet with the embedded IPv4 address as IPv4 destination.

IPv6 packets with 6to4 address have the same problems as those with IPv4 compatible address. See the previous section for the details of the problems, and possible solutions.

The latest 6to4 draft [Carpenter, 2000] do incorporate some of the solutions presented in the previous section, however, they do not make a complete protection against malicious parties.

3. Abuse of IPv4 mapped address

3.1. Problems

IPv6 basic socket API [Gilligan, 1999] defines the use of IPv4 mapped address with AF_INET6 sockets. IPv4 mapped address is used to handle inbound IPv4 traffic toward AF_INET6 sockets, and outbound IPv4 traffic from AF_INET6 sockets. Inbound case has higher probability of abuse, while outbound case contributes to the abuse as well. Here we briefly describe the kernel behavior in inbound case. When we have an AF_INET6 socket bound to IPv6 unspecified address (::), IPv4 traffic, as well as IPv6 traffic, will be captured by the socket. The kernel will present

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the address of the IPv4 peer to the userland program by using IPv4 mapped address. For example, if an IPv4 traffic from 10.1.1.1 is captured by an AF_INET6 socket, the userland program will think that the peer is at ::ffff:10.1.1.1. The userland program can manipulate IPv4 mapped address just like it would do against normal IPv6 unicast address.

We have three problems with the specification. First, IPv4 mapped address support complicates IPv4 access control mechanisms. For example, if you would like to reject accesses from IPv4 clients to a certain transport layer service, it is not enough to reject accesses to AF_INET socket. You will need to check AF_INET6 socket for accesses from IPv4 clients (seen as accesses from IPv4 mapped address) as well.

Secondly, malicious party may be able to use IPv6 packets with IPv4 mapped address, to bypass access control. Consider the following scenario:

- o Attacker throws unencapsulated IPv6 packets, with ::ffff:127.0.0.1 as source address.
- o The access control code in the server thinks that this is from localhost, and grants accesses.

Lastly, malicious party can make servers generate unexpected IPv4 traffic. This can be accomplished by sending IPv6 packet with IPv4 mapped address as a source (similar to abuse of IPv4 compatible address), or by presenting IPv4 mapped address to servers (like FTP bounce attack [Allman, 1999] from IPv6 to IPv4). The problem is slightly different from the problems with IPv4 compatible addresses and 6to4 addresses, since it does not make use of tunnels. It makes use of certain behavior of userland applications.

The confusion came from the dual use of IPv4 mapped address, for node-internal representation for remote IPv4 destination/source, and for real IPv6 destination/source.

3.2. Possible solutions

- o In IPv6 addressing architecture document [Hinden, 1998], disallow the use of IPv4 mapped addresses on the wire. The change will conflict with SIIT [Nordmark, 2000], which is the only protocol which tries to use IPv4 mapped address on IPv6 native packet. The dual use of IPv4 mapped address (as a host-internal representation of IPv4 destinations, and as a real IPv6 address) is the prime source of the problem.
- o Reject IPv6 packets, if it has IPv4 mapped address in IPv6 header fields. Note that we may need to check extension headers such as routing headers, as well. IPv4 mapped address is internal representation in a node, so doing this will raise no conflicts with existing protocols. We recommend to check the condition in IPv6 input

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packet processing, and transport layer processing (TCP input and UDP input) to be sure.

- o Reject DNS replies, or other host name database replies, which contain IPv4 mapped address. Again, IPv4 mapped address is internal representation in a node and should never appear on external host name databases.
- o Do not route inbound IPv4 traffic to AF_INET6 sockets. When an application would like to accept IPv4 traffic, it should explicitly open AF_INET sockets. You may want to run two applications instead, one for an AF_INET socket, and another for an AF_INET6 socket. Or you may want to make the functionality optional, off by default, and let the userland applications explicitly enable it. This greatly simplifies access control issues. This approach conflicts with what IPv6 basic API document says, however, it should raise no problem with properly-written IPv6 applications. It only affects server programs, ported by assuming the behavior of AF_INET6 listening socket against IPv4 traffic.
- o When implementing TCP or UDP stack, explicitly record the wire packet format (IPv4 or IPv6) into connection table. It is unwise to guess the wire packet format, by existence of IPv6 mapped address in the address pair.
- o We should separately fix problems like FTP bounce attack.
- o Applications should always check if the connection to AF_INET6 socket is from an IPv4 node (IPv4 mapped address), or IPv6 node. It should then treat the connection as from IPv4 node (not from IPv6 node with special address), or reject the connection. This is, however, dangerous to assume that every application implementers are aware of the issue. The solution is not recommended (this is not a solution actually).

4. Attacks by combining different address formats

Malicious party can use different address formats simultaneously, in a single packet. For example, suppose you have implemented checks for abuse against IPv4 compatible address in automatic tunnel egress module. Bad guys may try to send a native IPv6 packet with 6to4 destination address with IPv4 compatible source address, to bypass security checks against IPv4 compatible address in tunnel decapsulation module. Your implementation will not be able to detect it, since the packet will not visit egress module for automatic tunnels.

Analyze code path with great care, and reject any packets that does not look sane.

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5. Attacks using source address-based authentication

5.1. Problems

IPv6-to-IPv4 translators [Nordmark, 2000; Tsirtsis, 2000; Hagino, 2000] usually relay, or rewrite, IPv6 packet into IPv4 packet. The IPv4 source address in the IPv4 packet will not represent the ultimate source node (IPv6 node). Usually the IPv4 source address represents translator box instead. If we use the IPv4 source address for authentication at the destination IPv4 node, all traffic relayed/translated by the translator box will mistakenly be considered as authentic.

The problem applies to IPv4-to-IPv6 translators as well. The problem is similar to proxied services, like HTTP proxy.

5.2. Possible solutions

- o Do not use translators, for protocols that use IP source address as authentication credential (for example, rlogin [Kantor, 1991]).
- o translators must implement some sort of access control, to reject any IPv6 traffic from malicious IPv6 nodes.
- o Do not use source address based authentication. IP source address should not be used as an authentication credential from the first place, since it is very easy for malicious parties to spoof IP source address.

6. Conclusions

IPv6 transition technologies have been proposed, however, some of them looks immune against abuse. The document presented possible ways of abuse, and possible solutions against them. The presented solutions should be reflected to the revision of specifications referenced.

For coming protocols, the author would like to propose a set of guilelines for IPv6 transition technologies:

- o Tunnels must explicitly be configured. Manual configuration, or automatic configuration with proper authentication, should be okay.
- o Do not embed IPv4 addresses into IPv6 addresses, for tunnels or other cases. It leaves room for abuse, since we cannot practically check if embedded IPv4 address is sane.
- o Do not define an IPv6 address format that does not appear on the wire. It complicates access control issues.

The author hopes to see more deployment of native IPv6 networks, where tunnelling technologies become unnecessary.

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7. Security considerations

The document talks about security issues in existing IPv6 related protocol specifications. Possible solutions are provided.

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An Extension of format for IPv6 Scoped Addresses

Draft-ietf-ipngwg-scopedaddr-format-02.txt

INTERNET-DRAFT
June 28, 2000

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An Extension of Format for IPv6 Scoped Addresses

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Status of this Memo

This document is an Internet-Draft and is in full conformance with all provisions of Section 10 of RFC 2026 [STD-PROC].

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This Internet Draft will expire on December 28, 2000.

Abstract

This document defines an extension of the format for IPv6 scoped addresses. In the format, a zone identifier is attached to a scoped address in order to supplement ambiguity of the semantics of the address. Using the format with some library routines will make scope-aware applications simpler.

1. Introduction

There are several types of scoped addresses defined in the "IPv6 Addressing Architecture" [ADDRARCH]. Since uniqueness of a scoped address is guaranteed only within a corresponding zone [SCOPEARCH], the semantics for a scoped address is ambiguous on a zone boundary. For example, when a user specifies to send a packet from a node to a link-local address of another node, the user must specify the link of the destination as well, if the node is attached to more than one link.

This characteristic of scoped addresses may introduce additional cost to scope-aware applications; a scope-aware application may have to provide a way to specify a scope zone for each scoped address (e.g. a specific link for a link-local address) that the application uses. Also, it is hard for a user to "cut and paste" a scoped address due to the ambiguity of its scope.

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Format for IPv6 Scoped Addresses

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Applications that are supposed to be used in end hosts like telnet, ftp, and ssh, are not usually aware of scoped addresses, especially of link-local addresses. However, an expert user (e.g. a network administrator) sometimes has to give even link-local addresses to such applications.

Here is a concrete example. Consider a multi-linked router, called "R1", that has at least two point-to-point interfaces. Each of the interfaces is connected to another router, called "R2" and "R3". Also assume that the point-to-point interfaces are "unnumbered", that is, they have link-local addresses only.

Now suppose that the routing system on R2 hangs up and has to be reinvoked. In this situation, we may not be able to use a global address of R2, because this is a routing trouble and we cannot expect that we have enough routes for global reachability to R2.

Hence, we have to login R1 first, and then try to login R2 using link-local addresses. In such a case, we have to give the link-local address of R2 to, for example, telnet. Here we assume the address is fe80::2.

Note that we cannot just type like

```
% telnet fe80::2
```

here, since R1 has more than one interface (i.e. link) and hence the telnet command cannot detect which link it should try to connect.

Although R1 could spray neighbor solicitations for fe80::2 on all links that R1 attaches in order to detect an appropriate link, we cannot completely rely on the result. This is because R3 might also assign fe80::2 to its point-to-point interface and might return a neighbor advertisement faster than R2. There is currently no mechanism to (automatically) resolve such conflict. Even if we had one, the administrator of R3 might not accept to change the link-local address especially when R3 belongs to a different organization from R1's.

Another example is an EBGp peering. When two IPv6 ISPs establish an EBGp peering, using a particular ISP's global addresses for the peer would be unfair, and using their link-local addresses would be better in a neutral IX. In such a case, link-local addresses should be specified in a router's configuration file and the link for the addresses should be disambiguated, since a router usually connects to multiple links.

This document defines an extension of the format for scoped addresses in order to overcome this inconvenience. Using the extended format with some appropriate library routines will make scope-aware applications simpler.

2. Assumptions and Definitions

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In this document we adopt the same assumption of characteristics of scopes as described in the scoped routing document [SCOPEDROUTING].

The keywords MUST, MUST NOT, REQUIRED, SHALL, SHALL NOT, SHOULD, SHOULD NOT, RECOMMENDED, MAY, and OPTIONAL, if and where they appear in this document, are to be interpreted as described in [KEYWORDS].

3. Proposal

The proposed format for scoped addresses is as follows:

```
<scoped_address>%<zone_id>
```

where

<scoped_address> is a literal IPv6 address,
<zone_id> is a string to identify the scope zone of the address, and
'%' is a delimiter character to distinguish between
<scoped_address> and <zone_id>.

The following subsections describe detail definitions and concrete examples of the format.

3.1 Scoped Addresses

The proposed format is applied to all kinds of unicast and multicast scoped addresses, that is, all non-global unicast and multicast addresses.

The format should not be used for global addresses. However, an implementation which handles addresses (e.g. name to address mapping functions) MAY allow users to use such a notation (see also Appendix C).

3.2 Zone Identifiers

An implementation SHOULD support at least numerical identifiers as <zone_id>, which are non-negative decimal numbers. Positive identifiers MUST uniquely specify a single zone for a given scoped address. An implementation MAY use zero to have a special meaning, for example, a meaning that no scope zone is specified.

An implementation MAY support other kinds of non-null strings as <zone_id> unless the strings conflict with the delimiter character. The precise semantics of such additional strings is implementation dependent.

One possible candidate of such strings would be interface names, since interfaces uniquely disambiguate any type of scopes [SCOPEDROUTING]. In particular, if an implementation can assume that there is a one-to-one mapping between links and interfaces (and the assumption is usually reasonable,) using interface names as link identifiers would be natural.

An implementation could also use interface names as <zone_id> for

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larger scopes than links, but there might be some confusion in such use. For example, when more than one interface belongs to a same site, a user would be confused about which interface should be used. Also, a mapping function from an address to a name would encounter a same kind of problem when it prints a scoped address with an interface name as a zone identifier. This document does not specify how these cases should be treated and leaves it implementation dependent.

It cannot be assumed that a same identifier is common to all nodes in a zone. Hence, the proposed format **MUST** be used only within a node and **MUST NOT** be sent on a wire.

3.3 Examples

Here are examples. The following addresses

```
fe80::1234 (whose link identifier is 1)
fec0::5678 (whose site identifier is 2)
ff02::9abc (whose link identifier is 5)
ff08::def0 (whose organization identifier is 10)
```

would be represented as follows:

```
fe80::1234%1
fec0::5678%2
ff02::9abc%5
ff08::def0%10
```

If we use interface names as <zone_id>, those addresses could also be represented as follows:

```
fe80::1234%ne0
fec0::5678%ether2
ff02::9abc%pvc1.3
ff08::def0%interface10
```

where the interface "ne0" belongs to link 1, "ether2" belongs to site 2, and so on.

3.4 Omitting Zone Identifiers

This document does not intend to invalidate the original format for scoped addresses, that is, the format without the scope identifier portion. An implementation **SHOULD** rather provide a user with a "default" zone of each scope and allow the user to omit zone identifiers.

Also, when an implementation can assume that there is no ambiguity of any type of scopes on a node, it **MAY** even omit the whole functionality to handle the proposed format. An end host with a single interface would be an example of such a case.

4. Combinations of Delimiter Characters

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There are other kinds of delimiter characters defined for IPv6 addresses. In this section, we describe how they should be combined with the proposed format for scoped addresses.

The IPv6 addressing architecture [ADDRARCH] also defines the syntax of IPv6 prefixes. If the address portion of a prefix is scoped one and the scope should be disambiguated, the address portion SHOULD be in the proposed format. For example, the prefix fec0:0:0:1::/64 on a site whose identifier is 2 should be represented as follows:

```
fec0:0:0:1::%2/64
```

In this combination, it is important to place the zone identifier portion before the prefix length, when we consider parsing the format by a name-to-address library function (see Appendix A). That is, we can first separate the address with the zone identifier from the prefix length, and just pass the former to the library function.

The preferred format for literal IPv6 addresses in URL's are also defined [URLFORMAT]. When a user types the preferred format for an IPv6 scoped address whose zone should be explicitly specified, the user could use the proposed format combined with the preferred format.

However, the typed URL is often sent on a wire, and it would cause confusion if an application did not strip the <zone_id> portion before sending. Also, the proposed format might conflict with the URI syntax [URI], since the syntax defines the delimiter chracter ('%') as the escape character.

Hence, this document does not specify how the proposed format should be combined with the preferred format for literal IPv6 addresses. As for the conflict issue with the URI format, it would be better to wait until the relationship between the preferred format and the URI syntax is clarified. Actually, the preferred format for IPv6 literal addresses itself has same kind of conflict. In any case, it is recommended to use an FQDN instead of a literal IPv6 address in a URL, whenever an FQDN is available.

5. Related Issues

In this document, it is assumed that a zone identifier is not necessarily common in a single zone. However, it would be useful if a common notation is introduced (e.g. an organization name for a site). In such a case, the proposed format could be commonly used to designate a single interface (or a set of interfaces for a multicast address) in a scope zone.

When the network configuration of a node changes, the change may affect <zone_id>. Suppose that the case where numerical identifiers are sequentially used as <zone_id>. When a network interface card is newly inserted in the node, some identifiers may have to be renumbered accordingly. This would be inconvenient,

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especially when addresses with the numerical identifiers are stored in non-volatile storage and reused after rebooting.

6. Security Considerations

Since the use of this approach to represent IPv6 scoped addresses is restricted within a single node, it does not cause a security attack from the outside of the node.

However, a malicious node might send a packet that contains a textual IPv6 scoped address in the proposed format, intending to deceive the receiving node about the zone of the scoped address. Thus, an implementation should be careful when it receives packets that contain IPv6 scoped addresses as data.

Appendix A. Interaction with API

The proposed format would be useful with some library functions defined in the "Basic Socket API" [BASICAPI], the functions which translate a nodename to an address, or vice versa.

For example, if `getaddrinfo()` parses a literal IPv6 address in the proposed format and fills an identifier according to `<zone_id>` in the `sin6_scope_id` field of a `sockaddr_in6` structure, then an application would be able to just call `getaddrinfo()` and would not have to care about scopes.

Also, if `getnameinfo()` returns IPv6 scoped addresses in the proposed format, a user or an application would be able to reuse the result by a simple "cut and paste" method.

The kernel should interpret the `sin6_scope_id` field properly in order to make these extensions feasible. For example, if an application passes a `sockaddr_in6` structure that has a non-zero `sin6_scope_id` value to the `sendto()` system call, the kernel should send the packet to the appropriate zone according to the `sin6_scope_id` field. Similarly, when a packet arrives from a scoped address, the kernel should detect the correct zone identifier based on the address and the receiving interface, fill the identifier in the `sin6_scope_id` field of a `sockaddr_in6` structure, and then pass the packet to an application via the `recvfrom()` system call, etc.

Note that the ipng working group is now revising the basic socket API in order to support scoped addresses appropriately. When the revised version is available, it should be preferred to the description of this section.

Appendix B. Implementation Experiences

The WIDE KAME IPv6 stack implements the extension to the `getaddrinfo()` and the `getnameinfo()` functions described in Appendix A of this document. The source code is available as free software, bundled in the KAME IPv6 stack kit.

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The current implementation assumes a one-to-one mapping between links and interfaces, and hence it uses interface names as <zone_id> for links.

For instance, the implementation shows its routing table as follows:

Internet6: Destination	Gateway	Flags	Intface
default	fe80::fe32:93d1%ef0	UG	ef0

This means that the default router is fe80::fe32:93d1 on the link identified by the interface "ef0". A user can "cut and paste" the result in order to telnet to the default router like this:

```
% telnet fe80::fe32:93d1%ef0
```

even on a multi-linked node.

As another example, we show how the implementation can be used for the problem described in Section 1.

We first confirm the link-local address assigned to the point-to-point interface of R2:

```
(on R1)% ping ff02::1%pvc0

PING(56=40+8+8 bytes) fe80::1 --> ff02::1
16 bytes from fe80::1%lo0, icmp_seq=0 hlim=64 time=0.474 ms
16 bytes from fe80::2%pvc0, icmp_seq=0 hlim=64 time=0.374 ms (DUP!)
...
(we assume here that the name of the point-to-point interface
on R1 toward R2 is "pvc0" and that the link-local address on
the interface is "fe80::1".)
```

So the address should be fe80::2. Then we can login R2 using the address by the telnet command without ambiguity:

```
% telnet fe80::2%pvc0
```

Though the implementation supports the extended format for all type of scoped addresses, our current experience is limited to link-local addresses. For other type of scopes, we need more experience.

The implementation also supports the notion of "default" scope zone as described in Section 3.4. If a user specified "pvc0" as the default link in the above example, the user can just type

```
% telnet fe80::2
```

then the kernel will automatically use the link identified by "pvc0" as the link of the address fe80::2.

Appendix C. A Comprehensive Description of KAME's getXXXinfo Functions

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The following tables describe the behavior of the KAME's implementation we mentioned in Appendix B using concrete examples. Note that those tables are not intended to be standard specifications of the extensions but are references for other implementors.

Those tables summarize what value the getXXXinfo functions return against various arguments. For each of two functions we first explain typical cases and then show non-typical ones.

The tables for getaddrinfo() have four columns. The first two are arguments for the function, and the last two are the results. The tables for getnameinfo() also have four columns. The first three are arguments, and the last one is the results.

Columns "Hostname" contain strings that are numeric or non-numeric IPv6 hostnames.

Columns "NI_NUMERICHOST" or "NHOST" show if the NI_NUMERICHOST is set to flags for the corresponding getXXXinfo function. Columns "NSCOPE" show if the NI_NUMERICSCOPE is set to flags for the corresponding getnameinfo function. The value "1" means the flag is set, and "0" means the flag is clear. "-" means that the field does not affect the result.

Columns "sin6_addr" contain IPv6 binary addresses in the textual format, which mean the values of the sin6_addr field of the corresponding sockaddr_in6 structure.

Columns "sin6_scope_id" contain numeric numbers, which mean the values of the sin6_scope_id field of the corresponding sockaddr_in6 structure.

If necessary, we use an additional column titled "N/B" to note something special.

If an entry of a result column has the value "Error", it means the corresponding function fails.

In the examples, we assume the followings:

- The hostname "foo.kame.net" has a AAAA DNS record "3ffe:501::1". We also assume the reverse map is configured correctly.
- There is no FQDN representation for scoped addresses.
- The numeric link identifier for the interface "ne0" is 5.
- We have an interface belonging to a site whose numeric identifier is 10.
- The numeric identifier "20" is invalid for any type of scopes.
- We use the string "none" as an invalid non-numeric zone identifier.

Typical cases for getaddrinfo():

Hostname	NI_NUMERICHOST	sin6_addr	sin6_scope_id
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"foo.kame.net"	0	3ffe:501::1	0	
"3ffe:501::1"	-	3ffe:501::1	0	
"fec0::1%10"	-	fec0::1	10	
"fe80::1%ne0"	-	fe80::1	5	
"fe80::1%5"	-	fe80::1	5	

Typical cases for getnameinfo():

sin6_addr	sin6_scope_id	NHOST	NSCOPE	Hostname
3ffe:501::1	0	0	-	"foo.kame.net"
3ffe:501::1	0	1	-	"3ffe:501::1"
fec0::1	10	-	-	"fec0::1%10"
fe80::1	5	-	0	"fe80::1%ne0"
fe80::1	5	-	1	"fe80::1%5"

Non-typical cases for getaddrinfo():

Hostname	NI_NUMERICHOST	sin6_addr	sin6_scope_id	N/B
"foo.kame.net"	1	Error		
"foo.kame.net%20"	-	Error		(*1)
"foo.kame.net%none"	-	Error		(*1)
"3ffe:501::1%none"	-	Error		
"3ffe:501::1%0"	-	3ffe:501::1	0	(*2)
"3ffe:501::1%20"	-	3ffe:501::1	20	(*2)
"fec0::1%none"	-	Error		
"fec0::1"	-	fec0::1	0	(*3)
"fec0::1%0"	-	fec0::1	0	(*4)
"fec0::1%20"	-	fec0::1	20	(*5)
"fe80::1%none"	-	Error		
"fe80::1"	-	fe80::1	0	(*3)
"fe80::1%0"	-	fe80::1	0	(*4)
"fe80::1%20"	-	fe80::1	20	(*5)

- (*1) <zone_id> against an FQDN is invalid.
- (*2) We do not expect that <zone_id> is specified for a global address, but we don't regard it as invalid.
- (*3) We usually expect that a scoped address is specified with <zone_id>, but if no identifier is specified we just set 0 to the sin6_scope_id field.
- (*4) Explicitly specifying 0 as <zone_id> is not meaningful, but we just treat the value as opaque.
- (*5) The <zone_id> portion is opaque to getaddrinfo() even if it is invalid. It is kernel's responsibility to raise errors, if there is any connection attempt that the kernel cannot handle.

Non-typical cases for getnameinfo():

sin6_addr	sin6_scope_id	NHOST	NSCOPE	Hostname	N/B
3ffe:501::1	20	1	-	"3ffe:501::1%20"	(*6)
3ffe:501::1	20	0	-	"foo.kame.net"	(*7)
fec0::1	20	-	-	"fec0::1%20"	
fec0::1	0	-	-	"fec0::1"	(*8)
fe80::1	20	-	-	"fe80::1%20"	
fe80::1	0	-	-	"fe80::1"	(*8)

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- (*6) We do not expect that a global IPv6 address has a non-zero zone identifier. But if it is the case, we just treat it as opaque.
- (*7) Despite the above, if the NI_NUMERICHOST is clear, we resolve the address to a hostname and print the name without scope zone information. We might have to reconsider this behavior.
- (*8) We usually expect that a scoped address has a non-zero zone identifier. But if the identifier is 0, we simply print the address portion without scope zone information.

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Protocol Independence Using the Sockets API

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**PROTOCOL INDEPENDENCE
USING THE SOCKETS API**

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Protocol Independence Using the Sockets API

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Abstract

The BSD sockets API provides abstractions and other features that help applications be protocol-independent. Unfortunately, not all of the API is abstract and generic, and many programs do not use the APIs in a protocol-independent way. This means that most network programs, in practice, only work with one layered set of communications protocols – usually TCP over IP. This hinders compatibility with older protocols and deployment of new ones, and is making IP a victim of its own success.

During the course of next-generation IP development, implementors worked to convert protocol-dependent applications into protocol-independent applications. Along the way, they defined new interfaces to fix some problems and they found a number of usage problems that lead to protocol dependencies.

This paper explains many of the problems encountered, using examples from freely available software, and how to solve them. It also explains many of the new protocol-independent interfaces.

1 Introduction

The single most painful lesson learned by implementors of next generation IP proposals (such as IPv6) was how deeply most network programs are dependent on the network protocol that they were originally written to use. The widespread success of the IP Internet has put it into the position of being the only network protocol that matters for most network applications, and so there is currently little incentive to support anything else.

Even today, this is a problem. There are other network protocols that are in use today – such as Appletalk, ATM, AX.25, DECnet, Frame Relay, IPX, and OSI – and few applications actually support them. This is also a serious problem for the future, as any research into new network protocols is greatly constrained by the lesson of IPv6: that anything not IP

will not be supported by the applications people want to use, and that anything that is not supported by existing applications will encounter great difficulty gaining acceptance.

The core of the BSD sockets API, especially the actual system calls, is not tied to any particular protocol. The problems fall in two major categories: supporting APIs that are protocol-dependent, and poor programming practices that are common. There have been great advances made in fixing the networking APIs in the system libraries through the efforts of the IETF's IPng working group[1] and the IEEE's POSIX p1003.1g (networking API) working group. New library functions, data structures, and pre-processor symbols together allow addresses and other network properties to be treated as variable-length abstract objects whose internal format can be changed without the application's involvement. But there is still a serious problem of programmer education, which in turn requires good documentation of the problems and how to solve them. To date, this documentation still does not exist.

In the NRL IPv6 implementation[2], standard networking applications from BSD and from the Internet were taken and modified to support protocol independence. For most applications, this was straightforward once we had done a few applications and knew what to look for. The end result was not only a conversion to allow the applications to support almost any protocol, but also a significant cleanup of the applications' code.

In this paper, I will first discuss the problems that need to be solved to make programs protocol-independent: what is wrong, why it is wrong, and how it can be done right. I will then discuss the new protocol-independent API functions and compare them with older BSD networking API functions in light of the problems that need to be solved. I will also present in more detail some additional functions that we found necessary to solve certain problems that have not yet been standardized. Specific examples from

freely available networking programs will be used.

2 Protocol Independence Problems

Fundamentally, the problem with protocol independence is that software has not been written with the intent of being protocol-independent. Some common programs, such as Sendmail, support multiple protocols, but are still only capable of operating with certain protocols that they know about (and usually only one protocol really works). A protocol-independent application hides away knowledge of particular protocols into run-time abstractions that allow the same operations to apply regardless of what actual protocols happen to be in use. In some cases, it is not possible to make operations completely generic, in which case protocol-dependent code needs to be carefully guarded and some reasonable default actions must be available for other protocols. But most importantly, programs must be tested with several different protocols to prove that they can handle them. The jump from supporting one protocol to two is the biggest hurdle, and clearing that in a reasonable way makes supporting other protocols much easier.

2.1 Hard Coding

The most obvious protocol dependence problem seen in network programs is to hard-code the use of one protocol. Figure 1 shows an example from 4.BSD-Lite2[3]'s telnet program. There are three major problems here. First, the protocol family to be used is hard-coded as `AF_INET`. That basically prevents protocols other than IP from being used. The family needs to be chosen based on the name resolution information, as will be discussed later. Second, the socket address used is a protocol-dependent address, in this case `sockaddr_in`. This structure is not big enough to hold addresses for some protocols, and in any case manipulating the fields in the structure itself is a protocol-dependent activity. Sockaddrs need to be treated as an opaque buffer manipulated by protocol-independent library functions or carefully guarded code. Third, IP-specific socket options are being used without any guards. That is, if the first two problems were fixed, the IP-specific `setsockopt` calls would still be done and they should always fail. Depending on the particular option being set, the socket option call needs to be replaced with an abstract equivalent or needs to be surrounded by a guard that skips the call if the protocol in use is not IP.

This particular bit of code also carries a common bug: it tries to be slightly protocol-independent and ends up worse off for the effort. It uses the protocol family returned by `gethostbyname()` and copies

addresses in a variable-length way, but copies that into a field within a `sockaddr_in` and later tries to `connect()` to that address using an `AF_INET` socket while specifying the length of the `sockaddr_in` as the length of the address information. If the family was something other than `AF_INET`, the `sockaddr_in` would probably not be filled in with something meaningful, and `connect()` call would probably fail regardless because the protocol family of the target address was not the same as that of the socket. As long as the only addresses that ever get returned by `gethostbyname()` are IP addresses, this practice will actually work. If addresses other than IP addresses were returned, programs written this way would break. This creates an interesting problem: interfaces that might be made protocol independent cannot be, because legacy programs don't use them correctly and changing what they return would break software. Using a new interface designed for protocol independence (like `getaddrinfo()`) and using it correctly will solve this problem.

A variation of this problem is hard coding addressing information, such as addresses and ports. Figure 2 shows an example from Sendmail 8.7.6[4]. There are three major problems here. First, the code always treats the address as a `sockaddr_in` without any guards. As in the example above, this is bad for protocol independence. Second, the code hard-codes an address and a port. While this is sometimes useful, it is usually bad practice and always bad practice when not combined with a test to check the protocol family. Third, the code explicitly specifies TCP as the transport protocol being used. This hard-codes a transport protocol and implies that only a small number of network protocols are usable (those that TCP has been made to run over). The second and third problems can be solved by using protocol-independent name resolution functions correctly.

2.2 Inflexible Storage

Another class of problems comes about when storing information needed by various protocols. This was already mentioned in the discussion of Figure 1, where not only does the use of `sockaddr_in` hard-code the address format of a particular protocol, but it also does not provide enough space to store the addresses of many protocols. The most common place where this problem comes into play is when used with `getpeername()`. Figure 3 shows an example of this from the 4.BSD-Lite2's `fingerd` source; similar code sequences can be found in almost any server program. This code example also shows the assumption that the returned socket will be an IP socket; while originally a fair assumption, this needs to be fixed in order to be protocol-independent.

```

temp = inet_addr(hostp);
if (temp != (unsigned long) -1) {
    sin.sin_addr.s_addr = temp;
    sin.sin_family = AF_INET;
    (void) strcpy(_hostname, hostp);
    hostname = _hostname;
} else {
    host = gethostbyname(hostp);
    if (host) {
        sin.sin_family = host->h_addrtype;
#if defined(h_addr) /* In 4.3, this is a #define */
        memmove((caddr_t)&sin.sin_addr,
                host->h_addr_list[0], host->h_length);
...

net = socket(AF_INET, SOCK_STREAM, 0);
setuid(getuid());
if (net < 0) {
    perror("telnet: socket");
    return 0;
}
#if defined(IP_OPTIONS) && defined(IPPROTO_IP)
if (srp && setsockopt(net, IPPROTO_IP, IP_OPTIONS, (char *)srp, srllen) <
    0)
    perror("setsockopt (IP_OPTIONS)");
#endif
...

if (connect(net, (struct sockaddr *)&sin, sizeof(sin)) < 0) {

```

Figure 1: Hard-Coding the Network Protocol (4.4BSD Telnet)

```

if (DaemonAddr.sin.sin_family == 0)
    DaemonAddr.sin.sin_family = AF_INET;
if (DaemonAddr.sin.sin_addr.s_addr == 0)
    DaemonAddr.sin.sin_addr.s_addr = INADDR_ANY;
if (DaemonAddr.sin.sin_port == 0)
{
    register struct servent *sp;

    sp = getservbyname("smtp", "tcp");
    if (sp == NULL)
    {
        syserr("554 service \"smtp\" unknown");
        DaemonAddr.sin.sin_port = htons(25);
    }
    else
        DaemonAddr.sin.sin_port = sp->s_port;
}

```

Figure 2: Hard Coding Addresses and Ports (Sendmail 8.7.6)

```

    struct sockaddr_in sin;
    ...
    if (logging) {
        sval = sizeof(sin);
        if (getpeername(0, (struct sockaddr *)&sin, &sval) < 0)
            err("getpeername: %s", strerror(errno));
        if (hp = gethostbyaddr((char *)&sin.sin_addr.s_addr,
                               sizeof(sin.sin_addr.s_addr), AF_INET))
            lp = hp->h_name;
        else
            lp = inet_ntoa(sin.sin_addr);
        syslog(LOG_NOTICE, "query from %s", lp);
    }

```

Figure 3: Use of a `sockaddr_in` to Store Arbitrary Addresses (4.4BSD `fingerd`)

A similar problem is also seen frequently in servers: the use of a generic `sockaddr` to store address information. Like the IP protocol specific structure, it is not big enough to hold addresses for many protocols (on most systems, the two structures are actually the same size). When the size of the address to be stored is known, a buffer of that size can be allocated. When it is not, a maximal-length buffer can be allocated using a `sockaddr_storage`, which will be discussed later.

A particularly bad special case of this problem comes about in some IP-only programs. Because IP addresses happen to be 32 bit unsigned integers and many modern systems have that as a native data type, some programs simply use integers to store IP addresses. Figure 4 shows an example from `vat 4.0b2[5]`, which uses `u_int32_t`s internally to store network addresses (this is a bit less bad than using more generic integer types, but still hopelessly IP-dependent). Due to a particularly common example of this in earlier versions of BSD, this is sometimes referred to as the “all the world’s a `u_long`” problem, and has a lot in common with the old “all the world’s a VAX” problem. Optimizing assumptions are being made about the size and form of an address that happen to work on most currently interesting systems and protocols. But they’re still poor assumptions that break portability, both in terms of supporting different systems and supporting different protocols. 4.4BSD-Lite2 has fixed this problem in many places by using `in_addr` instead, which is still protocol-dependent but at least is the correct type. In general, raw addresses should not be stored – socket addresses should be used instead.

Also, some protocols have variable-length addresses. Most existing programs treat addresses as fixed-length objects and do not store the real length as provided by run-time functions. Programs must store the length of addresses along with the addresses themselves – as with the address type, this can be necessary information for interpreting the address. This also means that

the sizes of buffers used to hold addresses should not be arbitrarily bounded.

Using the generic `sockaddr` or the wrong protocol-specific structure also creates problems with alignment. Most network protocols have some alignment requirement for their protocol-specific address structures that may not be satisfied by other structures. Care must be taken to either use the correct protocol specific address structure or to arrange for the buffer used to store addresses to be properly aligned.

The generic `sockaddr` *should* be used as a structure to which an arbitrary socket address can be cast in order to access the `sa_family` and `sa_len` fields. While those fields should have the same type no matter what protocol specific structure is used to access the buffer, it is still good use of types to use the generic `sockaddr` for access where the network protocol in use are not yet known, rather than to using the wrong protocol-specific type.

Finally, many programs assume that a “port” is an integer. The concept of an integer port number is not universal. Some protocols use string service names instead, or use other formats that are at least convertible to a string. Service endpoints should be represented as strings that may or may not end up converted to another format for representation in a socket address.

2.3 Inflexible User Interface

Many programs get address information through some sort of user interface or user parameter syntax. For example, web clients get resource information through URLs, free network programs such as `tcp_wrappers` [6] read configuration files, and some GUI network programs use four three-digit entry blanks to enter a numeric address. In many cases, the user interface or syntax that these clients use is dependent on the syntax of particular kinds of addresses. The use of colons and

slashes in URLs, for example, makes it difficult to use those characters in network addresses (colons are the delimiter for IPv6 addresses, so this is a real problem). Similarly, the configuration files for `tcp_wrappers` 7.6 uses colons as the field separator. The generic solution to this problem is to provide support for escaping and/or quoting so that somewhat arbitrary characters can be used in address information. In many cases, a quick-fix solution can be made by changing the fields or delimiters, but this is not backwards compatible and only fixes things until the next new address syntax comes along.

Another problem is that more information may need to be provided to a program in order for it to know how to correctly interpret an address. For example, a host name may be valid in multiple protocol families. If the user wants to use a specific protocol, then this needs to be somehow specified. Programs need to have enough flexibility in their user interfaces to add these sort of options.

2.4 Not Handling Multiple Addresses

Multi-homed IP support in programs is still not as common as it should be. The problem of multi-homing support – supporting multiple interfaces with one or more IP address – is similar to the problem of supporting multiple addresses for different network protocols. In both cases, some subset of the available addresses may need to be listened on (for a server) or be available for an outgoing connection. The selection of these addresses creates interesting problems. In particular, it sometimes (esp. in the case of servers) creates the need to have multiple network sockets open at once and to handle traffic on any of them. Most networking programs are written to use only one network socket, and changing that requires significant work.

Both multi-homing and multi-protocol support requires extra user interface capability. For example, both will cause multiple addresses to be returned from some name lookups, of which a subset might be reachable endpoints. The user should be either be given a choice among this set or some attempt should be made to progress in a reasonable way (for example, trying each in sequence until one succeeds). Whatever actually happens, the user should be made aware of what's happening.

2.5 Protocols Carrying Address Information

Some IP application protocols, such as FTP and talk, pass address information over the network. This means that the application protocol will need to be modified to be multi-protocol, which generally means

adding flexibility similar to what has to be done inside a network program. Exactly how to do this is outside the scope of this document, but an example is the approach used for FTP[7]. In general, the best solution to this problem is to change the application protocol to not send address information over the network, because this practice causes problems for many network/protocol translation devices.

3 New Interfaces

The IETF's IPng working group and the POSIX p1003.1g working group have made a good bit of progress in identifying and standardizing new APIs needed to develop protocol-independent programs. Beyond this, the NRL IPv6 implementation found several other interfaces that we felt needed to be present in order to develop fully functional protocol-independent applications. In many cases, the BSD sockets interfaces were almost good enough but in practice misused. The new interfaces extend many BSD interfaces and supersede others.

The new interfaces break down into roughly two categories. The first are functions to perform name resolution operations (name to addresses, address to name) in a clean way. The second are operations to help use socket addresses (sockaddrs) in a clean way.

3.1 Name Resolution

Figure 5 shows a brief summary of the new name resolution interfaces.

The `getaddrinfo()` and `getnameinfo()` functions provide a protocol-independent way of mapping names to addresses information and of mapping address information back to names. Given a host name, a service name, and other information to constrain the lookup, `getaddrinfo()` returns either an integer error or a list of filled in `addrinfo` structures. Each contains the information that needs to be passed to `socket()` to open a socket as well as the information that needs to be passed to `connect()` or `sendmsg()` to reach the named endpoint.

Many programs can simply take the returned list and iterate through it, executing `socket()` and `connect()` calls with the information in each list element, until one attempt succeeds completely or the list has been exhausted. Figure 6 gives an example of how to do this. Notice how the program never needs to manipulate addresses directly. The program only needs to take information out of the `addrinfo` structure and feed it into other functions. This simple block of code is capable of obtaining a connected socket with any stream protocol that is supported in both the kernel and in the runtime library. If the runtime library

```

int Network::dorecv(u_char* buf, int len, u_int32_t& from, int fd)
{
    sockaddr_in sfrom;
    int fromlen = sizeof(sfrom);
    int cc = ::recvfrom(fd, (char*)buf, len, 0,
                       (sockaddr*)&sfrom, &fromlen);
    if (cc < 0) {
        if (errno != EWOULDBLOCK)
            perror("recvfrom");
        return (-1);
    }
    from = sfrom.sin_addr.s_addr;
}

```

Figure 4: Using an Integer for an Address (from vat 4.0b2)

```

#define AI_PASSIVE      /* Socket address is intended for bind() */
#define AI_CANONNAME    /* Request for canonical name */
#define AI_NUMERICHOST /* Don't ever try nameservice */

struct addrinfo {
    int ai_flags;           /* input flags */
    int ai_family;         /* protocol family for socket */
    int ai_socktype;       /* socket type */
    int ai_protocol;       /* protocol for socket */
    int ai_addrlen;        /* length of socket-address */
    struct sockaddr *ai_addr; /* socket-address for socket */
    char *ai_canonname;     /* canonical name for service location (iff req) */
    struct addrinfo *ai_next; /* pointer to next in list */
};

int getaddrinfo(const char *name, const char *service,
               const struct addrinfo *req, struct addrinfo **pai);

void freeaddrinfo(struct addrinfo *ai);

char *gai_strerror(int ecode);

#define NI_MAXHOST      /* Maximum host name buffer length needed */
#define NI_MAXSERV      /* Max. service name buffer length needed */
#define NI_NUMERICHOST  /* Don't do name resolution for the host */
#define NI_NUMERICSERV  /* Don't do name resolution for the service */
#define NI_NOFQDN       /* Don't fully qualify host names */
#define NI_NAMEREQD     /* Fail if name resolution for the host fails */
#define NI_DGRAM        /* Service is for a DGRAM socket (not a STREAM) */

int getnameinfo(const struct sockaddr *sa, size_t addrlen, char *host,
               size_t hostlen, char *serv, size_t servlen, int flags);

int nrl_afnametonom(const char *name); /* (Nonstandard) */
const char *nrl_afnumtoname(int num); /* (Nonstandard) */
int nrl_socktypenametonom(const char *name); /* (Nonstandard) */
const char *nrl_socktypenumtoname(int num); /* (Nonstandard) */

```

Figure 5: Summary of New Name Resolution APIs

does not support a protocol, it will not be returned by `getaddrinfo()`. If the kernel does not support a protocol, this function will print an error for those sockets and skip that protocol. This is especially important for binaries to be shipped on systems where the protocols available in the runtime library and/or kernel can be configured by the end user; one binary will be able to work as long as the system is configured so that there is one protocol that the entire system supports.

Note that `getaddrinfo()` and `getnameinfo()` handle both host names and printable numeric addresses, as appropriate. One historical problem with functions like `gethostbyname()` and `gethostbyaddr()` is that on some systems they handle printable numeric addresses and on some systems they do not. Portable programs must be written to attempt printable-numeric conversion separately, just in case – programs that assume the system handles these have encountered portability problems. Some programs have bugs caused by the old printable numeric conversion functions, making this even more of a problem. These new functions should hopefully put these problem to rest.

As shown in the example, the `gai_strerror()` function converts the errors returned by `getaddrinfo()` and `getnameinfo()` into human-printable form. There are also constants for the error values, but few programs need to distinguish between the types of failures beyond giving an appropriate error message. The `freeaddrinfo()` function releases the memory used by the result list, and *must* be called when the result is no longer needed.

The functions `nrl_afnametonum()` and `nrl_afnumtoname()` convert address family names (inet, inet6, local, etc.) to numbers and back. This is needed in order to support user entry of an address family to constrain `getaddrinfo()` lookups. For example, many NRL IPv6-enabled applications support a command line flag that the user can use to specify a family, such as “inet” or “inet6,” that selects what protocol to use. The number-to-name function is also helpful for diagnostic output. Similarly, the functions `nrl_socktypenametounum()` and `nrl_socktypenumtoname` convert socket type names (stream, dgram, seqpacket, etc.) to numbers and back. These are less useful for user input, but are still useful for diagnostic purposes.

3.2 Socket Addresses

Figure 7 shows a brief summary of the new socket address interfaces. The major new addition is the `sockaddr_storage`, which is defined as a structure that is big enough to hold any socket address that the system supports or might support in the future, and provides sufficient alignment for any socket address that the system supports or might support in

the future. In practice, the size of the structure is bounded on many systems by the capacity of the eight bit integer used in the `sa_len` field of all socket addresses. On other systems, the bound might be provided by other structures’ fields. The bound actually chosen can be selected by the systems’ authors, but the `sockaddr_storage` is defined to have whatever size is needed. The alignment provided by the `sockaddr_storage` will typically be the largest alignment available on the system, though again the exact choice is up to the systems’ implementors.

Note that the `sockaddr_storage` is required to have fields of the same type and in the same place as the `sa_len` and `sa_family` fields in the systems’ `sockaddrs`, but that the standards that specify this data structure do not actually require those fields to have a known name and give examples with names that makes them “hidden.” While it is hoped that the long term solution will be to fix this problem in the standards, the short term most portable way to use these fields is to cast a `sockaddr_storage` to a `sockaddr` and to use the fields through the latter type.

The `sockaddr_storage` is used where a socket address needs to be stored before its exact length is known. Figure 8 shows some of the example in Figure 3, changed to take advantage of this structure as well as `getnameinfo()`. The code is not very different, but the use of the `sockaddr_storage` guarantees that any protocol-specific socket address can be safely stored in the buffer.

A controversial API extension that was used heavily in the NRL code is the `SA_LEN()` macro. On systems whose `sockaddr` has a `sa_len` field, this expands to return the contents of that field and has the same semantics except that it is only defined to be an rvalue. On systems whose `sockaddr` does not, this expands into an operation that returns the correct value based on the value of the `sa_family` field. This macro solves the problem of needing a `sockaddr`’s length for many function calls well after existing code has lost the length information. It is frequently far easier to replace a hard coded value such as `sizeof(struct sockaddr_in)` with a macro use like `SA_LEN(sa)` than it is to gut an entire program and fix this. Using the macro, this technique is portable to systems with and without `sa_len` support. Authors who have used this technique extensively have been quite supportive of it, while authors of systems that don’t have `sa_len` fields have been opposed to it.

3.3 State of Deployment

New API functions are fine as long as they are available everywhere, but deployment does not happen quickly. The interfaces described as non-standard are just that, and are unlikely to be present any-

```

int get_stream(char *host, *service)
{
    int error, fd;
    struct addrinfo req, *ai, *ai2;
    char hbuf[NI_MAXHOST], sbuf[NI_MAXSERV];

    memset(&req, 0, sizeof(struct addrinfo));
    req.ai_socktype = SOCK_STREAM;

    if (error = getaddrinfo(host, service, NULL, &ai)) {
        fprintf(stderr, "getaddrinfo(%s, %s, ...): %s(%d)", gai_strerror(error),
            error);
        return -1;
    }

    for (ai2 = ai; ai = ai->ai_next) {
        if (error = getnameinfo(ai->ai_addr, ai->ai_addrlen, hbuf, sizeof(hbuf),
            sbuf, sizeof(sbuf), NI_NUMERICHOST | NI_NUMERICSERV)) {
            fprintf(stderr, "getnameinfo(%p, %d, %p, %d, %p, %d, %d): %s(%d)\n",
                ai->ai_addr, ai->ai_addrlen, hbuf, sizeof(hbuf), sbuf, sizeof(sbuf),
                NI_NUMERICHOST | NI_NUMERICSERV, gai_strerror(error), error);
            continue;
        }

        fprintf(stdout, "Trying %s.%s...\n", hbuf, sbuf);

        if ((fd = socket(ai->ai_family, ai->ai_socktype, ai->ai_protocol)) < 0) {
            fprintf(stderr, "socket(%d, %d, %d): %s(%d)\n", ai->ai_family,
                ai->ai_socktype, ai->ai_protocol, strerror(errno), errno);
            continue;
        }

        if (connect(fd, ai->ai_addr, ai->ai_addrlen) < 0) {
            fprintf(stderr, "connect(%d, %p, %d): %s(%d)\n", fd, ai->ai_addr,
                ai->ai_addrlen, strerror(errno), errno);
            close(fd);
            continue;
        }

        freeaddrinfo(ai2);
        return fd;
    }

    freeaddrinfo(ai2);
    fprintf(stderr, "No connections result.\n");
    return -1;
}

```

Figure 6: Using `getaddrinfo()` to Get one Stream Connection

References

IPv6:

IPv6: The New Internet Protocol (2nd edition)

Christian Huitema

ISBN 0138505055

A comprehensive book on the history of IPv6 design, development, and the specification itself. It was published in 1997, so, it is based on the old IPv6 specification (RFC 1883) rather than the latest one (RFC 2460).

Network Programming Using Socket API:

UNIX Network Programming, Volume 1: Networking APIs—Sockets and XTI (2nd edition)

W. Richard Stevens

ISBN 013490012X

A definitive book on programming using socket API. Note, however, that the description of IPv6 API is out-of-date, so don't refer to it. Refer to this book and/or RFC 2553.

TCP/IP Illustrated, Volume 1: The Protocols

W. Richard Stevens

ISBN 0201633469

Describes the design of TCP/IP protocols, as well as actual packet flows. It will help you understand what will happen after you make certain socket API calls.

IPv6-Related RFCs:

RFC 2373 IP Version 6 Addressing Architecture

R. Hinden, S. Deering. July 1998. (Format: TXT = 52,526 bytes) (Obsoletes RFC 1884) (Status: PROPOSED STANDARD)

Defines various types of IPv6 addresses, such as multicast addresses or link-local addresses. The document also defines textual notation for the IPv6 address (hexadecimals separated by colons).

RFC 2460 Internet Protocol, Version 6 (IPv6) Specification

S. Deering, R. Hinden. December 1998. (Format: TXT = 85,490 bytes) (Obsoletes RFC 1883) (Status: DRAFT STANDARD)

The base specification of IPv6. Defines IPv6 header and various extension headers.

RFC 2461 Neighbor Discovery for IP Version 6 (IPv6)

T. Narten, E. Nordmark, W. Simpson. December 1998. (Format: TXT = 22,2516 bytes) (Obsoletes RFC 1970) (Status: DRAFT STANDARD)

Defines Neighbor Discovery (ND) protocol, which is necessary for IPv6 communication over the Ethernet. ND is the the IPv6 counterpart for IPv4 ARP.

RFC 2462 IPv6 Stateless Address Autoconfiguration

S. Thomson, T. Narten. December 1998. (Format: TXT = 61,210 bytes) (Obsoletes RFC 1971) (Status: DRAFT STANDARD)

Specification on address autoconfiguration, which is an important feature of IPv6.

RFC 2463 Internet Control Message Protocol (ICMPv6) for the Internet Protocol Version 6 (IPv6) Specification

A. Conta, S. Deering. December 1998. (Format: TXT = 34,190 bytes) (Obsoletes RFC 1885) (Status: DRAFT STANDARD)

Defines ICMP for IPv6. RFCs can be downloaded from <ftp://ftp.ietf.org/rfc/>.

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