Inside Mac OS X

Network Kernel Extensions

Technical Publications

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PREFACE

About This Manual

This manual describes Network Kernel Extensions for Mac OS X. Network Kernel Extensions provide a mechanism for adding and removing protocol families, individual protocols, and other networking modules to the Mac OS X kernel while the kernel is running.

Note
The information presented in this manual is preliminary and subject to change. ◆

Conventions used in this manual

The Courier font is used to indicate text that you type or see displayed. This manual includes special text elements to highlight important or supplemental information:

Note
Text set off in this manner presents sidelights or interesting points of information. ◆

IMPORTANT
Text set off in this manner—with the word Important—presents important information or instructions. ▲

▲ **WARNING**
Text set off in this manner—with the word Warning—indicates potentially serious problems. ▲

For more information

The following sources provide additional information that may be of interest to developers of network kernel extensions:

- *The Design and Implementation of the 4.4 BSD Operating System* . M. K. McKusick. et al., Addison-Wesley, Reading, 1996.
- *Unix Network Programming, Second Edition, Volume 1*. Richard W. Stevens, Prentice Hall, New York, 1998.
- *TCP/IP Illustrated, Volume 1, The Protocols*. Richard W. Stevens, Addison-Wesley, Reading, 1994.
- *TCP/IP Illustrated, Volume 2, The Implementation*. Richard W. Stevens and Gary R. Wright, Addison-Wesley, Reading, 1995.
- *TCP/IP Illustrated, Volume 3, Other Protocols*. Richard W. Stevens, Addison-Wesley, Reading, 1996.

The following websites provide information about the Berkeley Software Distribution (BSD):

- http://www.FreeBSD.org
- http://www.NetBSD.org
- http://www.OpenBSD.org/

Apple Computer's developer website (http://www.apple.com/developer/) is a general repository for developer documentation.

C H A P T E R 1

About Network Kernel Extensions

Network kernel extensions (NKEs) provide a way to extend and modify the networking infrastructure of Mac OS X while the kernel is running and therefore without requiring the kernel to be recompiled, relinked, or rebooted.

NKEs allow you to

- create protocol stacks that can be loaded and unloaded dynamically and configured automatically.
- create modules that can be loaded and unloaded dynamically at specific positions in the network hierarchy. These modules can monitor network traffic, modify network traffic, and receive notification of asynchronous events at the data link and network layers from the driver layer, such as power management events and interface status changes.

An NKE is a specific case of a Mac OS X kernel extension. It is a separately compiled module (produced, for example, by Project Builder using the Kernel Extension project type).

An installed and enabled NKE is invoked automatically, depending on its position in the sequence of protocol components, to process an incoming or an outgoing packet. Loading (installing) a kernel extension is handled by the `kextload`(8) command line utility, which adds the NKE to the running Mac OS X kernel as part of the kernel's address space. Eventually, the system will provide automatic mechanisms for loading extensions. Currently, automatic loading is only possible for IOKit extensions and other extensions that IOKit extensions depend on.

As a kernel extension, an NKE provides initialization and termination routines that the Kernel Extension Manager invokes when it loads or unloads an NKE. The initialization routine handles any operations needed to complete the incorporation of the NKE into the kernel, such as updating `protosw` and `domain` structures. Similarly, the termination routine must remove references to the NKE from these structures in order to unload itself successfully. NKEs must provide a mechanism, such as a reference count, to ensure that the NKE can terminate without leaving dangling pointers.

NKE Implementation

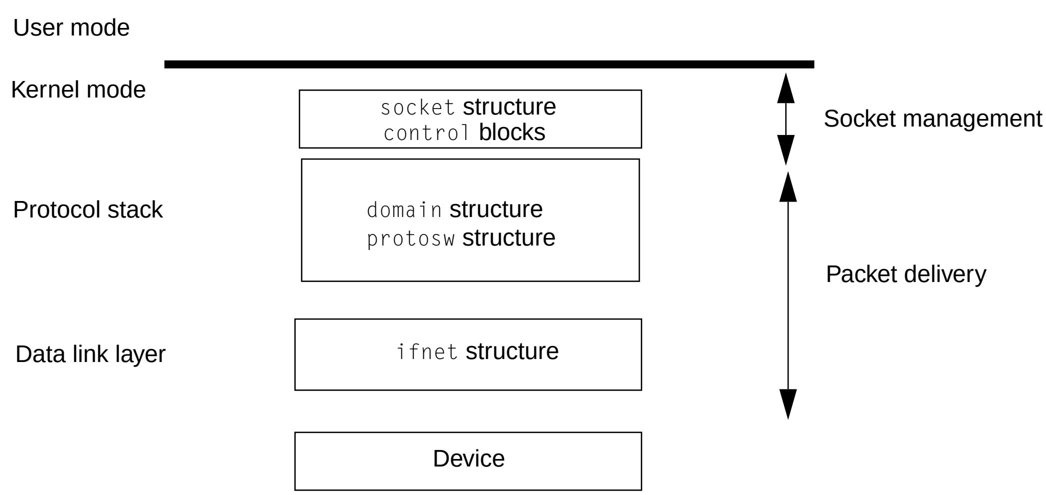
Review of 4.4 BSD Network Architecture

Mac OS X is based on the 4.4BSD UNIX operating system. The following structures control the 4.4BSD network architecture:

- `socket` structure, which the kernel uses to keep track of sockets. The `socket` structure is referenced by file descriptors from user mode.
- `domain` structure, which describes protocol families.
- `protosw` structure, which describes protocol handlers. (A protocol handler is the implementation of a particular protocol in a protocol family.)
- `ifnet` structure, which describes a network device and contains pointers to interface device driver routines.

None of these structures is used uniformly throughout the 4.4BSD networking infrastructure. Instead, each structure is used at a specific level, as shown in Figure 1-1.

Figure 1-1 4.4BSD network architecture



The `socket` structure is used to manage the socket while the `domain`, `protosw`, and `ifnet` structures are used to manage packet delivery to and from the network device.

NKE Types

Making the 4.4BSD network architecture dynamically extensible requires several NKE types that are used at specific locations within the kernel.

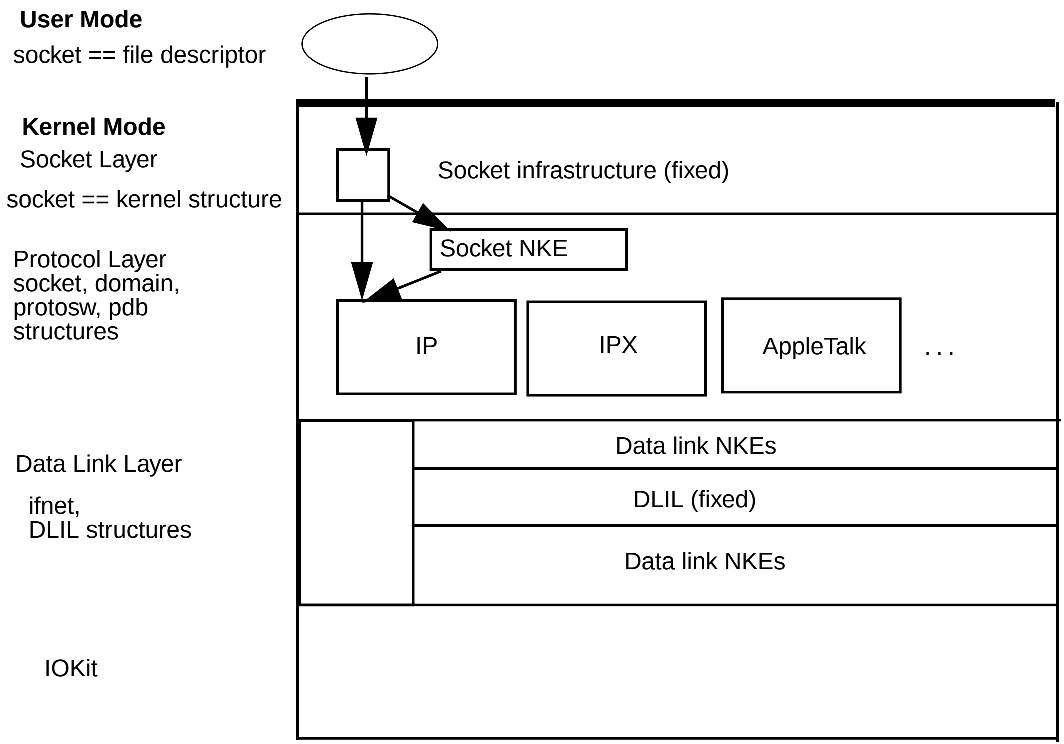
- socket NKEs, which reside between the network layer and protocol handlers and are invoked through a `protosw` structure. Socket NKEs use a new set of override dispatch vectors that intercept specific socket and socket buffer utility functions.
- protocol family NKEs, which are collections of protocols that share a common addressing structure. Internally, a `domain` structure and a chain of `protosw` structures describe each protocol.
- protocol handler NKEs, which process packets for a particular protocol within the context of a protocol family. A `protosw` structure describes a protocol handler and provides the mechanism by which the handler is

invoked to process incoming and outgoing packets and for invoking various control functions.

- data link NKEs, which are inserted below the protocol layer and above the network interface layer. This type of NKE can passively observe traffic as it flows in and out of the system (for example, a sniffer) or can modify the traffic (for example, encrypting or performing address translation). Data link NKEs can provide media support functions (performing demultiplexing, framing, and pre-output functions, such as ARP) and can act as “filters” that are inserted between a protocol stack and a device or above a device.)

Figure 1-2 summarizes the NKE architecture.

Figure 1-2 NKE architecture



Global and Programmatic NKEs

Socket NKEs can operate in one of two modes: programmatic or global.

A **global NKE** is an NKE that is automatically enabled for sockets of the type specified for the NKE.

A **programmatic NKE** is a socket NKE that is enabled only under program control, using socket options, for a specfic socket.

Data link 'filters' are essentially global in that they can't be accessed by specific sockets.

Tracking NKE Usage

To support the dynamic addition and removal of NKEs in Mac OS X, the kernel keeps track of the use of NKEs by other parts of the system.

Use of protocol family NKEs is tracked by the `dom_refs` member of the `domain` structure, which has been added to support NKEs in Mac OS X. The kernel's `socreate` function increments `dom_refs` each time `socreate` is called to create a socket in an NKE domain. The `socreate` function is called when user-mode applications call `socket` or when `sonewconn` successfully connects to a local listening socket. The `dom_refs` member is decremented each time `soclose` is called to close a socket connection.

Use of protocol handler NKEs is tracked by the `pr_refs` member of the `protosw` structure, which has been added to support NKEs in Mac OS X. Like the `dom_refs` member of the `domain` structure, the `pr_refs` member of the `protosw` structure tracks the use of the protocol between calls to `socreate` and `sonewconn` to create a socket and `soclose` to close a socket.

The most important aspect of removing an NKE is ensuring that all references to NKE resources are eliminated and that all system resources allocated by the NKE are returned to the system. The NKE must track its use of resources, such as socket structures and protocol control blocks, so that the NKE's termination routine can eliminate references and return system resources.

Modifications to 4.4BSD Networking Architecture

To support NKEs in Mac OS X, the 4.4BSD `domain` and `protosw` structures were modified as follows:

- The protosw array referenced by the domain structure is now a linked list, thereby removing the array's upper bound. The new dom_maxprotohdr member defines the maximum protocol header size for the domain. The new dom_refs member is a reference count that is incremented when a new socket for this address family is created and is decremented when a socket for this address family is closed.
- The protosw structure is no longer an array. The pr_next member has been added to link the structures together. This change has implications for protox usage for AF_INET and AF_ISO input packet processing. The pr_flags member is an unsigned integer instead of a short. NKE hooks have been added to link NKE descriptors together (pr_sfilter).

PF_NKE Domain

Mac OS X defines a new domain — the PF_NKE domain— whose purpose is to provide a way for applications to configure and control NKEs. The PF_NKE domain has two protocols:

- NKEPROTO_SOCKET for configuring and controlling NKEs that the operate at the socket layer
- NKEPROTO_DLINK for configuring and controlling NKEs that operate at the data link layer

The PF_NKE domain's initialization function is called when the PF_NKE domain is initially added to the system. The initialization function adds the NKEPROTO_SOCKET and NKEPROTO_DLINK protocols to the domain's protosw list and performs other initialization tasks.

Each protocol in the PF_NKE domain has its own protosw structure. Each protosw structure contains pointers to functions that operate on the protocol for that protosw structure. The functions associated with each protocol in the PF_NKE domain are

- pr_input — allows a control program to read data from an NKE. The format of the data is specific to the NKE. For an example of an NKE that uses pr_input, see "Sample Source Code for TCPLogger" in Appendix A.
- pr_output — allows a control program to send data to an NKE. The effect of sending data to an NKE is specific to the NKE.

- `pr_ctlinput` — handles events from the NKE. These are the `PRC_*` constants defined in `protosw.h`.
- `pr_ctloutput` — allows NKE-specific socket options to be processed.
- `pr_init` — initializes protocol handlers.
- `pr_fasttimo` — a 200 millisecond timer.
- `pr_slowtimo` — a 500 millisecond timer.
- `pr_usrreq` — points to a table of function pointers that dispatch functions for handling the socket operations listed in Table 1-1.

Note
In earlier versions of BSD, socket operations were handled by a single procedure (`pr_usrreq`), using `PRU_*` constants as function selectors. In recent versions of FreeBSD, these operations are handled by individual functions, specified in the `pr_usrreqs` table. Corresponding functions begin with `pru_`. Mac OS X networking is based on FreeBSD 3.1. ◆

Table 1-1 Dispatch entries used by the pr_usrreq function for PF_NKE protocols

pru_abort	Abort the connection to the NKE.
pru_accept	Accept a connection from an NKE.
pru_attach	Attach to a protocol. Allows the calling process to attach to an NKE independent of its normal operation. This entry is invoked when you want to access a specific NKE, for example, to configure the NKE for a specific operation. `s = socket(SOCK_RAW, PF_NKE, val)` where `val` is the constant `NKEPROTO_DLINK` or `NKEPROTO_SOCKET`.
pru_bind	Not used.
pru_connect	Establish a connection to an NKE.
pru_connect2	Not used.
pru_control	Call the NKE's ioctl routine to perform control operations.
pru_detach	Detach from a protocol. This entry is used to terminate a connection with an NKE.
pru_disconnect	Disconnect from an NKE.
pru_fasttimo	Execute a specified task for 200 ms.
pru_listen	Listen for a connection.
pru_peeraddr	Get the address of the remote socket.
pru_protorcv	Not used.
pru_protosend	Not used.
pru_rcvd	Not supported.
pru_rcvoobu	Retrieve out-of-band data.
pru_shutdown	Indicate that the controlling application won't send or receive any more data.
pru_send	Send the specified data to the NKE.
pru_sendoob	Send out-of-band data.
pru_sense	Return zero.
pru_slowtimo	Execute a specified task for 500 ms.
pru_sockaddr	Get the address of the local socket.
pru_sopoll	
pru_soreceive	
pru_sosend	

Socket NKE Control Commands

Socket NKEs can be configured, started, and halted by control commands. The following generic control commands are defined:

- FILT_CONFIG — passes a structure, by agreement with the NKE, describing the configuration the NKE is to use.
- FILT_START — starts the NKE.
- FILT_HALT — terminates the NKE, but the NKE remains installed and ready to be started again.

The PF_NKE domain receives these commands from the controlling program via a setsockopt call specifying NKEPROTO_DLINK or NKEPROTO_SOCKET and passes them to the NKE after examining and possibly modifying them.

Other socket options can be defined for individual NKEs. By definition, NKE-specific control commands are a matter of agreement between the NKE and the control program. Like the generic socket options, NKE-specific control commands are passed from the control program to the NKE by the setsockopt call with a FILTERPROTO_* level. The filter manager passes to the NKE without modification any commands that the filter manager does not recognize.

NKE control commands invoke the NKE's PRCO_SETOPT function using pru_control in the pr_usrreq table in the NKE's protosw structure.

About Protocol Family NKEs

Adding and removing protocol family NKEs is accomplished by calling net_add_domain and net_del_domain, respectively. These calls are described in "Protocol Family NKE Functions" (page 51). For detailed information about implementing protocol families, see *The Design and Implementation of the 4.4 BSD Operating System* by M. K. McKusick. et al. and *TCP/IP Illustrated* by Richard W. Stevens.

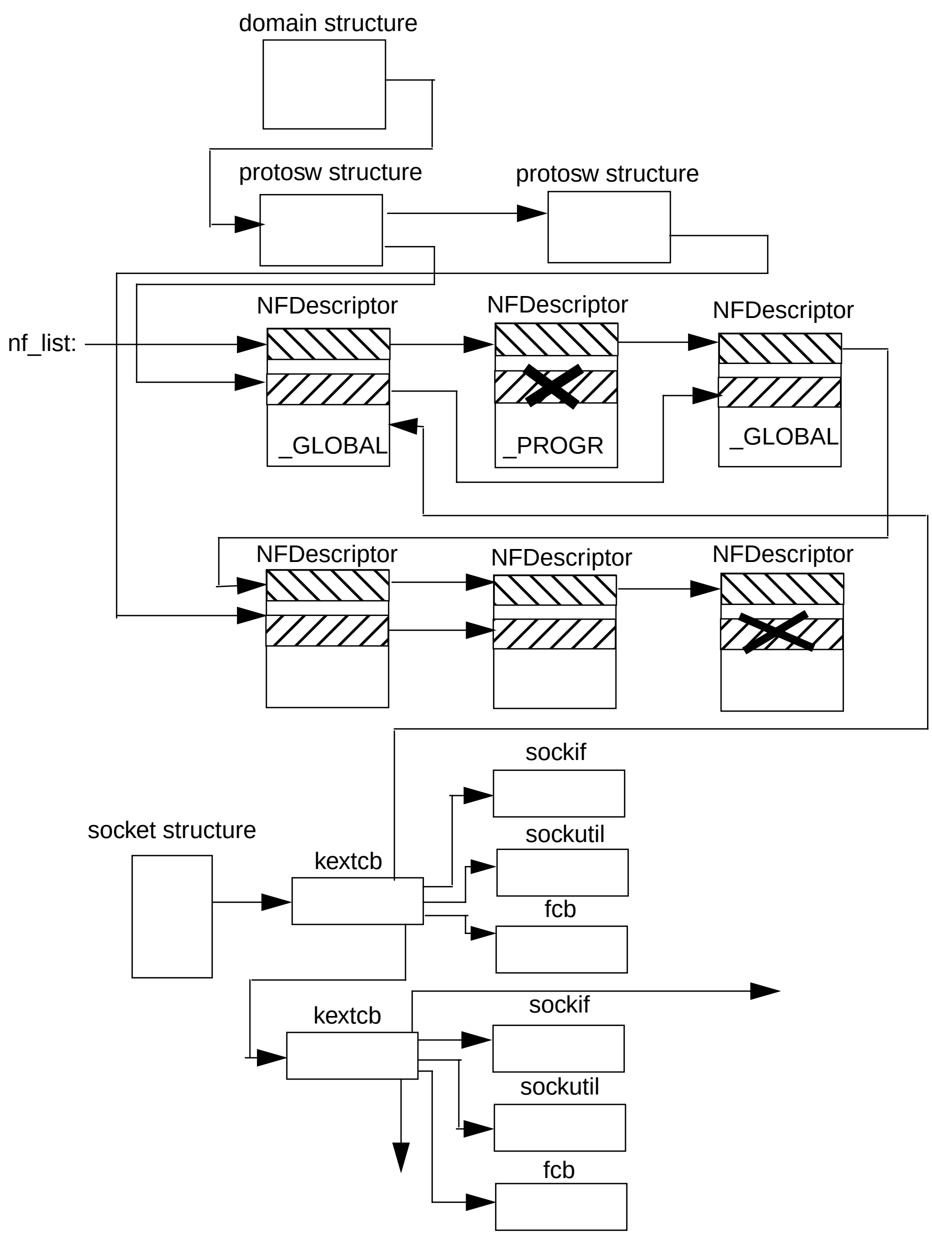
About Protocol Handler NKEs

Adding and removing protocol handler NKEs is accomplished by calling `net_add_proto` and `net_del_proto`, respectively. These calls are described in "Protocol Handler NKE Functions" (page 53). For detailed information about implementing protocol families, see *The Design and Implementation of the 4.4 BSD Operating System* by M. K. McKusick. et al. and *TCP/IP Illustrated* by Richard W. Stevens.

About Socket NKEs

Socket NKEs are installed in the kernel by calling `register_sockfilter` typically from the NKE's initialization routine. Each socket NKE provides a descriptor structure that is linked into a global list (`nf_list`). A second chain runs through the filter descriptor to link it to a `protosw` for global NKEs. Figure 1-3 shows the interconnections for these data structures.

Figure 1-3 Domain structure and protosw interconnections



When you call socreate to create a socket, any global NKEs associated with the corresponding protosw structure are attached to the socket structure using the so_ext field to link together ketcb structures that are allocated when the socket is created. (See Figure 1-3.) These ketcb structures are initialized to point to the extension descriptor and two dispatch vectors of intercept functions (one for socket operations and one for socket buffer utilities).

The filter descriptor for a programmatic NKE is linked into the nf_list in the same way as are global NKEs but the file descriptor does not appear in the list associated with a protosw. A program can call setsocketopt using socket option SO_NKE) to insert a programmatic NKE into its NKE chain in the same way that it would call setsocketopt to insert a global NKE.

Each socket NKE has two dispatch vectors, a sockif structure and a sockutil structure, that contain pointers to the NKE's implementation of these functions. The functions are called when the corresponding socket and sockbuf functions are are called. The dispatch vectors permit the NKE to selectively intercept socket and socket buffer utilities. Here is an example:

```
int (*sf_sobind)(struct socket *, struct mbuf *, st kextcb);
```

The kernel's sobind function calls the NKE's bind entry point with the arguments passed to sobind and the kextcb pointer for the NKE. The sockaddr structure contains the name of the local endpoint being bound.

Each of the intercept functions can return an integer value. A return value of zero is interpreted to mean that processing at the call site can continue. A non-zero return value is interpreted as an error (as defined in <sys/errno.h>) that causes the processing of the packet or opertation to halt. If the return value is EJUSTRETURN, the calling function (for example, sobind) returns at that point with a value of zero. Otherwise, the function returns the non-zero error code. In this way, an NKE can "swallow" a packet or an operation. An NKE may reinject the packet at a later time. (Note that the injection mechanism is not yet defined.)

A program can insert a socket NKE on an open socket by calling setsockopt as follows:

```
setsockopt(s, SOL_SOCKET, SO_NKE, &so_nke, sizeof (struct so_nke);
```

The so_nke structure is defined as follows:

```
struct so_nke
{
    unsigned int nke_handle;
    unsigned int nke_where;
    int nke_flags;
};
```

The nke_handle specifies the NKE to be linked to the socket (with the so_ext link). It is the programmer's task to locate the appropriate NKE, assure that it is loaded, and retain the returned handle for use in the setsockopt call.

The nke_where value specifies an NKE assumed to be in this linked list. If nke_where is NULL, the NKE represented by nke_handle is linked at the beginning or end of the list, depending on the value of nke_flags.

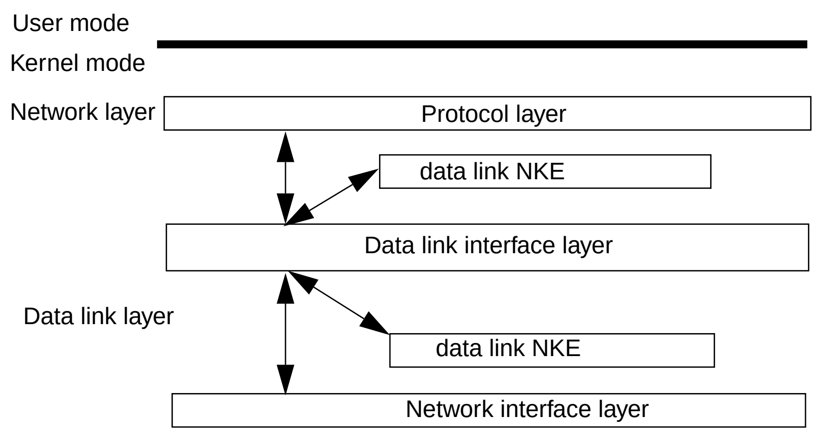
The nke_flags value specifies where, relative to nke_where, the NKE represented by nke_handle will be placed. Possible values are NFF_BEFORE and NFF_AFTER defined in <net/kext_net.h>.

The nke_handle and nke_where values are assigned by Apple Computer from the same name space as the type and creator codes used in Mac OS 8 and Mac OS 9 and using the same registration mechanism.

About Data Link NKEs

This section describes the programming interface for creating data link NKEs, which are inserted below the protocol layer and above the network interface layer. Data link NKEs depend on the Data link interface layer (DLIL), shown in Figure 1-4, which provides a fixed point for the insertion of data link NKEs.

Figure 1-4 Data Link Interface Layer



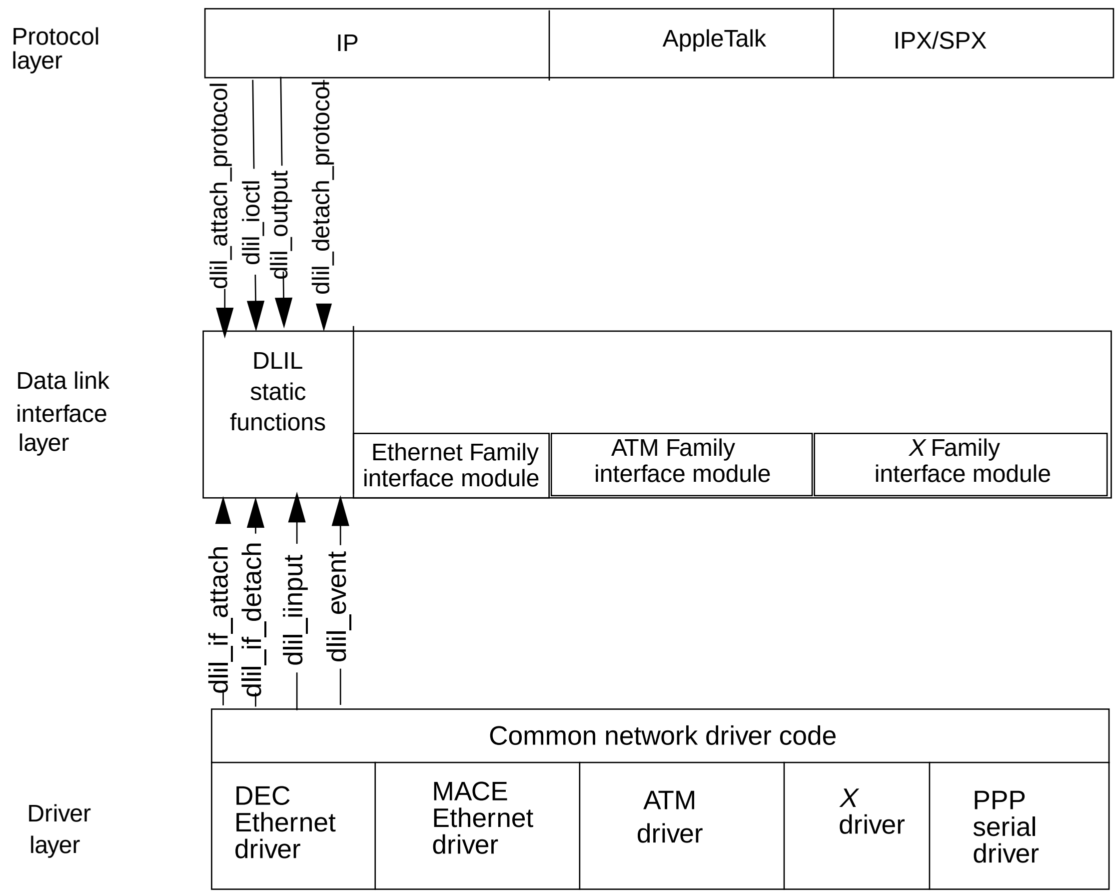
DLIL Static Functions

The DLIL defines the following static functions, which are called by protocols and drivers:

- `dlil_attach_protocol`, which attaches network protocol stacks to specific interfaces
- `dlil_detach_protocol`, which detaches network protocol stacks from the interfaces to which they were previously attached
- `dlil_if_attach`, which registers network interfaces with the DLIL
- `dlil_if_detach`, which deregisters network interfaces that have been registered with the DLIL
- `dlil_ioctl`, which sends ioctl commands to a network driver
- `dlil_input`, which sends data to the DLIL from a network driver
- `dlil_output`, which sends data to a network driver
- `dlil_event`, which processes events from other parts of the network and from IOKit components. (Note that the event mechanisms are still under development.)

In Figure 1-5, the DLIL static functions are shown in relation to the DLIL, the protocol layer, and the network driver layer.

Figure 1-5 DLIL static functions



Changes to the ifnet and if_proto Structures

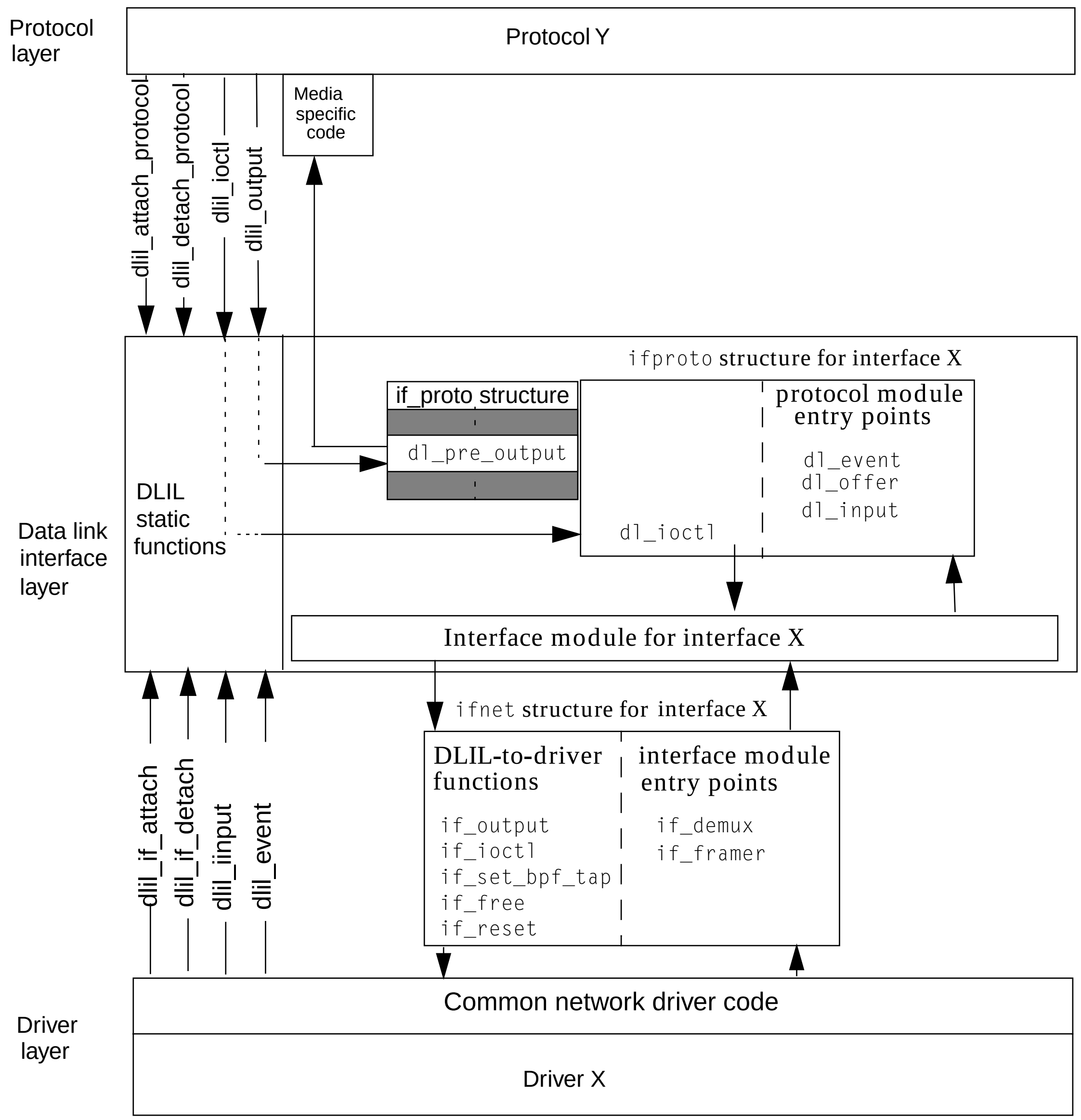
To support data link NKEs, the traditional `ifnet` structure as been extended in Mac OS X: the driver or software that supports the driver must allocate a separate `ifnet` structure for each logical interface. When an interface is attached (by calling `dlil_if_attach`)to the DLIL, the DLIL receives a pointer to that interface's `ifnet` structure.

Each interface can transmit and receive packets for multiple network protocol families, so for each attached protocol family the DLIL creates an `if_proto` structure chained off the `ifnet` structure for that interface.

The `if_proto` structure contains function pointers that the DLIL uses to pass incoming packets and event information to the protocol stack, as well as a pointer to the protocol dependent "pre-output" function that performs protocol-family specific operations such as network address translation on outbound packets.

Figure 1-6 shows the `ifnet` and `if_proto` structures in relation to a generic protocol and a generic interface.

Figure 1-6 Sample `ifnet` structure in relation to a protocol and a network driver



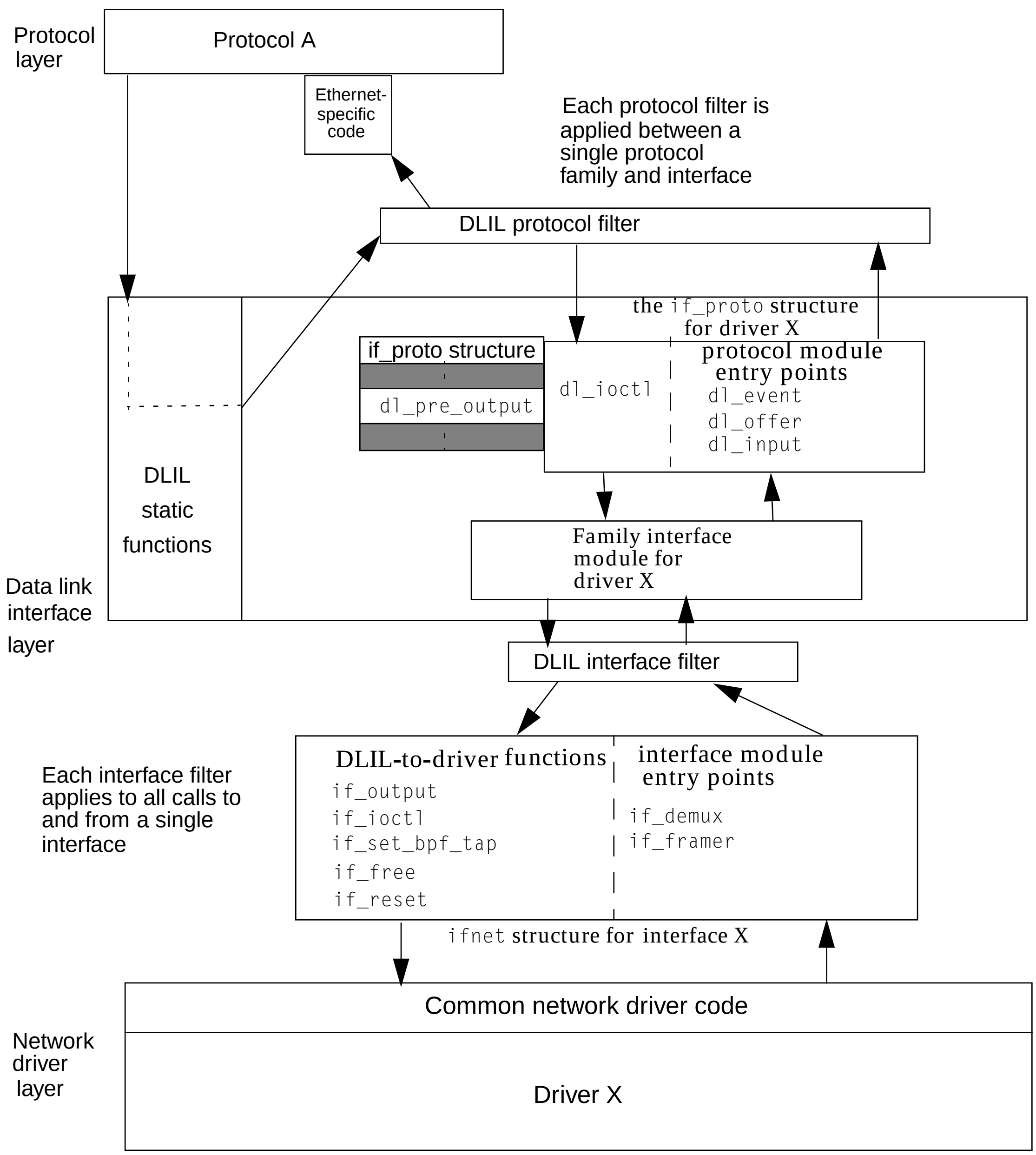
Installing and Removing Data Link NKEs

To support the dynamic insertion of filters into the data and control streams between the network layer and the interface layer and the removal of inserted filters, the DLIL defines the following static functions:

- `dlil_attach_protocol_filter`, which inserts an NKE between the DLIL and one of the attached protocols. Such an extension is known as a **DLIL protocol filter.** This type of NKE provides access to all function calls between the DLIL and the attached protocol for a specific protocol / interface pair.
- `dlil_attach_interface_filter`, which inserts an NKE between the DLIL and an attached interface. Such a filter is known as an **DLIL interface filter**. This type of NKE provides access to all frames flowing to or from an interface.
- `dlil_detach_filter`, which removes previously inserted DLIL protocol and interface filters.

Figure 1-7 shows the relationship of protocol and interface filters to the protocol stack layer, DLIL, and network driver layer.

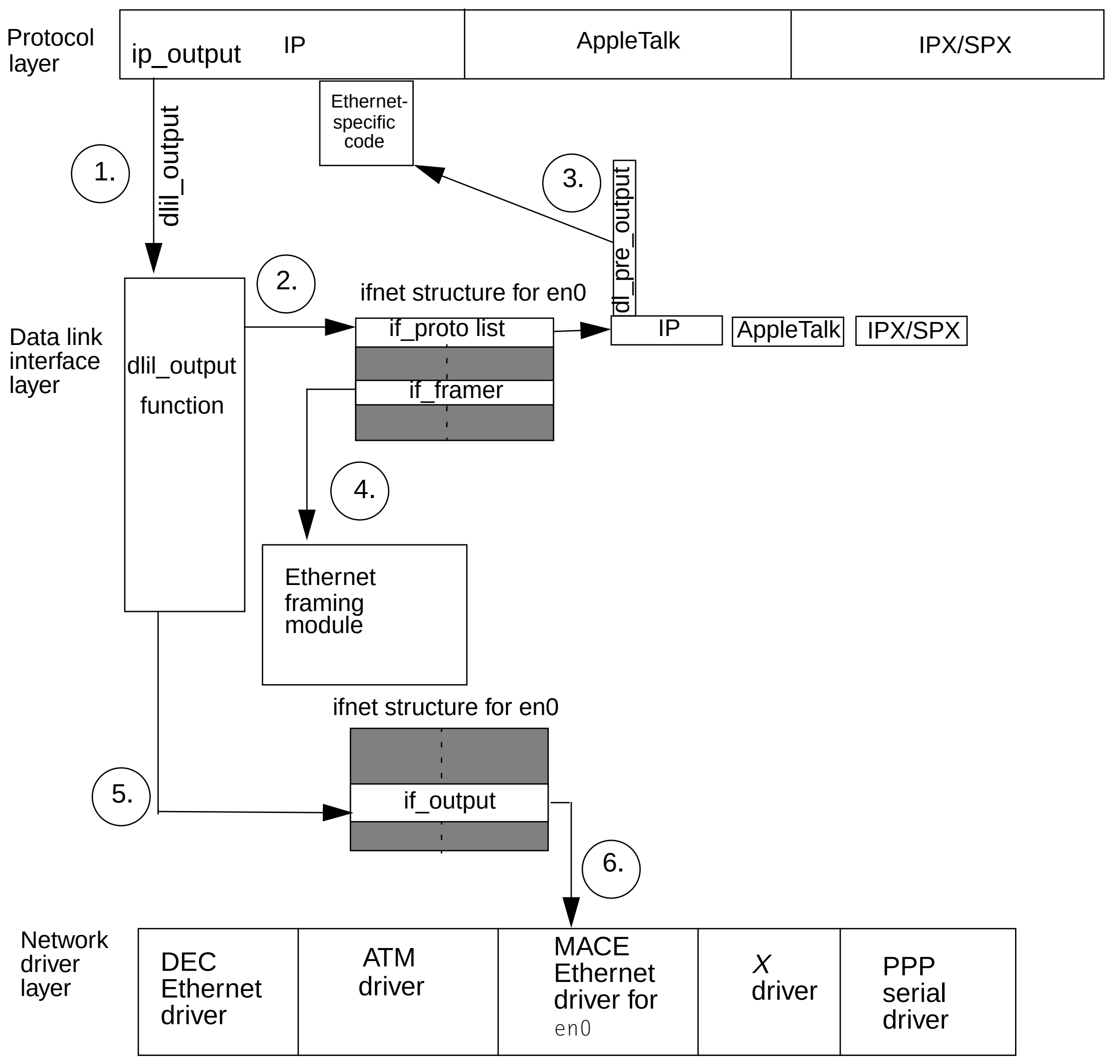
Figure 1-7 Protocol and interface extensions in relation to the DLIL



Sending Data

Figure 1-8 shows the sequence of calls required to send an IP packet over the MACE Ethernet interface (`en0`).

Figure 1-8 Example of sending an IP packet



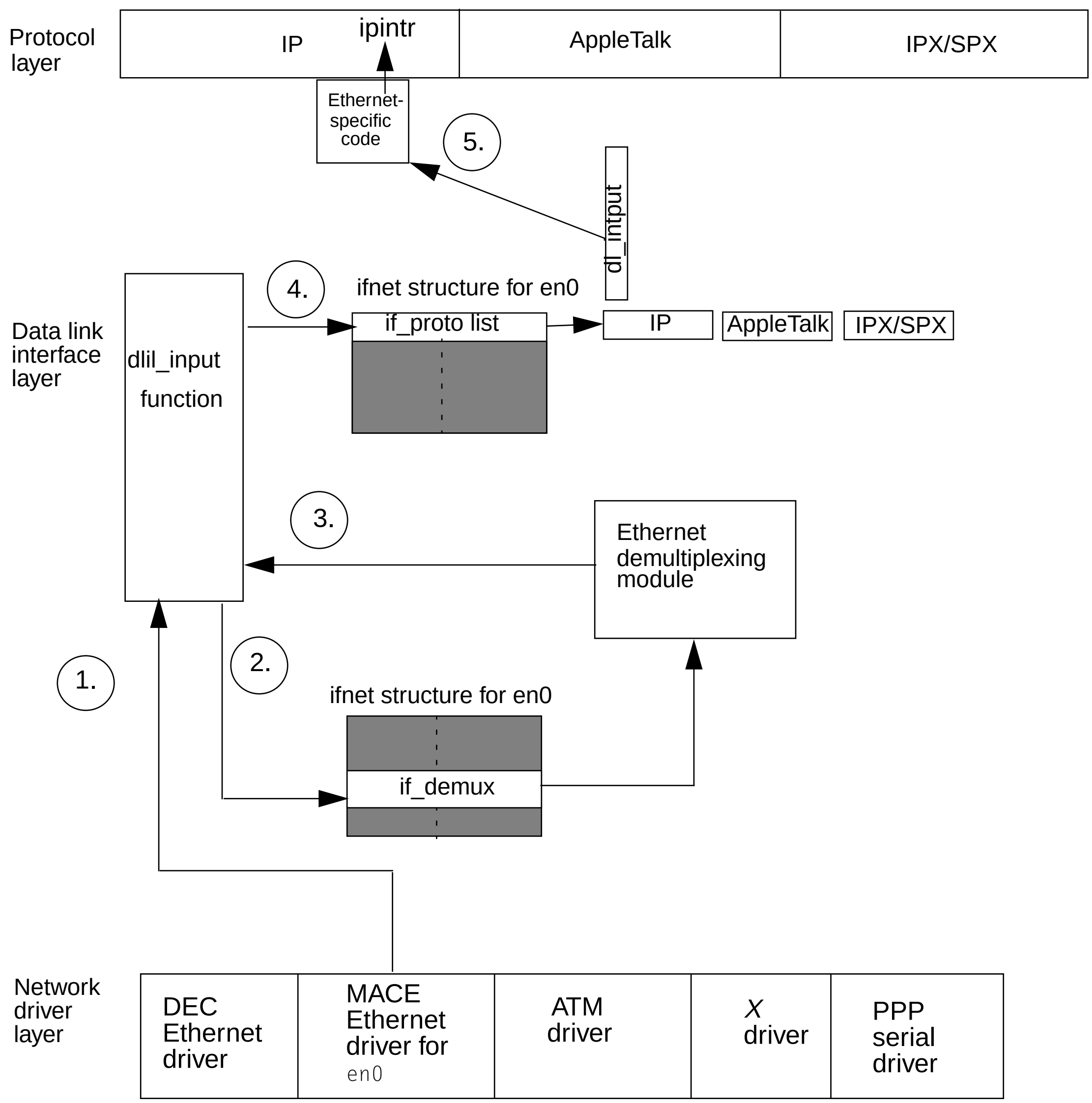
The following steps correspond to the numbers in Figure 1-8 and describe the process of sending a packet:

1. The `ip_output` routine in the IP protocol stack calls `dlil_output`, passing the `dl_tag` value for the stack's attachment to `en0`.
2. Using the `dl_tag` value, the `dlil_output` function locates the `dl_pre_output` pointer in the `if_proto` structure for IP.
3. The `dlil_output` function uses the `dl_pre_output` pointer in the `if_proto` structure to call IP's interface-specific output module. This module calls its `arpresolve` routine to resolve the target IP address into a media access control (MAC) address.
4. When IP's interface-specific output module returns, the `dlil_output` function uses the `if_framer` pointer in the `ifnet` structure to call the appropriate framing function in the DLIL interface module. The framing function prepends interface-specific frame data to the packet.
5. The `dlil_output` function calls the function pointed to by the `if_output` field in the `ifnet` structure for `en0` and sends the frame to the MACE Ethernet driver.

Receiving Data

Figure 1-9 shows the sequence of calls required to receive an IP packet from the MACE Ethernet interface (`en0`).

Figure 1-9 Example of receiving a packet



The following steps correspond to the numbers in Figure 1-9 and describe the process of receiving a packet:

1. The MACE Ethernet driver or its support code calls `dlil_input` with pointers to its `ifnet` structure and `mbuf` chain.
2. The `dlil_input` function uses the `if_demux` entry in the `ifnet` structure to call the demultiplexing function for the interface family (Ethernet in this case).
3. The demultiplexing function identifies the frame and returns an `if_proto` pointer to `dlil_input`.
4. The `dlil_input` function calls the protocol input module through the `dl_input` pointer in the `if_proto` structure.

Note
The Ethernet-specific module for IP receives the frame, removes the 802.2 or SNAP header (if any) and delivers the packet to the protocol's `ipintr` routine.

CHAPTER 2

Using Network Kernel Extensions

This chapter summarizes provides an overview for two sample NKEs (the code for these two NKEs is provided in Appendix A) and describes the development of a third NKE.

Example: VMSify NKE

The VMSify NKE converts remotely echoed characters typed into a telnet session to upper case.

When the VMSify NKE is loaded into the kernel, it is added to the list of TCP extensions. Thereafter, for each new TCP connection, the VMSify NKE checks the destination port. If the destination port is telnet, the VMSify NKE marks the `kextcb` structure for that socket. If the `kextcb` is marked when packets come in, the VMSify NKE maps lower-case characters in the packet to upper-case characters.

Given an unload command, the VMSify NKE removes itself from operation on new sockets, even if the unload command fails.

The VMSify NKE removes itself from sockets that aren't outbound telnet sessions by nullifying the dispatch vector pointers in the `kextcb` structure for this socket / filter pair. This works because no state is kept on a per-socket basis. For similar NKEs, you could replace the "normal" pointers with pointers to other dispatch vectors that clean up only at the end of a connection.

The source code for the VMSify NKE is provided in the section "Sample Source Code for VMSify NKE" in Appendix A.

Example: TCPLogger

TCPLogger is a socket NKE that is invoked for each TCP connection. It records detailed information about each connection, including the number of bytes sent to and from the system, the time the connection was up, and the remote IP address. When TCPLogger is loaded and initialized, it installs itself in the TCP protocol structure so that it is automatically invoked for each incoming and outgoing connection without direct knowledge or intervention by the program that caused the connection to be made.

The TCPLogger NKE keeps a buffer of connection records. If no control program attaches to it, the buffer is continually overwritten as connections are established and terminated. To retain or view the information that the TCPLogger NKE gathers, the system manager runs the TCPLogger program, which creates a `PF_NKE` socket, binds to the TCPLogger NKE, configures the TCPLogger NKE to send log records to the logger program. The TCPLogger program then loops, displaying and writing log records as the TCPLogger NKE creates them.

The source code for the TCPLogger NKE is provided in the section “Sample Source Code for TCPLogger” in Appendix A.

Example: A Packet-Viewing NKE

This example consists of a packet-viewing DLIL protocol filter NKE that uses no additional system resources and a corresponding packet-viewing program. To examine packets on the network, the user launches the packet-viewing program. When invoked, the packet-viewing program does the following:

- calls the kernel extension library to load the packet-viewing data link NKE
- opens a `PF_NKE` socket
- calls `connect` to bind packet-viewing DLIL protocol filter NKE
- sends the `FILT_CONFIG` socket option to the packet-viewing DLIL protocol filter NKE with a configuration structure that specifies the system’s IP stack

as the “top” and en0 (the driver for the built-in Ethernet interface) as the bottom.

- calls recv to receive full Ethernet packets for the packet-viewing program to display.

To expand the functionality of the packet-viewing program and DLIL protocol filter NKE to inject packets into the network, the packet-viewing program would call send on its socket using self-generated packets as data. The packet-viewing DLIL protocol filter NKE would send these packets to en0 by calling dlil_inject_pr_output.

C H A P T E R 3

Network Kernel Extensions Reference

This chapter describes the functions that NKEs can call and NKE-specific data types. The functions are organized into the following sections:

- “Kernel Utilities” (page 37) lists the kernel utilities that NKEs can call.
- “protosw Functions” (page 38) describes functions that access the `protosw` structure.
- “ifaddr Functions” (page 39) describes functions that access the `ifnet` structure.
- “mbuf Functions” (page 40) describes functions that access the `mbuf` structure.
- “Socket Functions” (page 41) describes functions that access the `socket` structure.
- “Socket Buffer Functions” (page 45) describes functions that access the sockbuf structure.
- “Protocol Family NKE Functions” (page 51) describes NKE functions that protocol families call.
- “Protocol Handler NKE Functions” (page 53) describes NKE functions that protocol handlers call.
- “Data Link NKE Functions” (page 54) describes functions that data link NKEs call.

Kernel Utilities

NKEs can call the following kernel utility functions:

- `_MALLOC`

- _FREE
- kalloc
- kfree
- kprintf
- psignal
- splimp
- splnet
- splx
- suser
- timeout
- tsleep
- untimeout
- wakeup

protosw Functions

This section describes the functions that access the protosw structure.

pffindproto

The pffindproto function obtains the protosw corresponding to the protocol family, protocol, and protocol type (or NULL). These values are passed to the socket(2) call from user mode.

```
extern struct protosw *pffindproto(int, int, int);
```

pffindtype

The pffindtype function obtains the protosw corresponding to the protocol and protocol type requested. These values are passed to the socket(2) call from user mode.

```
extern struct protosw *pffindtype(int, int);
```

ifaddr Functions

This section describes the functions that access the `ifaddr` structure.

ifa_ifwithaddr

The `ifa_ifwithaddr` function searches the `ifnet` list for an interface with a matching address.

```
struct ifaddr *ifa_ifwithaddr(struct sockaddr *);
```

ifa_ifwithdstaddr

The `ifa_ifwithdstaddr` function searches the `ifnet` list for an interface with a matching destination address.

```
struct ifaddr *ifa_ifwithdstaddr(struct sockaddr *);
```

ifa_ifwithnet

The `ifa_ifwithnet` function searches the `ifnet` list for an interface with the most specific matching address.

```
struct ifaddr *ifa_ifwithnet(struct sockaddr *);
```

ifa_ifwithaf

The `ifa_ifwithaf` function searches the `ifnet` list for an interface with the first matching address family.

```
struct ifaddr *ifa_ifwithaf(int);
```

ifa_ifafree

The `ifa_ifafree` function frees the specified `ifaddr` structure.

```
void ifafree(struct ifaddr*);
```

ifa_ifaof_ifpforaddr

The `ifa_ifaof_ifpforaddr` function searches the address list in the `ifnet` structure for the one matching the `sockaddr` structure. The matching rules are exact match, destination address on point-to-point link, matching network number, or same address family.

```
struct ifaddr *ifaof_ifpforaddr(struct sockaddr *, struct ifnet *);
```

mbuf Functions

```
struct mbuf *m_copy(struct mbuf *, int, int, int);
struct mbuf *m_free(struct mbuf *);
struct mbuf *m_get(int, int);
struct mbuf *m_getclr(int, int);
struct mbuf *m_gethdr(int, int);
struct mbuf *m_prepend(struct mbuf *, int, int);
struct mbuf *m_pullup(struct mbuf *, int);
struct mbuf *m_retryhdr(int, int);
```

```
void m_adj(struct mbuf *, int);
int m_clalloc(int, int);
void m_freem(struct mbuf *);
struct mbuf *m_devget(char *, int, int, struct ifnet, void  );
void m_cat(struct mbuf *, struct mbuf *);
void m_copydata(struct mbuf *, int, int, caddr_t);
void m_freem(struct mbuf *);
int m_leadingspace(struct mbuf *);
int m_trailingspace(struct mbuf *);
```

Socket Functions

This section describes the socket functions.

soabort

The `soabort` function calls the protocol's `pr_abort` function at `slpnet`.

```
soabort(struct socket *);
```

soaccept

The `soaccept` function calls the protocol's `pr_accept` function.

```
soaccept(struct socket *, struct mbuf *);
```

sobind

The sobind function calls the protocol's pr_bind function.

```
sobind(struct socket *, struct mbuf *);
```

soclose

The soclose function aborts pending and in-progress connections, calls sodisconnect for connected sockets, and sleeps if any connections linger or block. It then calls the protocol's pr_detach function and frees the socket.

```
soclose(struct socket *);
```

soconnect

If connected or connecting, the soconnect function tries to disconnect. It also calls the pr_connect function.

```
soconnect(struct socket *, struct mbuf *);
```

soconnect2

The soconnect2 function calls the pr_connect2 function. This function is generally not supported, but it is used to support pipe usage in the AF_LOCAL domain.

```
soconnect2(struct socket *, struct socket *);
```

socreate

The socreate function links the protosw structure and the socket. It calls the protocol's pr_attach function.

```
socreate(int, struct socket**, int, int);
```

sodisconnect

The sodisconect function calls the protocol's pr_disconnect function.

```
sodisconnect(struct socket *);
```

sofree

The sofree function removes the caller from q0 and q queues, releases the send sockbuf, flushes the receive sockbuf, and frees the socket.

```
sofree(struct socket *);
```

sogetopt

The sogetopt function processes SOL_SOCKET requests and always calls the PRCO_SETOPT function.

```
sogetopt(struct socket *, int, int, struct mbuf **);
```

sohasoutofband

The `sohasoutofband` function indicates that the caller has an out-of-band notifier.

```
sooutofband(struct socket *);
```

solisten

The `solisten` function calls the protocol's `pr_listen` function and sets the queue backlog.

```
solisten(struct socket *, int);
```

soreceive

The `soreceive` function receives data.

```
soreceive(struct socket *,
                    struct mbuf **,
                    struct uio *,
                    struct mbuf **,
                    struct mbuf **,
                    int *);
```

soflush

The `soflush` function locks the socket, marks it as "can't receive," unlocks the socket, and calls `sbrelease`.

```
soflush(struct socket *);
```

sosend

The `sosend` function sends data.

```
sosend(struct socket *,
                    struct mbuf *,
                    struct uio *, struct mbuf *,
                    struct mbuf *,
                    int);
```

sosetopt

The `sosetopt` function processes `SOL_SOCKET` requests and always calls the `PRCO_SETOPT` function.

```
sosetopt(struct socket *,
                    int,
                    int,
                    struct mbuf *);
```

soshutdown

The `soshutdown` function calls the `sorflush` function (`FREAD`) and the `pr_shutdown` function (`FWRITE`).

```
soshutdown(struct socket *,
                    int,
                    int,
                    struct mbuf *);
```

Socket Buffer Functions

This section describes the socket buffer functions.

sb_lock

The `sb_lock` function locks a `sockbuf` structure. It sets `WANT` and sleeps if the structure is already locked.

```
sb_lock(struct sockbuf *);
```

sbappend

The `sbappend` function conditionally calls `sbappendrecord` and calls `sbcompress`.

```
sbappend(struct sockbuf *,
                     struct mbuf *);
```

sbappendaddr

The `sbappendaddr` function conditionally calls `sbappendrecord` and `sbcompress`.

```
sbappendaddr(struct sockbuf *,
                     struct sockaddr *,
                     struct mbuf *,
                     struct mbuf *);
```

sbappendcontrol

The `sbappendcontrol` function calls `sbspace` and `sballoc`.

```
sbappendcontrol(struct sockbuf *,
                     struct mbuf *,
                     struct mbuf *);
```

sbappendrecord

The `sbappendrecord` function calls `sballoc` and `sbcompress`.

```
sbappendrecord(struct sockbuf *,
                     struct mbuf *);
```

sbcompress

The `sbcompress` function calls `sballoc`.

```
sbcompress(struct sockbuf *,
                     struct mbuf *,
                     struct mbuf *);
```

sbdrop

The `sbdrop` function calls `sbfree`.

```
sbdrop(struct sockbuf *, int);
```

sbdroprecord

The `sbdroprecord` function calls `sbfree`.

```
sbdroprecord(struct sockbuf *);
```

sbflush

The `sbflush` function calls `sbfree`.

```
sbflush(struct sockbuf *);
```

sbinsertoob

The `sbinsertoob` function calls `sballoc` and `sbcompress`.

```
sbinsertoob(struct sockbuf *,
                     struct mbuf *);
```

sbrelease

The `sbrelease` function calls `sbflush` and clears the `selwait` structure.

```
sbrelease(struct sockbuf *);
```

sbreserve

The `sbreserve` function sets up the `sockbuf` counts.

```
sbreserve(struct sockbuf *, u_long);
```

sbwait

The `sbwait` function sets `SB_WAIT` and calls `tsleep` on `sb_cc`.

```
sbwait(struct sockbuf *);
```

socantrcvmore

The socantrcvmore function marks socket and wakes up readers.

```
socantrcvmore(struct socket *);
```

socantsendmore

The socantsendmore function marks socket and wakes up writers.

```
socantsendmore(struct socket *);
```

soisconnected

The soisconnected function sets state bits. It calls soqremque, soqinsque, sorwakeup, and sowwakeup.

```
soisconnected(struct socket *);
```

soisconnecting

The soisconnecting function sets state bits.

```
soisconnecting(struct socket *);
```

soisdisconnected

The soisdisconnected function sets state bits, calls timer wakeup, and wakes up readers and writers.

```
soisdisconnected(struct socket *);
```

soisdisconnecting

The `soisdisconnecting` function sets state bits, calls timer wakeup, and wakes up readers and writers.

```
soisdisconnecting(struct socket *);
```

su_sonewconn1

The `su_sonewconn1` function allocates socket, sets state, inserts into head queue, and calls `pr_attach`.

```
struct socket *su_sonewconn1(struct socket *, int);
```

soqinsque

The `soqinsque` function adds the socket to `q` or `q0` of “head.”

```
soqinsque(struct socket *,
                    struct socket *,
                    int);
```

soqremque

The `soqremque` function removes socket from `q` or `q0` of “head.”

```
soqremque(struct socket *, int);
```

soreserve

The `soreserve` function sets up send and receive `sockbuf` structures.

```
soreserve(struct socket *,
                    struct sockbut *);
```

Protocol Family NKE Functions

This section describes the functions that support the dynamic addition and removal of protocol family NKEs.

net_add_domain

Adds a `domain` structure to the kernel's domain list.

```
void net_add_domain(struct domain *domain);
```

`domain`	On input, a pointer to a `domain` structure to be linked into the system's list of domains.
function result	None.

DISCUSSION

The `net_add_domain` function adds a `domain` (represented by the `domain` parameter) to the kernel's list of domains.

The `net_add_domain` function locks the `domain` structure, calls the domain's `init` function, and calls the protocol's `init` function for each attached protocol. The domain's `init` function updates certain system global structures, such as `max_protohdr`, and protects itself from repeated calls. You can choose whether to include the `protosw` structures in `domain`. The alternative is to attach protocol handler NKEs by calling `net_add_proto` (page 53).

This function does not return a value because it cannot fail.

net_del_domain

Removes a `domain` structure from the kernel's domain list.

```
int net_del_domain(struct domain *domain);
```

`domain` On input, a pointer to the `domain` structure that is to be removed.

function result 0 to indicate success, `EBUSY` when the reference count for the specified `domain` structure is not zero, and `EPFNOSUPPORT` if the specified `domain` structure cannot be found.

DISCUSSION

The `net_del_domain` function removes a `domain` structure from the kernel's list of `domain` structures.

You are responsible for reclaiming resources and handling dangling pointers before you call `net_del_domain`.

This function is only called from a domain implementation.

pffinddomain

Finds a domain.

```
struct domain *pffinddomain(int x);
```

`x` On input, a `PK` constant, such as `PF_INET` or `PF_NKE`.

function result A pointer to the requested `domain` structure or `NULL`, which indicates that the domain could not be found. If `pffinddomain` returns `NULL`, the caller should return `EPFNOSUPPORT` in addition to performing normal error cleanup.

DISCUSSION

The `pffinddomain` function locates the `domain` structure for the specified protocol family in the kernel's list of `domain` structures.

Note
This function depends on matching an integer value with a value in the kernel. You can verify that the proper `domain` structure has been located by checking the value of the `dom_name` field in the `domain` structure. ◆

Protocol Handler NKE Functions

This section describes the functions that support the dynamic addition and removal of protocol handler NKEs.

net_add_proto

Adds the specified `protosw` structure to the list of `protosw` structures for the specified domain.

```
int net_add_proto (struct protosw *protosw,
                   struct domain *domain);
```

`protosw`	On input, a pointer to a `protosw` structure.
`domain`	On input, a pointer to a `domain` structure.
function result	0 to indicate success or `EEXISTS` if the `pr_type` and the `pr_protocol` fields in the `protosw` structure that is being added match the `pr_type` and `pr_protocol` fields in an existing `protosw` entry for the specified domain.

DISCUSSION

The `net_add_proto` function adds the specified `protosw` to the domain's list of `protosw` structures.

If the `protosw` structure is successfully added, the protocol's `init` function (if present) is called.

net_del_proto

Removes a protosw structure from the list of protosw structures for the specified domain.

```
int net_del_proto(int type,
                     int protocol,
                     struct domain *domain);
```

type	On input, an integer value that specifies the type of the protosw structure that is to be removed.
protocol	On input, an integer value that specifies the protocol of the protosw structure that is to be removed.
domain	On input, a pointer to a domain structure.
function result	0 to indicate success or ENXIO if the specified values for type and protocol don't match a protosw structure in the domain's list of protosw structures.

DISCUSSION

The net_del_proto function removes the specified protosw structure from the list of protosw structures for the specified domain structure.

Data Link NKE Functions

This section describes the Data Link Layer Interface (DLIL) functions. The section is organized under the following topics:

- "Calling the DLIL From the Network Layer" (page 55)
- "Calling the Network Layer From the DLIL" (page 63)
- "Calling the Driver Layer From the DLIL" (page 68)
- "Calling the DLIL From the Driver Layer" (page 71)
- "Calling Interface Modules From the DLIL" (page 76)
- "Calling the DLIL From a DLIL Filter" (page 79)

Calling the DLIL From the Network Layer

This section describes DLIL functions that are called from the network layer. The functions are

- `dlil_attach_protocol_filter` (page 55) which is called to attach a protocol filter.
- `dlil_attach_interface_filter` (page 57) which is called to attach an interface filter.
- `dlil_attach_protocol` (page 58) which a protocol calls to attach itself to the DLIL.
- `dlil_detach_filter` (page 59) which a protocol calls to attach itself to the DLIL.
- `dlil_detach_protocol` (page 60) which a protocol calls to deattach itself from the DLIL.
- `dlil_output` (page 60) which a protocol calls to send data to a network interface.
- `dlil_ioctl` (page 62) which a protocol calls to send ioctl commands to a network interface.

dlil_attach_protocol_filter

Inserts a DLIL protocol filter between a protocol and the DLIL.

```
int dlil_attach_protocol_filter(
                u_long dl_tag,
                struct dlil_pr_flt_str *protocol_filter,
                u_long *filter_id,
                int insertion_point);
```

`dl_tag` On input, a value of type `u_long`, previously obtained by calling `dlil_attach_protocol` (page 58), that identifies the protocol/interface pair between which the NKE is to be inserted.

`protocol_filter`
A pointer to a `dlil_pr_fil_str` structure that contains pointers to the functions the DLIL is to call when it intercepts calls. Each

function pointed to by a member of this structure corresponds to a function pointed to by the ifnet structure for this protocol/interface pair.

filter_id
: On input, a pointer to a u_long. On output, filter_id points to a tag value that identifies the NKE that has been inserted. The tag value is required to remove the NKE or insert another NKE after the current NKE.

insertion_point
: On input, a value of type int. If this is the first DLIL protocol filter to be inserted, set insertion_point to DLIL_LAST_FILTER. If this is the second or greater insertion, set insertion_point to the value of filter_id returned by a previous call to dlil_attach_protocol_filter or to DLIL_LAST_FILTER to insert the filter at the end of the chain of inserted filters.

function result
: 0 for success.

DISCUSSION

The dlil_attach_protocol_filter function inserts a DLIL protocol filter between the specified protocol and the DLIL.

When more than one DLIL protocol filter is inserted, the DLIL calls the appropriate function of the first filter with the parameters provided by the caller. When that call returns successfully, the DLIL calls the appropriate function for the second filter with the parameters returned by the first filter, and so on until the appropriate functions have been called for each filter in the list. When the last filter in the list has been called, the DLIL calls the original destination function with the parameters returned by the last filter.

The DLIL skips any function pointers that are NULL, which allows DLIL protocol filters to intercept only a subset of the calls that may be made by a protocol to the interface to which the protocol is attached.

If a DLIL protocol filter returns a status other zero (which indicates success) or EJUSTRETURN, the DLIL frees any associated mbuf chain (for the filter_dl_pre_output and filter_dl_input functions only) and returns with that status.

If a DLIL protocol filter returns a status of EJUSTRETURN, the DLIL returns zero to indicate success without freeing any associated mbuf chain. The DLIL protocol filter is responsible for freeing or forwarding any associated mbuf chain.

dlil_attach_interface_filter

Inserts a DLIL interface filter between the DLIL and the interface.

```
int dlil_attach_interface_filter(
            struct ifnet *ifnet_ptr,
            struct dlil_if_flt_str *interface_filter,
            int *filter_id,
            u_long insertion_point);
```

`ifnet_ptr` A pointer to the `ifnet` structure for this interface.

`interface_filter`
A pointer to a `dlil_if_fil_str` structure that contains pointers to the function calls that the DLIL is to call when the family interface module calls common network driver code for the specified interface. Each function pointed to by a member of this structure corresponds to a function pointed to by the `ifnet` structure.

`filter_id` On input, a pointer to a value of type `int`. On output, `filter_id` points to a value that identifies the NKE that has been inserted. This value is required to remove the NKE or insert another NKE after it.

`insertion_point`
On input, a value of type `u_long`. If this is the first insertion, set `insertion_point` to `DLIL_LAST_FILTER`. If this is the second or greater insertion, set `insertion_point` to the value of `filter_id` returned by a previous call to `dlil_attach_interface_filter` or to `DLIL_LAST_FILTER` to insert the filter at the end of the chain of inserted filters.

function result 0 for success. Other possible errors are defined in `<errno.h>`.

DISCUSSION

The `dlil_attach_interface_filter` function inserts a DLIL interface filter between the DLIL and an interface. When the filter is in place, the DLIL intercepts all calls between itself and the interface's driver and passes the call and its parameters to the filter.

You can insert multiple DLIL interface filters, in which case the DLIL calls the filters in the order specified by `insertion_point` at the time of insertion. The order in which filters are executed is reversed when an incoming packet is being processed (that is, the last filter called for an outbound packet will be the first filter called for an inbound packet).

When more than one DLIL interface filter is installed, the DLIL calls the appropriate function for the first filter with the parameters provided by the caller. When that call returns successfully, the DLIL calls the appropriate function for the second filter with the parameters returned by the first filter, and so on until the appropriate functions have been called for each filter in the list. When the last filter has been called, the DLIL calls the original destination function with the parameters returned by the last filter.

The DLIL skips any null function pointers, which allows DLIL interface filters to intercept only a subset of the calls that the DLIL may make to the driver for the specified interface.

If a DLIL interface filter returns a status other than zero (which indicates success) or `EJUSTRETURN`, the DLIL frees any associated `mbuf` chain (for the `filter_if_output` and `filter_if_input` functions only) and returns with that status.

If a DLIL interface extension returns a status of `EJUSTRETURN`, the DLIL returns zero to indicate success. The DLIL interface filter is responsible for freeing or forwarding any associated `mbuf` chain.

With a return value of zero, the DLIL continues to process the list of NKEs.

dlil_attach_protocol

Attaches a protocol to the DLIL for use with an interface.

```
int dlil_attach_protocol(
                     struct dlil_proto_reg_str *proto_reg,
                     u_long *dl_tag);
```

`proto_reg` On input, a pointer to a `dlil_proto_reg_str` (page 84) structure containing all of the information required to complete the attachment.

`dl_tag`	On input, a pointer to a value of type `u_long`. On output, `dl_tag` points to an opaque value identifying the interface / protocol pair that is passed in subsequent calls to the `dlil_output`, `dlil_ioctl`, and `dlil_detach` functions.
function result	0 for success and `ENOENT` if the specified interface does not exist. Other possible errors are defined in `<errno.h>`.

DISCUSSION

The `dlil_attach_protocol` function attaches a protocol to the DLIL for use with a specific network interface. For example, you would call `dlil_attach_protocol` to attach the TCP / IP protocol family to `en0`, which is the first Ethernet family interface.

dlil_detach_filter

Removes a DLIL interface filter or a DLIL protocol filter.

```
int dlil_detach_filter( u_long filter_id );
```

`filter_id`	A value of type `u_long` obtained by previously calling `dlil_attach_interface_filter` (page 57) or `dlil_attach_protocol_filter` (page 55).
function result	0 for success or `ENOENT` of the specified filter does not exist.

DISCUSSION

The `dlil_detach_filter` function removes a DLIL interface filter or a DLIL protocol filter that was previously attached by calling `dlil_attach_interface_filter` (page 57) or `dlil_attach_protocol_filter` (page 55).

If the filter has a detach routine and a function pointer to it was supplied when the filter was attached, the DLIL calls the filter's detach routine before detaching the filter. The detach routine should complete any clean up tasks before it returns.

dlil_detach_protocol

Detaches a protocol from the DLIL.

```
int dlil_detach_protocol( u_long dl_tag );
```

`dl_tag` — On input, a value of type `u_long`, previously obtained by calling `dlil_attach_protocol` (page 58), that identifies the protocol and the interface from which the protocol is to be detached.

function result — 0 for success and `ENOENT` if the defined protocol is not currently attached. Other possible errors are defined in `<errno.h>`.

DISCUSSION

The `dlil_detach_protocol` function detaches a protocol that was previously attached to the DLIL by calling `dlil_attach_protocol` (page 58). Before detaching the protocol, the DLIL calls the detach filter callback functions for any NKEs that may have been inserted between the protocol and the interface that is being detached from.

The DLIL keeps a reference count of protocols attached to each interface. When the reference count reaches zero as a result of calling `dlil_detach_protocol`, the DLIL calls the `if_free` (page 70) function for the affected interface to notify the driver that no protocols are attached to the interface. The reference count can only reach zero if the driver detaches the interface.

dlil_output

Sends data to a network interface.

```
int dlil_output (u_long dl_tag,
                     struct mbuf *buffer,
                     caddr_t route,
                     struct sockaddr *dest,
                     int raw);
```

`dl_tag`	On input, a value of type `u_long`, previously obtained by calling `dlil_attach_protocol` (page 58), that identifies the associated protocol / interface pair.
`buffer`	On input, a pointer to the `mbuf` chain, which may contain multiple packets.
`route`	On input, a pointer to an opaque pointer-sized value whose use is specific to each protocol family, or `NULL`.
`dest`	On input, a pointer to an `sockaddr` structure that defines the target network address that the DLIL passes to the associated `dl_pre_output` function. If `raw` is `FALSE`, this parameter is ignored.
`raw`	On input, a Boolean value. Setting `raw` to `TRUE` indicates that the `mbuf` chain pointed to by `buffer` contains a link-level frame header (which means that no further processing by the protocol or by the interface family modules is required). If `raw` is `FALSE`, protocol filters are not called, but any interface filters attached to the target interface are called.
function result	0 for success.

DISCUSSION

The `dlil_output` function is a DLIL function that the network layer calls in order to send data to a network interface. The `dlil_output` function executes as follows:

1. If the `raw` parameter is `TRUE`, go to step 4. Otherwise, if the `raw` parameter is `FALSE` and the attached protocol identified by `dl_tag` has defined a `dl_pre_output` function, the DLIL calls that `dl_pre_output` function and passes to it all of the parameters passed to `dl_output` by the caller, as well as pointers to two buffers in which the `dl_pre_output` function can pass back the frame type and destination data link address.
2. If any data link protocol extensions are attached to the protocol / interface pair, those NKEs are called in the order they were inserted. If any NKE returns a value other than zero for success or `EJUSTRETURN`, the DLIL stops processing the packet, `dlil_output` frees the `mbuf` chain, and returns an error to its caller. When any NKE returns `EJUSTRETURN`, packet processing terminates without freeing the `mbuf` chain. In this case, the NKE is responsible for freeing or forwarding the `mbuf` chain.

3. If an if_framer function is defined for this interface, the DLIL calls the if_framer function. The if_framer function adds any necessary link-level framing to the outbound packet. This function usually prepends the frame header to the beginning of the mbuf chain.
4. If any data link interface NKEs have been attached to the interface specified by dl_tag, those NKEs are called in the order they were inserted. If any NKE returns a value other than zero for success or EJUSTRETURN, the DLIL stops processing the packet, frees the mbuf chain, and returns an error to its caller. When any NKE returns EJUSTRETURN, packet processing terminates without freeing the mbuf chain. In this case, the NKE is responsible for freeing or forwarding the mbuf chain.
5. As the last step, dlil_output calls if_output in order to pass the mbuf chain and a pointer to the ifnet structure to the interface's driver.

dlil_ioctl

Accesses DLIL-specific or driver-specific functionality.

```
int dlil_ioctl (u_long dl_tag,
                struct ifnet *ifp,
                u_long ioctl_code,
                caddr_t ioctl_arg);
```

dl_tag — On input, a value of type u_long, previously obtained by calling dlil_attach_protocol (page 58), that identifies the associated protocol / interface pair. If not zero, the DLIL uses the value of dl_tag to identify the target protocol module. If dl_tag is zero, ifp is not NULL, and the interface has defined an if_ioctl function, the DLIL calls the interface's if_ioctl function and passes to it the parameters supplied by the caller.

ifp — On input, a pointer to the ifnet structure associated with the target interface. This parameter is not used if dl_tag is non-zero.

ioctl_code — On input, a value of type u_long that specifies the specific ioctl function that is to be accessed.

ioctl_arg — On input, a value of type caddr_t whose contents depend on the value of ioctl_code.

function result 0 for success.

DISCUSSION

The `dlil_ioctl` function is a DLIL function that the network layer calls in order to send ioctl commands to a network interface.

Calling the Network Layer From the DLIL

This section describes network layerfunctions called by the DLIL. The functions are

- `dl_pre_output` (page 63), which the DLIL calls in order to perform protocol-specific processing (such as resolving the network address to a link-level address) for outbound packets.
- `dl_input` (page 65), which the DLIL calls in order to pass incoming packets to the protocol.
- `dl_offer` (page 66), which the DLIL calls in order to identify incoming frames.
- `dl_event` (page 67), which the DLIL calls in order to pass events from the driver layer to a protocol.

dl_pre_output

Obtains the destination link address and frame type for outgoing packets.

```
int (*dl_pre_output) (struct mbuf *mbuf_ptr,
                      caddr_t route_entry,
                      struct sockaddr *dest,
                      char *frame_type,
                      char *dest_linkaddr,
                      u_char dl_tag);
```

`mbuf_ptr` On input, a pointer to an `mbuf` structure containing one or more outgoing packets.

route_entry	On input, a value of type caddr_t that is passed to the DLIL when a protocol calls dlil_output (page 60).
dest	On input, a pointer to a sockaddr structure that describes the packets' destination network address, or NULL. This parameter is passed to the DLIL when the protocol calls dlil_output (page 60). The format of the sockaddr structure is specific to each protocol family.
frame_type	On input, a pointer to a byte array of undefined length. On output, frame_type contains the frame type for this protocol.
dest_linkaddr	On input, a pointer to a byte array of undefined length. On output, dest_linkaddr contains the destination link address.
dl_tag	On input, a value of type u_long, previously obtained by calling dlil_attach_protocol (page 58), that identifies the associated protocol/interface pair.
function result	0 for success. Errors are defined in <errno.h>.

DISCUSSION

The dl_pre_output function obtains the link address and frame type for outgoing packets whose destination is described by the dest parameter.

The dl_pre_output function pointer in the if_proto structure is optionally defined when a protocol calls the function dlil_attach_protocol (page 58) to register a protocol family. The DLIL calls the dl_pre_output function when a protocol calls dlil_output (page 60).

In addition to defining the destination link address and the frame type, the dl_pre_output function may also add a packet header, such as 802.2 or SNAP.

dl_input

Receives incoming packets.

```
int (*dl_input) (struct mbuf *mbuf_ptr,
                    char *frame_header,
                    struct ifnet *ifnet_ptr,
                    caddr_t dl_tag,
                    int sync_ok);
```

`mbuf_ptr`	On input, a pointer to an `mbuf` structure.
`frame_header`	On input, a pointer to a byte array of undefined length containing the frame header.
`ifnet_ptr`	On input, a pointer to the `ifnet` structure for this protocol / interface pair.
`dl_tag`	On input, a value of type `u_long`, previously obtained by calling `dlil_attach_protocol` (page 58), that identifies the associated protocol / interface pair.
`sync_ok`	Reserved.
function result	0 for success. Errors are defined in `<errno.h>`.

DISCUSSION

The `dl_input` function is called by the DLIL. When a DLIL module receives a frame from the driver and finishes interface-specific processing, it calls the target protocol through the `dl_input` function pointer. The interface family's demultiplexing module identifies the target protocol by matching the data provided in the demultiplexing descriptors when the protocol was attached.

The `dl_input` function pointer in the `if_proto` structure is defined by the `input` member of the `dlil_proto_reg_str` (page 84) structure, which the function `dlil_attach_protocol` (page 58) passes to the DLIL when a protocol is attached.

dl_offer

Examines unidentified frames.

```
int (*dl_offer) (struct mbuf *mbuf_ptr,
                        char *frame_header;
                        u_long dl_tag);
```

`mbuf_ptr` On input, a pointer to an `mbuf` structure containing incoming frames.

`dl_tag` On input, a value of type `u_long`, previously obtained by calling `dlil_attach_protocol` (page 58), that identifies the associated protocol / interface pair.

`frame_header` On input, a pointer to a byte array containing the frame header as received from the driver. The length of `frame_header` depends on the interface family.

function result `DLIL_FRAME_ACCEPTED` or `DLIL_FRAME_REJECTED`.

DISCUSSION

The `dl_offer` function accepts or rejects a frame that was not identified by a protocol's demultiplexing descriptors.

When the interface family demultiplexing module receives a frame that does not match any of the protocol's demultiplexing descriptors, the module calls any defined `dl_offer` function and passes to it the unidentified frame. The `dl_offer` function can accept or reject the frame.

The `dl_offer` function pointer in the `if_proto` structure is optionally defined by the `offer` member of the `dlil_proto_reg_str` (page 84) structure, which the `dlil_attach_protocol` (page 58) function passes to the DLIL when a protocol is attached.

If a `dl_offer` function accepts the frame, the frame is not offered to any other protocol's `dl_offer` function. If no `dl_offer` function accepts the frame, the frame is dropped.

Note
The `dl_offer` function only indicates whether it will accept the frame. It does not modify the frame or start processing it. Processing occurs when `dlil_input` calls the protocol's `dl_input` function. ◆

dl_event

Receives events passed by the DLIL from the interface's driver.

```
void (*dl_event) (struct event_msg *event,
                        u_long dl_tag);
```

`event`	On input, a pointer to an `event_msg` structure.
`dl_tag`	On input, a value of type `u_long`, previously obtained by calling `dlil_attach_protocol` (page 58), that identifies the associated protocol/interface pair. The `dl_event` function uses `dl_tag` to determine the interface that was the source of the event.
function result	None.

DISCUSSION

The `dl_event` function receives events from the interface's driver. When the DLIL receives an event from the driver, the module calls the defined `dl_event` functions of all protocols that are attached to the interface, passing in `event_msg` an event-specific code and an event value that is interpreted by the `dl_event` function.

If `dlil_attach_protocol` (page 58) was called with a null pointer for the `dl_event` function, no action is taken for that protocol family.

The `dl_event` function pointer in the `if_proto` structure is optionally defined by the `event` member of `dlil_proto_reg_str` (page 84) structure, which `dlil_attach_protocol` (page 58) passes to the DLIL when a protocol is attached.

Calling the Driver Layer From the DLIL

The functions described in this section are called by the DLIL to an interface's driver. The functions are

- `if_output` (page 68), which the DLIL calls in order to pass outgoing packets to the interface's driver.
- `if_ioctl` (page 69), which the DLIL calls in order to pass ioctl commands to the interface's driver.
- `if_set_bpf_tap` (page 69), which the DLIL calls in order to enable or disable a binary packet filter tap.
- `if_free` (page 70), which the DLIL calls in order to free the `ifnet` structure for an interface.

if_output

Accepts outgoing packets and passes them to the interface's driver.

```
int (*if_output) (struct ifnet *ifnet_ptr,
                        struct mbuf *buffer);
```

`ifnet_ptr`	On input, a pointer to the `ifnet` structure for this interface.
`buffer`	On input, a pointer to an `mbuf` structure containing one or more outgoing packets.
function result	0 for success. Errors are defined in `<errno.h>`.

DISCUSSION

The `if_output` function sends outgoing packets to the interface's driver. The DLIL calls `if_output` when the associated protocol calls `dlil_output` (page 60).

The `if_output` function must accept all of the packets in the `mbuf` chain.

The `if_output` function pointer is defined in the interface's `ifnet` structure and is initialized by the interface driver before the interface driver calls `dlil_if_attach` (page 71).

if_ioctl

Processes ioctl commands.

```
int (*if_ioctl) (struct ifnet *ifnet_ptr,
                     u_long ioctl_code,
                     caddr_t ioctl_arg);
```

`ifnet_ptr`	On input, a pointer to the `ifnet` structure for this interface.
`ioctl_code`	On input, a value of type `u_long` containing the ioctl command.
`ioctl_arg`	On input, a value of type `caddr_t` whose contents depend on the value of `ioctl_code`.
function result	0 for success. Other results are specific to the driver's ioctl function.

DISCUSSION

The `if_ioctl` function accepts and processes ioctl commands that access driver-specific functionality.

The `if_ioctl` pointer is defined in the interface's `ifnet` structure and is initialized by the interface driver before the interface driver calls `dlil_if_attach` (page 71).

if_set_bpf_tap

Enables or disables a binary packet filter tap for an interface.

```
int (*if_set_bpf_tap) (int mode,
                     struct ifnet *ifnet_ptr,
                     void (*bpf_callback) (
                     struct ifnet *ifnet_ptr,
                     struct mbuf *mbuf_ptr,
                     int direction);
```

`mode`	On input, a value of type `int` that is `BPF_TAP_DISABLE` (to disable the tap), `BPF_TAP_INPUT` (to enable the tap on incoming packets), `BPF_TAP_OUTPUT` (to enable the tap on outgoing packets), or `BPF_TAP_INPUT_OUTPUT` (to enable the tap on incoming and outgoing packets).
`ifnet_ptr`	On input, a pointer to the `ifnet` structure for this interface.
`callback`	On input, a function pointer to the tap.
function result	0 for success.

DISCUSSION

The `if_set_bpf_tap` function enables or disables a read-only binary packet filter tap for an interface. A tap is different from a NKE in that it is read-only and that it operates within the driver. Any network driver attached to the DLIL can be tapped.

The `if_set_bpf_tap` function pointer is defined in the interface's `ifnet` structure by the driver before the driver calls `dlil_if_attach` (page 71).

If the value of the `mode` parameter is `BPF_TAP_INPUT`, `BPF_TAP_OUTPUT`, or `BPF_TAP_INPUT_OUTPUT`, the `bfp_callback` parameter points to a C function the driver calls when transmitting or receiving data over the interface (depending on the value of `mode`). If the value of `mode` is `BPF_TAP_DISABLE`, the tap is disabled for incoming and outgoing packets.

When the driver calls its `bpf_callback` function, it passes a pointer to the interface's `ifnet` structure and a pointer to the incoming or outgoing `mbuf` chain.

if_free

Frees the `inet` structure for an interface.

```
void (*if_free) (struct ifnet *ifnet_ptr);
```

`ifnet_ptr`	On input, a pointer to the `ifnet` structure that is to be freed.
function result	None.

DISCUSSION

The if_free function frees the ifnet structure for an interface. It is called by the DLIL in response to a previous dlil_if_detach call from the driver that returned DLIL_WAIT_FOR_FREE. Once all references to the ifnet structure have been deallocated, the DLIL calls if_free (page 70) to notify the driver that the associated ifnet structure pointed to by ifnet_ptr is no longer being referenced and can be deallocated.

The if_free pointer is defined in the interface's ifnet structure before the interface driver calls dlil_if_attach (page 71).

Calling the DLIL From the Driver Layer

Drivers call the following DLIL functions:

- dlil_if_attach (page 71) to attach an interface to the DLIL.
- dlil_if_detach (page 72) to detach an interface from the DLIL.
- dlil_reg_if_modules (page 73) to register an interface family module.
- dlil_find_dl_tag (page 74) to locate the dl_tag value for a protocol and interface family pair.
- dlil_input (page 75) to pass incoming packets to the DLIL.
- dlil_event (page 75) to pass event codes to the DLIL.

dlil_if_attach

Attaches an interface to the DLIL for use by a specified protocol.

```
int dlil_if_attach( struct ifnet *ifnet_ptr );
```

ifnet_ptr — A pointer to an ifnet structure containing all of the information required to complete the attachment. The ifnet structure may be embedded within an interface-family–specific structure, in which case the ifnet structure must be the first member of that structure.

function result 0 for success and `ENOENT` if no interface family module is found. Other possible errors are defined in `errno.h`.

DISCUSSION

The `dlil_if_attach` function attaches an interface to the DLIL. If the DLIL interface family module for the specified interface has not been loaded, an error is returned. (See `dlil_reg_if_modules` (page 73).)

The DLIL calls the `add_if` (page 76) function for the interface family module in order to initialize the module's portion of the `ifnet` structure and perform any module-specific tasks. At minimum, the `add_if` function is responsible for initializing the `if_demux` (page 79) and `if_framer` function pointers in the `ifnet` structure. Later, the DLIL uses the `if_demux` function pointer to call the demultiplexing descriptors for the interface in order to demultiplex incoming frames and uses the `if_framer` function pointer to frame outbound packets.

Once `add_if` initializes the members of the `ifnet` structure for which it is responsible, the DLIL places the interface on the list of network interfaces, and `dlil_if_attach` returns.

dlil_if_detach

Detaches an interface from the DLIL.

```
int dlil_if_detach( struct ifnet *ifnet_ptr );
```

`inet_ptr` A pointer to an `ifnet` structure that was previously used to call `dlil_if_attach` (page 71).

function result 0 for success. `DLIL_WAIT_FOR_FREE` if the driver must wait for the DLIL to call the `if_free` (page 70) callback function before deallocating the `ifnet` structure.

DISCUSSION

The `dlil_if_detach` function detaches a network interface from the DLIL, thereby disabling communication to and from the interface. Then the DLIL marks the interface as detached in the interface's `ifnet` structure. To notify the protocols that are attached to the interface that the interface has been detached, the DLIL then calls the `dl_event` function for all of the protocols have defined such a function. In response, attached protocols should call `dlil_detach_protocol` to detach themselves from the interface.

The protocols or the socket layer may still have references to the `ifnet` structure for the detached interface, so interface drivers should wait to deallocate the interface's `ifnet` structure until the DLIL calls the interface's `if_free` (page 70) function to notify the driver that all protocols have detached from the interface.

dlil_reg_if_modules

Registers an interface family.

```
dlil_reg_if_modules(u_longinterface_family,
                    int (*add_if),
                    int (*del_if),
                    int (*add_proto),
                    int (*del_proto),
                    int (*shutdown)());
```

`interface_family`
: On input, a value of type `u_long` specified that uniquely identifies the interface family. Values for the current interface families are defined in `<net/if_var.h>`. You can define new interface family values by contacting DTS.

`add_if`
: On input, a pointer to the interface family module's `add_if` function.

`del_if`
: On input, a pointer to the interface family module's `del_if` function.

`add_proto`
: On input, a pointer to the interface family module's `add_proto` function.

`del_proto`
: On input, a pointer to the interface family module's `del_proto` function.

`shutdown`
: On input, a pointer to the interface family module's `shutdown` function.

function result 0 for success. Other errors are defined in `errno.h`.

DISCUSSION

The dlil_reg_if_modules function registers an interface family module that contains the necessary functions for processing inbound and outbound packets including if_demux and if_framer functions. Any null function pointers are skipped in DLIL processing.

dlil_find_dl_tag

Gets the dl_tag for an interface and protocol family pair.

```
dlil_find_dl_tag(u_longif_family;
                    short unit;
                    u_long proto_family;
                    u_long *dl_tag);
```

if_family	On input, a value of type u_long that uniquely identifies the interface family. See <net/if_var.h> for possible values.
unit	On input, a value of type short containing the unit number of the interface.
proto_family	On input, a value of type u_long that uniquely identifies the protocol family. See <net/if_var.h> for possible values.
dl_tag	On input, a pointer to a value of type u_long in which the dl_tag value for the specified interface and protocol family pair is to be returned.
function result	0 for success. EPROTONOSUPPORT if a matching pair is not found.

DISCUSSION

The dlil_find_dl_tag function locates the dl_tag value associated with the specified interface and protocol family pair.

dlil_input

Passes incoming packets to the DLIL.

```
int dlil_input(struct ifnet *ifp,
                    struct mbuf *m);
```

ifp	On input, a pointer to the ifnet structure for this interface.
m	On input, a pointer to the head of a chain of mbuf structures containing one or more incoming frames.
function result	0 for success.

DISCUSSION

The dlil_input function is called by the driver layer to pass incoming frames from an interface to the DLIL. The dlil_input function performs the following sequence:

1. Any interface filters attached to the associated interface are called.
2. Assuming all filters return successfully, if_demux (page 79) is called to determine the target protocol family. If if_demux cannot find a matching protocol family, dlil_input calls the dl_offer functions (if any) defined by the attached protocol families.
3. If no target protocol family is found, the frame is dropped.
4. Any protocol filters attached to the target protocol family / interface are called.
5. If all protocol filters return successfully, the frame is passed to the protocol family's dl_input function. DLIL frame processing is finished.

dlil_event

Notifies the DLIL of significant events.

```
void (*dlil_event) (struct ifnet *ifnet_ptr,
                    struct event_msg *event);
```

`ifnet_ptr`	On input, a pointer to the `ifnet` structure for this interface.
`event`	On input, a pointer to an `event_mgs` structure containing a unique event code and a pointer to event data.
function result	A result code.

DISCUSSION

The `dlil_event` function is called by the driver layer to pass event codes, such as a change in the status of power management, to the DLIL. The DLIL passes a pointer to the `ifnet` structure for this interface and the event parameter to those protocols that are attached to this interface and that have provided a pointer to a `dl_event` function for receiving events. The protocols may or may not react to any particular event code.

Calling Interface Modules From the DLIL

The DLIL calls the following interface module functions:

- `add_if` (page 76) to add an interface.
- `del_if` (page 77) to remove an interface.
- `add_proto` (page 77) which is called to add a protocol.
- `del_proto` (page 78) which is called to remove a protocol.

add_if

Adds an interface.

```
int (*add_if) struct ifnet *ifp);
```

`ifp`	On input, a pointer to the `ifnet` structure for the interface that is being added.
function result	0 for success.

DISCUSSION

The `add_if` function is called by the DLIL in response to a call to `dlil_if_attach` (page 71). The DLIL calls `add_if` in the interface family module in order to initialize the module's portion of the `ifnet` structure and perform any module-specific tasks.

At minimum, the `add_if` function initializes the `if_demux` (page 79) and `if_framer` function pointers in the `ifnet` structure. Later, the DLIL uses the `if_demux` function pointer to call the demultiplexing function for the interface to demultiplex incoming frames and calls the `if_framer` function to frame outbound packets.

del_if

Deinitializes portions of an `ifnet` structure.

```
int (*del_if) struct ifnet *ifp);
```

`ifp` On input, a pointer to the `ifnet` structure for the interface that is being deinitialized.

function result 0 for success.

DISCUSSION

The `del_if` function is called by the DLIL to notify an interface family module that an interface is being detached. The interface family module should remove any references to the interface and associated structures.

add_proto

Adds a protocol.

```
int (*add_proto)(struct ddesc_head_str *demux_desc_head)
                     struct if_proto *proto,
                     u_long dl_tag);
```

`demux_desc_head`
: On input, a pointer to the head of a linked list of one or more protocol demultiplexing descriptors for the protocol that is being added.

`proto` On input, a pointer to the `if_proto` structure for the protocol that is being added.

`dl_tag` On input, a value of type `u_long`, previously obtained by calling `dlil_attach_protocol` (page 58), that identifies the associated protocol / interface pair.

function result 0 for success.

DISCUSSION

The `add_proto` function is an interface family module function that processes the passed demux descriptor list, extracting any information needed to identify the attaching protocol in subsequent incoming frames.

del_proto

Removes a protocol.

```
int (*del_proto) (struct if_proto *proto,
                  u_long dl_tag);
```

`proto` On input, a pointer to the `if_proto` structure for the protocol that is being removed.

`dl_tag` On input, a value of type `u_long`, previously obtained by calling `dlil_attach_protocol` (page 58), that identifies the associated protocol / interface pair.

function result 0 for success.

DISCUSSION

The `del_proto` function is called by the DLIL to remove a protocol family from an interface family module's list of attached protocol families. Any references to the associated `if_proto` structure pointer should be removed before returning.

if_demux

Locates demultiplexing descriptors.

```
void (*if_demux) (struct ifnet *ifnet_ptr,
                        struct mbuf *mbuf_ptr,
                        char * frame_header);
```

`ifnet_ptr` On input, a pointer to the `ifnet` structure for this interface.

`mbuf_ptr` On input, a pointer to an `mbuf` structure containing one or more incoming frames.

`frame_header` On input, a pointer to a character string in the `mbuf` structure containing a frame header.

function result 0 for success.

DISCUSSION

The `if_demux` function is an interface family function called by `dlil_input` (page 75) to determine the target protocol family for an incoming frame. This function uses the demultiplexing data passed in from previous calls to the `add_proto` function. When a match is found, `if_demux` returns the associated `if_proto` pointer.

Calling the DLIL From a DLIL Filter

DLIL filters call the following DLIL functions in order to inject data into a data path:

- `dlil_inject_if_input` (page 80) is called by a DLIL interface filter to inject frames into the inbound data path.
- `dlil_inject_if_output` (page 81) is called by a DLIL interface filter to inject packets into the outbound data path.
- `dlil_inject_pr_input` (page 82) is called by a DLIL protocol filter to inject frames into the inbound data path.
- `dlil_inject_pr_output` (page 83) is called by a DLIL protocol filter to inject packets into the output data path.

dlil_inject_if_input

Injects frames into the inbound data path from the interface filter level.

```
int dlil_inject_if_input (struct mbuf *buffer,
                     char *frame_header,
                     ulong from_id);
```

`buffer` — On input, a pointer to a chain of `mbuf` structures containing the packets that are to be injected.

`frame_header` — On input, a pointer to a byte array of undefined length containing the frame header for the frames that are to be injected.

`from_id` — On input, a value of type `ulong` containing the filter ID of the calling filter obtained by previously calling `dlil_attach_interface_filter` (page 57). If `from_id` is set to `DLIL_NULL_FILTER`, all attached interface filters are called.

function result — 0 for success.

DISCUSSION

The `dlil_inject_if_input` function is called by an interface filter NKE to inject frames into the inbound data path. The frames can be frames that the filter generates or frames that were previously consumed.

When a filter injects a frame, the DLIL invokes all of the input interface filter NKEs that would normally be invoked after the filter identified by `filter_id`. The behavior is identical to the processing of a frame passed to `dlil_input` (page 75) from the driver layer except that all interface filter NKEs preceding and including the injecting filter are not executed.

dlil_inject_if_output

Injects packets into the outbound data path from the interface filter level.

```
int dlil_inject_if_output (
                    struct mbuf *buffer,
                    ulong from_id);
```

`buffer` On input, a pointer to a chain of `mbuf` structures containing the packets that is to be injected.

`from_id` On input, a value of type `ulong` containing the filter ID of the calling filter obtained by previously calling `dlil_attach_interface_filter` (page 57). If `from_id` is set to `DLIL_NULL_FILTER`, all attached interface filters are called.

function result 0 for success.

DISCUSSION

The `dlil_inject_if_output` function is called by an interface filter NKE to inject frames into the outbound data path. The packets can be packets that the filter generates or packets that were previously consumed.

When a filter injects a packet, the DLIL invokes all of the output interface filter NKEs that would normally be invoked after the filter that calls `dlil_inject_if_output` (page 81). This behavior is identical to the last steps of packet processing done by `dlil_output`, except that all output interface filter NKEs preceding and including the injecting filter are not executed.

Note
The injected packets must contain any frame header that the driver layer requires. ◆

dlil_inject_pr_input

Injects frames into the inbound data path from the protocol filter level.

```
int dlil_inject_pr_input (struct mbuf *buffer,
                          char *frame_header,
                          ulong from_id);
```

`buffer` On input, a pointer to a chain of `mbuf` structures containing the data that is to be injected.

`frame_header` On input, a pointer to a byte array of undefined length containing the frame header for the frames that are to be injected.

`from_id` On input, the filter ID of the calling filter obtained by previously calling `dlil_attach_protocol_filter` (page 55). If `from_id` is set to the constant `DLIL_NULL_FILTER`, all attached interface filters are called.

function result 0 for success.

DISCUSSION

The `dlil_inject_pr_output` function is called by a protocol filter NKE to inject frames into the outbound data path. The frames can be frames that the filter generates or frames that were previously consumed.

When a protocol filter calls `dlil_inject_pr_output`, the DLIL invokes all of the input protocol filter NKEs that would normally be invoked after the filter that calls `dlil_inject_pr_input`. This behavior is identical to the last steps of processing that occur when a frame is passed to `dl_input` (page 65), except that all protocol filter NKEs preceding and including the injecting filter are not executed.

dlil_inject_pr_output

Injects packets into the outbound data path from the protocol filter level.

```
int dlil_inject_pr_output (
                struct mbuf *buffer,
                struct sockaddr *dest,
                int raw,
                char *frame_type,
                char *dst_linkaddr,
                ulong from_id);
```

`buffer`	On input, a pointer to a chain of `mbuf` structures containing the data that is to be injected.
`dest`	On input, a pointer to an opaque pointer-sized variable whose use is specific to each protocol family, or `NULL`.
`raw`	On input, a Boolean value. Setting `raw` to `TRUE` indicates that the `mbuf` chain pointed to by `buffer` contains a link-level frame header, which means that no further processing by the protocol or the interface family modules is required. The value of `raw` does not affect whether the DLIL calls any NKEs that are attached to the protocol / interface pair.
`frame_type`	On input, a pointer to a byte array of undefined length containing the frame type. The length and content of `frame_type` are specific to each interface family.
`dst_linkaddr`	A pointer to a byte array of undefined length containing the destination link address.
`from_id`	On input, a value of type `ulong` containing the filter ID of the calling filter obtained by previously calling `dlil_attach_protocol_filter` (page 55). If `from_id` is set to `DLIL_NULL_FILTER`, all attached interface filters are called.
function result	0 for success.

DISCUSSION

The dlil_inject_pr_output function is called by a protocol filter NKE to inject packets into the outbound data path. The packets can be packets that the filter generates or packets that were previously consumed.

When a protocol filter calls dlil_inject_pr_output, the DLIL invokes all of the output protocol filter NKEs that would normally be invoked after the filter that calls dlil_inject_pr_output. This behavior is identical to the execution of dlil_output following the call to dl_pre_output except that all output protocol filters preceding and including the injecting filter are not executed.

NKE Structures and Data Types

This section describes the NKE structures and data types. The structures are

- dlil_proto_reg_str (page 84) which provides the information necessary to attach a protocol to the DLIL.
- dlil_proto_reg_str (page 84) which provides the information necessary to identify a protocol's packets.
- dlil_if_flt_str (page 88) which contains pointers to all of the functions the DLIL may call when sending or receiving a frame from an interface.
- dlil_if_flt_str (page 88) which contains pointers to all of the functions the DLIL may call when it passes a call to an NKE.

Note
With the exception of the ifnet structure, the DLIL makes its own copy of all structures that are passed to it. ◆

dlil_proto_reg_str

The dlil_proto_reg_str structure is passed as a parameter to the dlil_attach_protocol (page 58) function, which attaches network protocol stacks to interfaces.

```
struct dlil_proto_reg_str {
    struct ddesc_head_str demux_desc_head;
    u_long interface_family;
    u_long protocol_family;
    short unit_number;
    int default_proto;
    dl_input_func input;
    dl_pre_output_func pre_output;
    dl_event_func event;
    dl_offer_func offer;
    dl_ioctl_func ioctl;
};
```

Field descriptions

`ddesc_head_str` The head of a linked list of one or more protocol demultiplexing descriptors. Each demultiplexing descriptor defines several sub-structures that are used to identity and demultiplex incoming frames belonging to one or more attached protocols. When multiple methods of frame identification are used for an interface family, a chain of demultiplexing descriptors may be passed to `dlil_attach_protocol` (page 58) and to `add_if` (page 76) to identify each method.

`interface_family` A unique unsigned long value that specifies the interface family. Values for current interface families are defined in `<net/if_var.h>`. Developers may define new interface family values through DTS.

`protocol_family` A unique unsigned long value defined that specifies the protocol family being attached. Values for current protocol families are defined in `<net/dlil.h>`. Developers may define new protocol family values through DTS.

`unit_number` Specifies the unit number of the interface to which the protocol is to be attached. Together, the `interface_family` and `unit_number` fields identify the interface to which the protocol is to be attached.

`default_proto` Reserved. Always 0.

`input` Contains a pointer to the function that the DLIL is to call in order to pass input packets to the protocol stack.

`pre_output`	Contains a pointer to the function that the DLIL is to call in order to perform protocol-specific processing for outbound packets, such as adding an 802.2/SNAP header and defining the target address.
`event`	Contains a pointer to the function that the DLIL is to call in order to notify the protocol stack of asynchronous events, or is `NULL`. If this field is `NULL`, events are not passed to the protocol stack.
`offer`	Contains a pointer to the function that the DLIL is to call in order to offer a frame to the attached protocol, or is `NULL`. If `offer` is `NULL`, the DLIL will not be able to offer frames that cannot be identified to the protocol and the frame may be dropped.
`ioctl`	Contains a pointer to the function that the DLIL is to call in order to send ioctl calls to the interface's driver.

dlil_demux_desc

The `dlil_demux_desc` structure is a member of the `dlil_proto_reg_str` (page 84) structure. The `dlil_demux_desc` structure is the head of a linked list of protocol demultiplexing descriptors that identify the protocol's packets in incoming frames.

```
struct dlil_demux_desc {
    TAILQ_ENTRY(dlil_demux_desc) next;
    int type;
    u_char *native_type;
    union {
        struct {
            u_long proto_id_length;
            u_char *proto_d;
            u_char *proto_id_mask;
        } bitmask;

        struct {
            u_char dsap;
            u_char ssap;
            u_char control_code;
```

```
            u_char pad;
        } desc_802_2;

        struct {
            u_char dsap;
            u_char ssap;
            u_char control_code;
            u_char org[3];
            u_short protocol_type;
        } desc_802_2_SNAP;
    } variants;
}

TAILQ_HEAD(ddesc_head_str, dlil_demux_desc);
```

Field descriptions

`next`	A link pointer used to chain multiple descriptors.
`type`	Specifies which variant of the descriptor has been defined. For Ethernet, the possible values are `DESC_802_2`, `DESC_802_2_SNAP`, and `DESC_BITMASK`.
`native_type`	A pointer to a byte array containing a self-identifying frame ID, such as the two-byte Ethertype field in an Ethernet II frame. This field may be used by itself, may be used in combination with other identifying information, or may not be used at all, in which case, its value is `NULL`.
`variants`	Three structures that comprise a union. The `bitmask` structure describes any combination of bits that identify frames that do not match Ethernet 802.2 frames and Ethernet 802.2 / SNAP frames. The `desc_802_2` structure and the `desc_802_2_SNAP` structure describe Ethernet 802.2 frames and Ethernet 802.2 / SNAP frames, respectively.

For each Ethernet interface, the following sequence must take place. The actual implementation may optimize the process.

1. The first `if_proto` structure is referenced. The structure is found through the `proto_head` pointer in the associated `ifnet` structure.
2. The frame is compared with the first demultiplexing descriptor in the protocol's list of demultiplexing descriptors (the `bitmask` structure).

3. If the native type is `NULL` or if the interface family's frame doesn't have a frame type field, go to step 4. Otherwise, the octet string in `native-type` is compared with the interface family's native frame-type specification field. The frame format for each interface family defines the number of bits to compare. If there is a match and the `proto_id` and `proto_id_mask` fields are defined, go to step 4. If there is a match and the `proto_id` and `proto_id_mask` fields are `NULL`, the frame is passed to the protocol's input function, thereby terminating DLIL processing of the frame.
4. If the `proto_id` or `proto_id_mask` fields in the `bitmask` structure are `NULL`, or if the `proto_id_length` field is 0, go to step 5. Otherwise, compare the first `proto_id_length` bytes of the frame's data field with `proto_id`, ignoring any bits defined as zero in the `proto_id_mask`. If there is a match, the frame is passed to the protocol's input function, thereby terminating DLIL processing of the frame.
5. This demultiplexing descriptor could not provide a match. Advance to the next demultiplexing descriptor in the list and go to step 3.
6. None of the demultiplexing descriptors could provide a match. If there is another `if_proto` structure in the interface's protocol list, go back to step 2 using the first demultiplexing descriptor for this protocol.
7. No match could be found using any demultiplexing descriptor for any of the protocols attached to the interface. Go back through the `if_proto` structures for the attached protocols and call any defined `dl_offer` function. If a `dl_offer` function returns `DLIL_FRAME_ACCEPTED`, the DLIL passes the frame to the responding protocol's `dl_input` function, thereby terminating DLIL processing of the frame.
8. None of the protocols attached to this interface have accepted the frame. The `mbuf` chain is freed and the frame is dropped.

The `bitmask` structure or one of the predefined 802.2 structures can be used to identify frames.

dlil_if_flt_str

The `dlil_ir_flt_str` structure is a parameter to the `dlil_attach_interface_filter` (page 57) function, which inserts DLIL interface filters between the DLIL and an interface.

This structure contains pointers to all of the functions that are called at the point at which the filter is placed.

```
struct dlil_if_flt_str {
caddr_t cookie;
int (*filter_if_input)  (caddr_t cookie,
                         struct ifnet **ifnet_ptr,
                         struct mbuf **mbuf_ptr,
                         char **frame_ptr);
int (*filter_if_event)  (caddr_t cookie,
                         struct ifnet **ifnet_ptr,
                         struct event_msg **event_msg_ptr);
int (*filter_if_output) (caddr_t cookie,
                         struct ifnet **ifnet_ptr,
                         struct mbuf **mbuf_ptr);
int (*filter_if_ioctl)  (caddr_t cookie,
                         struct ifnet **ifnet_ptr,
                         u_long ioctl_code_ptr,
                         caddr_t ioctl_arg_ptr);
int (*filter_if_free)   (caddr_t cookie,
                         struct ifnet **ifnet_ptr);
int (*filter_detach)    (caddr_t cookie);
};
```

Field descriptions

`filter_if_input` A pointer to the `filter_if_input` function for this DLIL interface filter. The parameters for this function are `cookie`, (an opaque value that is passed by the filter and is returned so that the filter can identify one attachment among many attachments), a pointer to the `ifnet` structure for this interface, a pointer to an `mbuf` structure, and pointer to the frame.

`filter_if_event` A pointer to the `filter_if_event` function for this DLIL interface filter. The parameters for this function are `cookie`, (an opaque value that is passed by the filter and is returned so that the filter can identify one attachment among many attachments), a pointer to the `ifnet` structure for this interface, and a pointer to an `event_msg` structure containing the event that is being passed to the extension.

`filter_if_output` A pointer to the `filter_if_output` function for this DLIL interface filter. The parameters for this function are `cookie` (an opaque value that is passed by the filter and is returned so that the filter can identify one attachment among many attachments), a pointer to the `ifnet` structure for this interface, and a pointer to the memory buffer for this packet.

`filter_if_ioctl` A pointer to the `filter_if_ioctl` function for this DLIL interface filter. The parameters for this function are `cookie` (an opaque value that is passed by the filter and is returned so that the filter can identify one attachment among many attachments), a pointer to the `ifnet` structure for this interface, an unsigned long that points to the I/O control code for this call, and a pointer to parameters that the DLIL passes to the `filter_if_ioctl` function.

`filter_if_free` A pointer to the `filter_if_free` function for this DLIL interface filter. The parameters for this function are `cookie` (an opaque value that is passed by the filter and is returned so that the filter can identify one attachment among many attachments) and a pointer to the `ifnet` structure for this interface.

`filter_detach` A pointer to the `filter_detach` function for this DLIL interface filter. The parameter for this function is `cookie` (an opaque value that is passed by the filter and is returned so that the filter can identify one attachment among many attachments). For details, see `dlil_detach_filter` (page 59).

dlil_pr_flt_str

The `dlil_pr_flt_str` structure is a parameter to the function `dlil_attach_protocol_filter` (page 55), which inserts DLIL protocol filters between a protocol and the DLIL.

This structure contains pointers to all of the functions that are called at the point at which the filter is placed.

```
struct dlil_if_flt_str {
caddr_t cookie;
int (*filter_dl_input)  (caddr_t cookie,
                         struct mbuf **m,
                         char **frame_header,
                         struct ifnet **ifp);
int (*filter_dl_output) (caddr_t cookie,
                         struct mbuf **m,
                         struct ifnet **ifp,
                         struct sockaddr **dest,
                         char *dest_linkaddr,
                         char *frame_type);
int (*filter_dl_event)  (caddr_t cookie,
                         struct event_msg *event_msg);
int (*filter_dl_ioctl)  (caddr_t cookie,
                         struct ifnet **ifp,
                         u_long ioctl_cmd,
                         caddr_t ioctl_arg);
int (*filter_detach)    (caddr_t cookie);
};
```

Field descriptions

`filter_dl_input`
: A pointer to the `filter_dl_input` function for this DLIL protocol filter. The parameters for this function are `cookie`, (an opaque value that is passed by the filter and is returned so that the filter can identify one attachment among many attachments), a pointer to an `mbuf` structure, and a pointer to the `ifnet` structure for the interface.

`filter_dl_output`
: A pointer to a `filter_dl_output` function for this DLIL protocol filter. The parameters for this function are `cookie` (an opaque value that is passed by the filter and is returned so that the filter can identify one attachment among many attachments), a pointer to the `ifnet` structure for the interface, a pointer to the socket address for this destination, a pointer to the link address for this destination, and a pointer to the frame type.

`filter_dl_event`
: A pointer to the `filter_pr_event` function for this DLIL protocol filter. The parameters for this function are `cookie`, (an opaque value that is passed by the filter and is returned so that the filter can identify one attachment among many

attachments), a pointer to the `ifnet` structure for the interface, and a pointer to an `event_msg` structure containing the event that is being passed to the extension.

`filter_dl_ioctl` A pointer to a `filter_if_ioctl` function for this DLIL protocol filter. The parameters for this function are `cookie` (an opaque value that is passed by the filter and is returned so that the filter can identify one attachment among many attachments), a pointer to the `ifnet` structure for the interface, an `u_long` that points to the I/O control command for this call, and a pointer to parameters that the DLIL passes to the `filter_if_ioctl` function.

`filter_detach` A pointer to the `filter_detach` function for this DLIL protocol filter. The parameter for this function is `cookie` (an opaque value that is passed by the filter and is returned so that the filter can identify one attachment among many attachments).

A P P E N D I X   A

Sample Code

Sample Source Code for VMSify NKE

Here is a sample code for an NKE that converts to uppercase remotely echoed characters typed into a telnet session.

Listing 3-1 VMSIfy.c

```
/*
 * VMSIfy - a Mac OS X global filter NKE *
 */

#define DO_LOG 0
#include <sys/param.h>
#include <sys/systm.h>
#include <sys/socket.h>
#include <sys/protosw.h>
#include <sys/socketvar.h>
#include <net/route.h>
#include <sys/domain.h>
#include <sys/mbuf.h>
#include <net/if.h>
#include <sys/fcntl.h>
#if DO_LOG
#include <sys/syslog.h>
#endif

#include <sys/malloc.h>
#include <sys/queue.h>
#include <net/kext_net.h>
```

```
#include <netinet/in.h>
#include <netinet/in_systm.h>
#include <netinet/ip.h>
#include <netinet/ip_var.h>
#include <netinet/ip_icmp.h>
#include <netinet/in_pcb.h>
#include <netinet/tcp.h>
#include <netinet/tcp_timer.h>
#include <netinet/tcp_var.h>

#include <mach/kern_return.h>
#include <mach/vm_types.h>
#include <mach/kernel_extension.h>

#define sotoextcb(so) (struct kextcb *)(so->so_ext)

extern char *inet_ntoa(struct in_addr);
extern void kprintf(const char *, ...);
extern int splhigh(void);
extern void splx(int);

struct socket *ctl;             /* Non-null if controlled */

/*
 * Theory of operation:
 * At init time, add us to the list of extensions for TCP.
 * For each new connection (active only), check the destination
 * port.  If telnet, mark the 'kextcb'.  On input, if the 'kextcb'
 * is marked, map lower- to upper-case.

 * The filter will take itself out of operation (for new sockets)
 * on an unload command, even if the command fails.

 * The filter tries to remove itself from sockets that aren't outbound
 *  telnet sessions by nullifying the dispatch vector pointers in the
 *  kextcb for this socket/filter pair.
 * This works because there's no state kept on a per-socket basis.  For
 *  others, one could replace the "normal" pointers with pointers to
 *  other dispatch vectors that only clean up at the end of a connection.
 */
```

```
int     vif_attach(),
        vif_read(), vif_write(),
        vif_get(), vif_set();

void    vif_detach(), vi_input(), vi_ctlinput();

static int vi_initted = 0,
           vi_inhibit = 0;

int
vi_accept(), vi_create(), vi_connect(), vi_close(), vi_listen();

/* Dispatch vector for VMSIfy socket functions */
struct sockif VIsockif =
{       NULL,           /* soabort */
        vi_accept,      /* soaccept */
        NULL,           /* sobind */
        vi_close,       /* soclose */
        vi_connect,     /* soconnect */
        NULL,           /* soconnect2 */
        vi_create,      /* socreate */
        NULL,           /* sodisconnect */
        NULL,           /* sofree */
        NULL,           /* sogetopt */
        NULL,           /* sohasoutofband */
        vi_listen,      /* solisten */
        NULL,           /* soreceive */
        NULL,           /* sorflush */
        NULL,           /* sosend */
        NULL,           /* sosetopt */
        NULL,           /* soshutdown */
        NULL,           /* socantrcvmore */
        NULL,           /* socantsendmore */
        NULL,           /* soisconnected */
        NULL,           /* soisconnecting */
        NULL,           /* soisdisconnected */
        NULL,           /* soisdisconnecting */
        NULL,           /* sonewconn1 */
        NULL,           /* soqinsque */
        NULL,           /* soqremque */
```

```
        NULL,           /* soreserve */
        NULL,           /* sowakeup */
};

void
vi_sbappend();
/* Dispatch vector for VMSIfy socket buffer functions */
struct sockutil VIsockutil =
{       NULL,           /* sb_lock */
        vi_sbappend,    /* sbappend */
        NULL,           /* sbappendaddr */
        NULL,           /* sbappendcontrol */
        NULL,           /* sbappendrecord */
        NULL,           /* sbcompress */
        NULL,           /* sbdrop */
        NULL,           /* sbdroprecord */
        NULL,           /* sbflush */
        NULL,           /* sbinsertoob */
        NULL,           /* sbrelease */
        NULL,           /* sbreserve */
        NULL,           /* sbwait */
};

/* Dispatch vectors when VMSIfy has pulled out */
struct sockif VIsockif_null;
struct sockutil VIsockutil_null;

#define VMSIFY_HANDLE 0xfacefeed

struct NFDescriptor VMSIfy =
{       {NULL, NULL},
        {NULL, NULL},
        VMSIFY_HANDLE,
        NFD_GLOBAL,
        vif_attach, vif_detach,
        vif_read, vif_write,
        vif_get, vif_set,
        NULL, NULL
};
```

```
int vi_use_count = 0;
int VI_recvspace = 8192;        /* SWAG */

/* =================================== */

int
VMSIfy_module_start(kext_info_t *ki, void *data)
{       extern int VI_init(int);
        return(VI_init(0));
}

int
VI_init(int init_arg)
{       int retval;
        struct protosw *pp;

        if (vi_initted)
                return(KERN_SUCCESS);

        /* Find the protosw we want to sidle up to */
        pp = pffindproto(AF_INET, IPPROTO_TCP, SOCK_STREAM);
        if (pp == NULL)
                return(EPFNOSUPPORT);
        VMSIfy.nf_soif = &VIsockif;
        VMSIfy.nf_soutil = &VIsockutil;

        /* Register the filter */
        retval = register_sockfilter(&VMSIfy, NULL, pp, NFF_AFTER);
        if (!retval)
        {       vi_initted = 1;
                retval = KERN_SUCCESS;
        }
#if DO_LOG
        else
                log(LOG_WARNING, "VMSIfy init: %d\n", retval);
#endif
        return(retval);
}
```

```
/*
 * Close down the VMSIfy filter
 */

int
VMSIfy_module_stop(kext_info_t *ki, void *data)
{       extern int VI_terminate(int);
        return(VI_terminate(0));
}

int
VI_terminate(int term_arg)
{       int retval;
        struct protosw *pp;
        extern int unregister_sockfilter(struct NFDescriptor *,
                                         struct protosw *, int);

        if (!vi_initted)
                return(0);
        pp = pffindproto(AF_INET, IPPROTO_TCP, SOCK_STREAM);
        if (pp == NULL)
        {
#if DO_LOG
                log(LOG_WARNING, "VMSIfy: No TCP\n");
#endif
                return(EPFNOSUPPORT);
        }
        retval = unregister_sockfilter(&VMSIfy, pp, 0);
        if (vi_use_count == 0)
        {
#if DO_LOG
                if (retval)
                     log(LOG_WARNING, "VMSIfy terminate: %d\n", retval);
#endif
        } else
        {
#if DO_LOG
                log(LOG_WARNING, "VMSIfy termination attempted;
                        failed\n");
```

```
#endif
                retval = EBUSY;
        }

        vi_inhibit = 1;
        return(retval);
}

/*
 * socreate calls this function when a new socket is created
 * Clear the 'fcb' pointer (used as a zero/non-zero flag).
 * If activity is inhibited, clear out the intercept pointers.
 */

int
vi_create(struct socket *so, struct protosw *prp, register struct
                kextcb *kp)
{
        if (!vi_inhibit)
        {       kp->e_fcb = (void *)NULL;
                vi_use_count++;
        }
        return(0);
}

/*
 * On input, map incoming text to upper case.  First cut: ignore the
 *  possibility that a byte isn't a character (Telnet options).
 * Make sure we're looking at the receive sockbuf.
 */

void
vi_sbappend(struct sockbuf *sb, struct mbuf *m, struct kextcb *kp)
{       register struct socket *so;
        extern void map_upper(struct mbuf *);

        so = sbtoso(sb);
        if ((int)kp->e_fcb == 1)
        {       if (sb->sb_flags & SB_RECV)
                        map_upper(m);
```

```
        } else if ((int)kp->e_fcb)
                kprintf("FCB1: %x\n", kp->e_fcb);
}

/* Clear out our presence */
int
vi_close(register struct socket *so, struct kextcb *kp)
{
        if ((int)kp->e_fcb == 1)
        {       vi_use_count--;
                (int)kp->e_fcb = 0;

        } else if ((int)kp->e_fcb)
                kprintf("FCB2: %x\n", kp->e_fcb);
        return(0);
}

/* Check remote port for Telnet.  If so, turn on the receive checking */
int
vi_connect(struct socket *so, struct sockaddr_in *nam, struct kextcb *kp)
{
        if (nam->sin_port == 23)        /* A telnet connection! */
                (int)kp->e_fcb = 1;
        else
        {       vi_use_count--;
                kp->e_soif = NULL;
                kp->e_sout = NULL;
        }
#if DO_LOG
        log(LOG_INFO, "Socket %x: Turning on VMSIfy\n", so);
#endif
        return(0);
}

/*
 * An accept() call means that this is an inbound connection.
 * Drop it like a hot rock.
 */
```

```
int
vi_accept(struct socket *so, struct sockaddr_in **nam, struct kextcb
                *kp)
{
        vi_use_count--;
        kp->e_soif = NULL;
        kp->e_sout = NULL;
#if DO_LOG
        log(LOG_INFO, "Socket %x: Turning off VMSIfy (accept)\n", so);
#endif
        return(0);
}

/* If we're listening, we don't need to look further */
int
vi_listen(struct socket *so, struct kextcb *kp)
{
        vi_use_count--;
        kp->e_soif = NULL;
        kp->e_sout = NULL;
#if DO_LOG
        log(LOG_INFO, "Socket %x: Turning off VMSIfy (listen)\n", so);
#endif
        return(0);
}

/*
 * We have a control (PF_FILTER) socket expressing interest.
 */
int
vif_attach(register struct socket *cso)
{       register int error;

        if (ctl)
                return(EISCONN);

        if (cso->so_snd.sb_hiwat == 0 || cso->so_rcv.sb_hiwat == 0) {
                error = soreserve(cso, 0, VI_recvspace);
                if (error)
                        return (error);
        }
```

```
        ctl = cso;
        return(0);
}

void
vif_detach()
{
        ctl = NULL;
}

int
vif_get()
{
        return(0);
}

int
vif_read()
{
        return(0);
}

int
vif_set()
{
        return(0);
}

int
vif_write()
{
        return(0);
}

void
map_upper(register struct mbuf *m)
{       register unsigned char *p;
        register int n;
        register unsigned char ch;
```

```
        while (m)
        {       p = m->m_data;
                n = m->m_len;
                while (n-- > 0)
                {       if ((ch = *p++) >= 'a' && ch <= 'z')
                        {       ch -= 0x20;
                                p[-1] = ch;
                        }
                }
                m = m->m_next;
        }
}
```

Sample Source Code for TCPLogger

Here is a sample code for the TCPLogger NKE, which records detailed information about data sent to and from the system via TCP.

Listing 3-2 TCPLogger.h

```
/*
 * Per-socket control block for the log function
 */
struct TCPLogEntry
{       TAILQ_ENTRY(TCPLogEntry) tl_next;       /* Active filters */
        int tl_flags;
        struct sockaddr_in tl_local;            /* Endpoints */
        struct sockaddr_in tl_remote;
        long int bytes_in;
        long int pkts_in;
        long int pkts_in_null;
        long int bytes_out;
        long int pkts_out;
        long int pkts_out_null;
        struct timeval tl_create;/* socreate timestamp */
        struct timeval tl_start;/* connection complete timestamp */
```

```
        struct timeval tl_stop; /* connection termination timestamp */
        struct socket *tl_so;   /* Back pointer to owning socket */
};

#define TLE_CONN         0x01           /* Connection completed */
#define TCPLOGGER_HANDLE 0xBABECAFE     /* Temp hack to identify this puppy */

/* Max # log entries to keep if not connected to reader */
#define TCPLOGGER_QMAX  200
```

Listing 3-3 TCPLogger.c

```
/*
* TCPLogger - a Mac OS X global filter NKE
*/

#define DO_LOG 1

#include <sys/param.h>
#include <sys/systm.h>
#include <sys/socket.h>
#include <sys/protosw.h>
#include <sys/socketvar.h>
#include <net/route.h>
#include <sys/domain.h>
#include <sys/mbuf.h>
#include <net/if.h>
#include <sys/fcntl.h>
#if DO_LOG
#include <sys/syslog.h>
#endif
#include <sys/malloc.h>
#include <sys/queue.h>
#include <net/kext_net.h>

#include <netinet/in.h>
#include <netinet/in_systm.h>
#include <netinet/ip.h>
#include <netinet/ip_var.h>
#include <netinet/ip_icmp.h>
```

A P P E N D I X   A

Sample Code

```
#include <netinet/in_pcb.h>
#include <netinet/tcp.h>
#include <netinet/tcp_timer.h>
#include <netinet/tcp_var.h>

#include <mach/kern_return.h>
#include <mach/vm_types.h>
#include <mach/kernel_extension.h>

#define sotoextcb(so) (struct kextcb *)(so->so_ext)

#include "TCPLogger.h"

/* KEXT_DECL(TCPLogger, "0.1");*/
extern char *inet_ntoa(struct in_addr);
extern void kprintf(const char *, ...);
extern void tl_detach(struct TCPLogEntry *, struct socket *, struct protosw *);
extern void tl_dump_backlog(struct socket *);

/* List of active 'Logging' sockets */
TAILQ_HEAD(tl_list, TCPLogEntry) tl_list;

/* List of terminated TCPLogEntry structs, waiting for harvesting */
struct tl_list tl_done;
int tl_done_count = 0;

struct socket *ctl;             /* Non-null if controlled */

/*
 * Theory of operation:
 * At init time, add us to the list of extensions for TCP.
 * For each new connection (active or passive), log the endpoint
 * addresses, keep track of the stats of the conection and log the
 * results and close time.
 * At a minimum, the stats are: recv bytes, pkts; xmit bytes, pkts
 * The stats and other info are kept in the extension control block.
 */
int     tlf_attach(),
        tlf_read(), tlf_write(),
        tlf_get(), tlf_set(),
        tl_ctloutput(), tl_usrreq();
```

```
void    tlf_detach(), tl_input(), tl_ctlinput();

static int tl_initted = 0,
           tl_inhibit = 0;

int tl_accept(), tl_bind(), tl_connect(), tl_discon(), tl_free(),
    tl_receive(), tl_send(), tl_shutdown(), tl_create();
void tl_soisconnected();

/* Dispatch vector for TCPLogger socket functions */
struct sockif TLsockif =
{       NULL,           /* soabort */
        tl_accept,      /* soaccept */
        tl_bind,        /* sobind */
        NULL,           /* soclose */
        tl_connect,     /* soconnect */
        NULL,           /* soconnect2 */
        tl_create,      /* socreate */
        tl_discon,      /* sodisconnect */
        tl_free,        /* sofree */
        NULL,           /* sogetopt */
        NULL,           /* sohasoutofband */
        NULL,           /* solisten */
        tl_receive,     /* soreceive */
        NULL,           /* sorflush */
        tl_send,        /* sosend */
        NULL,           /* sosetopt */
        tl_shutdown,    /* soshutdown */
        NULL,           /* socantrcvmore */
        NULL,           /* socantsendmore */
        tl_soisconnected,/* soisconnected */
        NULL,           /*soisconnecting */
        NULL,           /* soisdisconnected */
        NULL,           /* soisdisconnecting */
        NULL,           /* sonewconn1 */
        NULL,           /* soqinsque */
        NULL,           /* soqremque */
        NULL,           /* soreserve */
        NULL,           /* sowakeup */
};
```

```
void tl_sbappend();

/* Dispatch vector for TCPLogger socket buffer functions */
struct sockutil TLsockutil =
{       NULL, /* sb_lock */
        tl_sbappend, /* sbappend */
        NULL, /* sbappendaddr */
        NULL, /* sbappendcontrol */
        NULL, /* sbappendrecord */
        NULL, /* sbcompress */
        NULL, /* sbdrop */
        NULL, /* sbdroprecord */
        NULL, /* sbflush */
        NULL, /* sbinsertoob */
        NULL, /* sbrelease */
        NULL, /* sbreserve */
        NULL, /* sbwait */
};

struct NFDescriptor TCPLogger =
{       {NULL, NULL},
        {NULL, NULL},
        TCPLOGGER_HANDLE,
        NFD_GLOBAL,
        tlf_attach, tlf_detach,
        tlf_read, tlf_write,
        tlf_get, tlf_set,
        NULL, NULL
};

int TL_recvspace = 8192;        /* SWAG */
int TL_sendspace = 8192;

/* ==================================== */

int
TCPLogger_module_start(kext_info_t *ki, void *data)
{       extern int TL_init(int);

        return(TL_init(0));
}
```

```
int
TL_init(int init_arg)
{       int retval;
        struct protosw *pp;

        if (tl_initted)
                return(KERN_SUCCESS);

        if (sizeof (struct TCPLogEntry) > MHLEN)
                return(E2BIG);

        TAILQ_INIT(&tl_list);
        TAILQ_INIT(&tl_done);
        /* Find the protosw we want to sidle up to */
        pp = pffindproto(AF_INET, IPPROTO_TCP, SOCK_STREAM);
        if (pp == NULL)
                return(EPFNOSUPPORT);
        TCPLogger.nf_soif = &TLsockif;
        TCPLogger.nf_soutil = &TLsockutil;
        /* Register the NKE */
        retval = register_sockfilter(&TCPLogger, NULL, pp, NFF_AFTER);
        if (!retval)
        {       tl_initted = 1;
               retval = KERN_SUCCESS;
        }
#if DO_LOG
        else
                log(LOG_WARNING, "TCPLogger init: %d\n", retval);
#endif
        return(retval);
}

/*
 * Close down the TCPLogger NKE
 * For this implant, we can slide it out of the way
 *  without harming the underlying TCP connection.
 * Experiment: soshutdown both sides
 *  Works on the send side (SIGPIPE delivered)
 *  Blows chunks on the "read" side.
 */
```

```
int
TCPLogger_module_stop(kext_info_t *ki, void *data)
{       extern int TL_terminate(int);

        return(TL_terminate(0));
}

int
TL_terminate(int term_arg)
{       int retval;
        struct protosw *pp;
        extern int unregister_sockfilter(struct NFDescriptor *,
                                         struct protosw *, int);

        if (!tl_initted)
                return(0);

        pp = pffindproto(AF_INET, IPPROTO_TCP, SOCK_STREAM);
        if (pp == NULL)
        {
#if DO_LOG
                log(LOG_WARNING, "TCPLogger: No TCP\n");
#endif
                return(EPFNOSUPPORT);
        }
        retval = unregister_sockfilter(&TCPLogger, pp, 0);
        if (tl_list.tqh_first == NULL)
        {
#if DO_LOG
                if (retval)
                        log(LOG_WARNING, "TCPLogger terminate: %d\n", retval);
#endif
        } else
        {
#if DO_LOG
                log(LOG_WARNING, "TCPLogger termination attempted; failed\n");
#endif
                retval = EBUSY;
}
        if (retval == 0)
                while (tl_done.tqh_first)
```

```
                        TAILQ_REMOVE(&tl_done, tl_done.tqh_first, tl_next);
        tl_inhibit = 1;
        return(retval);
}

/*
 * socreate calls this function when a new socket is created
 * Fill in a new TCPLogEntry and tag the socket
 */
int
tl_create(struct socket *so, struct protosw *prp,
          register struct kextcb *kp)
{       register struct TCPLogEntry *tlp;
        extern struct timeval time;

        if (!tl_inhibit)
        {       tlp = (struct TCPLogEntry *)_MALLOC(sizeof (struct TCPLogEntry),
                                                    M_TEMP, M_WAITOK);
                bzero(tlp, sizeof (*tlp));
                TAILQ_INSERT_TAIL(&tl_list, tlp, tl_next);
                tlp->tl_create = time;  /* Record for later */
                kp->e_fcb = (void *)tlp;
        }
        return(0);
}

/*
 * On input, we won't get notified as a protocol (since
 *  we aren't one), so we snag incoming data when it's
 *  appended.  Make sure it's the receive sockbuf we're
 *  looking at.
 */
void
tl_sbappend(struct sockbuf *sb, struct mbuf *m, struct kextcb *kp)
{       register struct TCPLogEntry *tlp;
        register struct socket *so;

        so = sbtoso(sb);
        tlp = (struct TCPLogEntry *)kp->e_fcb;
```

```
        if (sb->sb_flags & SB_RECV)
        {       if (m)
                {       tlp->pkts_in++;
                        do
                                tlp->bytes_in += m->m_len;
                        while ((m = m->m_next));
                } else
                        tlp->pkts_in_null++;
        }
}

/*
 * Called when TWH is complete.  Record start time, endpoint addrs
 */
void
tl_soisconnected(struct socket *so, struct kextcb *kp)
{       register struct TCPLogEntry *tlp;
        register struct inpcb *inp;
        extern struct timeval time;

        inp = sotoinpcb(so);
        tlp = (struct TCPLogEntry *)kp->e_fcb;
        if (tlp->tl_flags & TLE_CONN)
        {
#if DO_LOG
                log(LOG_WARNING, "Called isconnected twice!\n");
#endif
                return;
        }
        tlp->tl_start = time;
        tlp->tl_remote.sin_port = inp->inp_fport;
        tlp->tl_remote.sin_addr.s_addr = inp->inp_faddr.s_addr;
        tlp->tl_local.sin_port = inp->inp_lport;
        tlp->tl_local.sin_addr.s_addr = inp->inp_laddr.s_addr;
#if DO_LOG
        log(LOG_WARNING, "Remote Addr: %x:%d\n", tlp->tl_remote.sin_addr.s_addr,
            tlp->tl_remote.sin_port);
#endif
}
/* Record remote addr, update local - noop*/
int
```

```
tl_accept(struct socket *so, struct sockaddr **m, struct kextcb *kp)
{
        return(0);
}

/* Record local address */
int
tl_bind(struct socket *so, struct mbuf *nam, struct kextcb *kp)
{       register struct inpcb *inp;
        register struct TCPLogEntry *tlp;

        inp = sotoinpcb(so);
        tlp = (struct TCPLogEntry *)kp->e_fcb;
        tlp->tl_local.sin_port = inp->inp_lport;
        tlp->tl_local.sin_addr.s_addr = inp->inp_laddr.s_addr;
#if DO_LOG
        log(LOG_INFO, "Socket %x: bound to  %s:%d\n", so,
            inet_ntoa(tlp->tl_local.sin_addr), inp->inp_lport);
#endif
        return(0);
}

/* Log stats */
int
tl_discon(register struct socket *so, struct kextcb *kp)
{       register struct TCPLogEntry *tlp;
        struct timeval now;
        extern struct timeval time;
#if DO_LOG
        int usec, sec;
#endif

        tlp = (struct TCPLogEntry *)kp->e_fcb;
        now = time;
        tlp->tl_stop = now;
        /* We've gone to all this trouble; we oughta do something with it  */
#if DO_LOG
        sec = now.tv_sec-tlp->tl_start.tv_sec;
        usec = now.tv_usec-tlp->tl_start.tv_usec;
        if (usec < 0)
        {       usec += 100000;
```

```
                sec -= 1;
        }
        log(LOG_INFO, "Socket %x: disconnecting\n", so);
        log(LOG_INFO, "Socket %x: %d.%6d sec duration\n", so, sec, usec);
        log(LOG_INFO, "Socket %x - Payload in: %d pkts, %d bytes\n",
            so, tlp->pkts_in, tlp->bytes_in);
        log(LOG_INFO, "Socket %x - Payload out: %d pkts, %d bytes\n",
            so, tlp->pkts_out, tlp->bytes_out);
        if (tlp->pkts_in_null || tlp->pkts_out_null)
                log(LOG_INFO, "Socket %x - Null payload: %d out, %d in\n",
                    so, tlp->pkts_out_null, tlp->pkts_in_null);
#endif
        TAILQ_REMOVE(&tl_list, tlp, tl_next);
        if (tl_done_count > TCPLOGGER_QMAX)
                TAILQ_REMOVE(&tl_done, tl_done.tqh_first, tl_next);
        else
                tl_done_count++;
        TAILQ_INSERT_TAIL(&tl_done, tlp, tl_next);
        if (ctl)
                tl_dump_backlog(ctl);
        return(0);
}

/* Log stats */
int
tl_shutdown(register struct socket *so, int how, struct kextcb *kp)
{       struct TCPLogEntry *tlp;
        struct timeval now;
        extern struct timeval time;
#if DO_LOG
        int usec, sec;
#endif

        tlp = (struct TCPLogEntry *)kp->e_fcb;
        now = time;
        tlp->tl_stop = now;
#if DO_LOG
        sec = now.tv_sec-tlp->tl_start.tv_sec;
        usec = now.tv_usec-tlp->tl_start.tv_usec;
        if (usec < 0)
        {       usec += 100000;
```

```
                sec -= 1;
        }
        log(LOG_INFO, "Socket %x: Shutting down\n", so);
        log(LOG_INFO, "Socket %x: %d.%6d sec duration\n", so, sec, usec);
        log(LOG_INFO, "Socket %x - Payload in: %d pkts, %d bytes\n", so, tlp->pkts_in,
            tlp->bytes_in);
        log(LOG_INFO, "Socket %x - Payload out: %d pkts, %d bytes\n", so,
            tlp->pkts_out, tlp->bytes_out);
#endif
        return(0);
}

/*
 * Record out count
 * We could do this here or via sbappend override
 * For output, we'll do it here, to avoid thrashing whilst
 *  sosend() makes up its mind what to send...
 */
int
tl_send(struct socket *so, struct mbuf **m, struct uio **uio,
        struct mbuf **nam, struct mbuf **control, int *flags, struct kextcb *kp)
{       register struct TCPLogEntry *tlp;

        tlp = (struct TCPLogEntry *)kp->e_fcb;
        if (m && *m)
        {       tlp->pkts_out++;
                tlp->bytes_out += (*m)->m_pkthdr.len;   /* heh */
        } else if (uio && *uio)
        {       tlp->pkts_out++;
                tlp->bytes_out += (*uio)->uio_resid;    /* heh */
        } else
                tlp->pkts_out_null++;
        return(0);
}

/* Rely on su_sbappend() to record in-count */
int
tl_receive(struct socket *so, struct mbuf **m, struct uio **uio,
           struct mbuf **nam, struct mbuf **control, int *flags,
           struct kextcb *kp)
{
```

```
        /* For now, it's a no-op */
        return(0);
}

/* Record remote addr */
int
tl_connect(struct socket *so, struct sockaddr *nam, struct kextcb *kp)
{       register struct inpcb *inp;
        register struct sockaddr_in *sp = (struct sockaddr_in *)nam;
        register struct TCPLogEntry *tlp;

        inp = sotoinpcb(so);
        tlp = (struct TCPLogEntry *)kp->e_fcb;
        tlp->tl_remote.sin_port = sp->sin_port;
        tlp->tl_remote.sin_addr.s_addr = sp->sin_addr.s_addr;
#if DO_LOG
        log(LOG_INFO, "Socket %x: connecting to  %s:%d\n", so,
            inet_ntoa(tlp->tl_remote.sin_addr), inp->inp_fport);
#endif
        return(0);
}

int tl_free(struct socket *so, struct kextcb *kp)
{
    return(0);
}

/*
 * We have a control (PF_NKE) socket expressing interest.
 */
int tlf_attach(register struct socket *cso)
{       register int error;

        if (ctl)
                return(EISCONN);

        if (cso->so_snd.sb_hiwat == 0 || cso->so_rcv.sb_hiwat == 0) {
                error = soreserve(cso, TL_sendspace, TL_recvspace);
                if (error)
                        return (error);
        }
```

```
        ctl = cso;
        tl_dump_backlog(cso);
        return(0);
}

void
tlf_detach(register struct socket *cso)
{
        if (ctl == cso)
                ctl = NULL;
}

int tlf_get()
{
        return(0);
}

int tlf_read()
{
        return(0);
}

int tlf_set()
{
        return(0);
}

int tlf_write()
{
        return(0);
}

/*
 * Called opportunistically to dump log entries from the 'tl_done'
 *  list to the controlling socket.
 */
void
tl_dump_backlog(struct socket *so)
{       struct mbuf *m;
```

```
struct TCPLogEntry *tlp;
extern int splimp(void);
extern int splx(int);

while ((tlp = tl_done.tqh_first) != NULL)
{       char *p;

                    if (sbspace(&ctl->so_rcv) < sizeof (*tlp))
                            return;
                    MGETHDR(m, M_WAITOK, MT_PCB);
                    if (m == NULL)  /* Huh? */
                            return;
                    tl_done_count--;
                    p = m->m_data;
                    p = (char *)(((int)p+3)&(~0x3));
                    m->m_data = (caddr_t)p;
                    bcopy(tlp, mtod(m, caddr_t), sizeof (*tlp));
                    m->m_len = sizeof (*tlp);
                    m->m_flags |= M_EOR;
                    sbappend(&ctl->so_rcv, m);
                    sorwakeup(ctl);
                    TAILQ_REMOVE(&tl_done, tlp, tl_next);
      _FREE(tlp, M_TEMP);
              }
      }
```

A P P E N D I X   A

Sample Code

Glossary

domain A complete protocol family.

extension A general term for an object module that can be dynamically added to a running system. A synonym for kernel extension.

Data Link Interface Layer (DLIL) The fixed part of the network kernel extension architecture that exists between protocol stacks and the network drivers.

data link interface module A network kernel extension that handles demultiplexing or packet framing.

data link NKE A network kernel extension that exists between the protocol stacks and the device layer.

DLIL interface filter A network kernel extension that is installed between the DLIL and one or more network interfaces.

DLIL protocol filter A network kernel extension that is installed between the DLIL and a network protocol stack.

data link protocol module A network kernel extension that handles the specific interface for the protocol's attachment to a particular interface family.

global NKE An NKE that is automatically enabled for sockets of the type specified for the NKE.

network kernel extension (NKE) 1) The architecture that allows modules to be added to the Mac OS X networking subsystem while the system is running. 2) A module that can be added to a running system.

plug-in A general term for an object module that can be dynamically added to a running system.

programmatic filter NKE An NKE that is enabled only under program control, using socket options, for a specific socket.

protocol family NKE A network kernel extension that implements a domain.

protocol handler A network kernel extension that implements a specific protocol within a domain.

socket NKE A network kernel extension that is installed between the socket layer and the protocol stack or network device layers.

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