Network Working Group
Request for Comments: 2367
Category: Informational

D. McDonald
C. Metz
B. Phan

July 1998

PF_KEY Key Management API, Version 2

Status of this Memo

Copyright Notice

Abstract

A generic key management API that can be used not only for IP Security [Atk95a] [Atk95b] [Atk95c] but also for other network security services is presented in this document. Version 1 of this API was implemented inside 4.4-Lite BSD as part of the U. S. Naval Research Laboratory's freely distributable and usable IPv6 and IPsec implementation[AMPMC96]. It is documented here for the benefit of others who might also adopt and use the API, thus providing increased portability of key management applications (e.g. a manual keying application, an ISAKMP daemon, a GKMP daemon [HM97a][HM97b], a Photuris daemon, or a SKIP certificate discovery protocol daemon).

Table of Contents

1 Introduction

PF_KEY is a new socket protocol family used by trusted privileged key management applications to communicate with an operating system's key management internals (referred to here as the "Key Engine" or the Security Association Database (SADB)). The Key Engine and its structures incorporate the required security attributes for a session and are instances of the "Security Association" (SA) concept described in [Atk95a]. The names PF_KEY and Key Engine thus refer to more than cryptographic keys and are retained for consistency with the traditional phrase, "Key Management".

PF_KEY is derived in part from the BSD routing socket, PF_ROUTE. [Skl91] This document describes Version 2 of PF_KEY. Version 1 was implemented in the first five alpha test versions of the NRL IPv6+IPsec Software Distribution for 4.4-Lite BSD UNIX and the Cisco ISAKMP/Oakley key management daemon. Version 2 extends and refines this interface. Theoretically, the messages defined in this document could be used in a non-socket context (e.g. between two directly communicating user-level processes), but this document will not discuss in detail such possibilities.

Security policy is deliberately omitted from this interface. PF_KEY is not a mechanism for tuning systemwide security policy, nor is it intended to enforce any sort of key management policy. The developers of PF_KEY believe that it is important to separate security mechanisms (such as PF_KEY) from security policies. This permits a single mechanism to more easily support multiple policies.

1.1 Terminology

Even though this document is not intended to be an actual Internet standard, the words that are used to define the significance of particular features of this interface are usually capitalized. Some of these words, including MUST, MAY, and SHOULD, are detailed in [Bra97].

- CONFORMANCE and COMPLIANCE

Conformance to this specification has the same meaning as compliance to this specification. In either case, the mandatory-to-implement, or MUST, items MUST be fully implemented as specified here. If any mandatory item is not implemented as specified here, that implementation is not conforming and not compliant with this specification.

This specification also uses many terms that are commonly used in the context of network security. Other documents provide more definitions and background information on these [VK83, HA94, Atk95a]. Two terms deserve special mention:

- (Encryption/Authentication) Algorithm

For PF_KEY purposes, an algorithm, whether encryption or authentication, is the set of operations performed on a packet to complete authentication or encryption as indicated by the SA type. A PF_KEY algorithm MAY consist of more than one cryptographic algorithm. Another possibility is that the same basic cryptographic algorithm may be applied with different modes of operation or some other implementation difference. These differences, henceforth called _algorithm differentiators_, distinguish between different PF_KEY algorithms, and options to the same algorithm. Algorithm differentiators will often cause fundamentally different security properties.

For example, both DES and 3DES use the same cryptographic algorithm, but they are used differently and have different security properties. The triple-application of DES is considered an algorithm differentiator. There are therefore separate PF_KEY algorithms for DES and 3DES. Keyed-MD5 and HMAC-MD5 use the same hash function, but construct their message authentication codes differently. The use of HMAC is an algorithm differentiator. DES-ECB and DES-CBC are the same cryptographic algorithm, but use a different mode. Mode (e.g., chaining vs. code-book) is an algorithm differentiator. Blowfish with a 128-bit key, however, is similar to Blowfish with a 384-bit key, because the algorithm’s workings are otherwise the same and therefore the key length is not an algorithm differentiator.

In terms of IP Security, a general rule of thumb is that whatever might be labeled the "encryption" part of an ESP transform is probably a PF_KEY encryption algorithm. Whatever might be labelled the "authentication" part of an AH or ESP transform is probably a PF_KEY authentication algorithm.

1.2 Conceptual Model

This section describes the conceptual model of an operating system that implements the PF_KEY key management application programming interface. This section is intended to provide background material useful to understand the rest of this document. Presentation of this conceptual model does not constrain a PF_KEY implementation to strictly adhere to the conceptual components discussed in this subsection.

Key management is most commonly implemented in whole or in part at the application layer. For example, the ISAKMP/Oakley, GKMP, and Photuris proposals for IPsec key management are all application-layer protocols. Manual keying is also done at the application layer. Even parts of the SKIP IP-layer keying proposal can be implemented at the application layer. Figure 1 shows the relationship between a Key Management daemon and PF_KEY. Key management daemons use PF_KEY to communicate with the Key Engine and use PF_INET (or PF_INET6 in the case of IPv6) to communicate, via the network, with a remote key management entity.

The "Key Engine" or "Security Association Database (SADB)" is a logical entity in the kernel that stores, updates, and deletes Security Association data for various security protocols. There are logical interfaces within the kernel (e.g. getassocbyspi(), getassocbysocket()) that security protocols inside the kernel (e.g. IP Security, aka IPsec) use to request and obtain Security Associations.

In the case of IPsec, if by policy a particular outbound packet needs processing, then the IPsec implementation requests an appropriate Security Association from the Key Engine via the kernel-internal interface. If the Key Engine has an appropriate SA, it allocates the SA to this session (marking it as used) and returns the SA to the IPsec implementation for use. If the Key Engine has no such SA but a key management application has previously indicated (via a PF_KEY SADB_REGISTER message) that it can obtain such SAs, then the Key Engine requests that such an SA be created (via a PF_KEY SADB_ACQUIRE message). When the key management daemon creates a new SA, it places it into the Key Engine for future use.

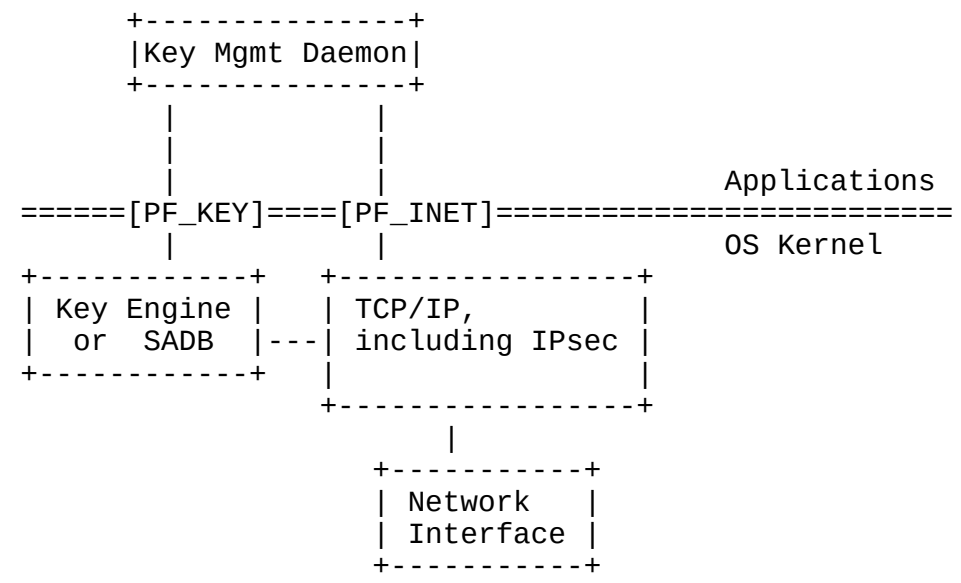


Figure 1: Relationship of Key Mgmt to PF_KEY

For performance reasons, some security protocols (e.g. IP Security) are usually implemented inside the operating system kernel. Other security protocols (e.g. OSPFv2 Cryptographic Authentication) are implemented in trusted privileged applications outside the kernel. Figure 2 shows a trusted, privileged routing daemon using PF_INET to communicate routing information with a remote routing daemon and using PF_KEY to request, obtain, and delete Security Associations used with a routing protocol.

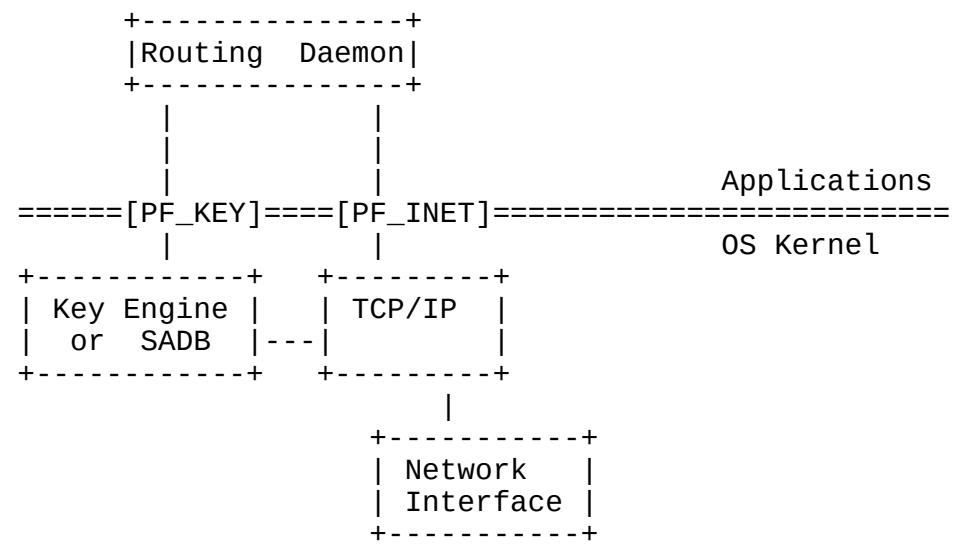


Figure 2: Relationship of Trusted Application to PF_KEY

When a trusted privileged application is using the Key Engine but implements the security protocol within itself, then operation varies slightly. In this case, the application needing an SA sends a PF_KEY SADB_ACQUIRE message down to the Key Engine, which then either returns an error or sends a similar SADB_ACQUIRE message up to one or more key management applications capable of creating such SAs. As before, the key management daemon stores the SA into the Key Engine. Then, the trusted privileged application uses an SADB_GET message to obtain the SA from the Key Engine.

In some implementations, policy may be implemented in user-space, even though the actual cryptographic processing takes place in the kernel. Such policy communication between the kernel mechanisms and the user-space policy MAY be implemented by PF_KEY extensions, or other such mechanism. This document does not specify such extensions. A PF_KEY implementation specified by the memo does NOT have to support configuring systemwide policy using PF_KEY.

Untrusted clients, for example a user’s web browser or telnet client, do not need to use PF_KEY. Mechanisms not specified here are used by such untrusted client applications to request security services (e.g. IPsec) from an operating system. For security reasons, only trusted, privileged applications are permitted to open a PF_KEY socket.

1.3 PF_KEY Socket Definition

The PF_KEY protocol family (PF_KEY) symbol is defined in <sys/socket.h> in the same manner that other protocol families are defined. PF_KEY does not use any socket addresses. Applications using PF_KEY MUST NOT depend on the availability of a symbol named AF_KEY, but kernel implementations are encouraged to define that symbol for completeness.

The key management socket is created as follows:

```
#include <sys/types.h>
#include <sys/socket.h>
#include <net/pfkeyv2.h>

int s;
s = socket(PF_KEY, SOCK_RAW, PF_KEY_V2);
```

The PF_KEY domain currently supports only the SOCK_RAW socket type. The protocol field MUST be set to PF_KEY_V2, or else EPROTONOSUPPORT will be returned. Only a trusted, privileged process can create a PF_KEY socket. On conventional UNIX systems, a privileged process is a process with an effective userid of zero. On non-MLS proprietary operating systems, the notion of a "privileged process" is implementation-defined. On Compartmented Mode Workstations (CMWs) or other systems that claim to provide Multi-Level Security (MLS), a process MUST have the "key management privilege" in order to open a PF_KEY socket[DIA]. MLS systems that don’t currently have such a specific privilege MUST add that special privilege and enforce it with PF_KEY in order to comply and conform with this specification. Some systems, most notably some popular personal computers, do not have the concept of an unprivileged user. These systems SHOULD take steps to restrict the programs allowed to access the PF_KEY API.

1.4 Overview of PF_KEY Messaging Behavior

A process interacts with the key engine by sending and receiving messages using the PF_KEY socket. Security association information can be inserted into and retrieved from the kernel’s security association table using a set of predefined messages. In the normal case, all properly-formed messages sent to the kernel are returned to all open PF_KEY sockets, including the sender. Improperly formed messages will result in errors, and an implementation MUST check for a properly formed message before returning it to the appropriate listeners. Unlike the routing socket, most errors are sent in reply messages, not the errno field when write() or send() fails. PF_KEY message delivery is not guaranteed, especially in cases where kernel or socket buffers are exhausted and messages are dropped.

Some messages are generated by the operating system to indicate that actions need to be taken, and are not necessarily in response to any message sent down by the user. Such messages are not received by all PF_KEY sockets, but by sockets which have indicated that kernel-originated messages are to be received. These messages are special because of the expected frequency at which they will occur. Also, an implementation may further wish to restrict return messages from the kernel, in cases where not all PF_KEY sockets are in the same trust domain.

Many of the normal BSD socket calls have undefined behavior on PF_KEY sockets. These include: bind(), connect(), socketpair(), accept(), getpeername(), getsockname(), ioctl(), and listen().

1.5 Common PF_KEY Operations

There are two basic ways to add a new Security Association into the kernel. The simplest is to send a single SADB_ADD message, containing all of the SA information, from the application into the kernel's Key Engine. This approach works particularly well with manual key management, which is required for IPsec, and other security protocols.

The second approach to add a new Security Association into the kernel is for the application to first request a Security Parameters Index (SPI) value from the kernel using the SADB_GETSPI message and then send an SADB_UPDATE message with the complete Security Association data. This second approach works well with key management daemons when the SPI values need to be known before the entire Security Association data is known (e.g. so the SPI value can be indicated to the remote end of the key management session).

An individual Security Association can be deleted using the SADB_DELETE message. Categories of SAs or the entire kernel SA table can be deleted using the SADB_FLUSH message.

The SADB_GET message is used by a trusted application-layer process (e.g. routed(8) or gated(8)) to retrieve an SA (e.g. RIP SA or OSPF SA) from the kernel's Key Engine.

The kernel or an application-layer can use the SADB_ACQUIRE message to request that a Security Association be created by some application-layer key management process that has registered with the kernel via an SADB_REGISTER message. This ACQUIRE message will have a sequence number associated with it. This sequence number MUST be used by followup SADB_GETSPI, SADB_UPDATE, and SADB_ADD messages, in order to keep track of which request gets its keying material. The sequence number (described below) is similar to a transaction ID in a

remote procedure call.

The SADB_EXPIRE message is sent from the kernel to key management applications when the "soft lifetime" or "hard lifetime" of a Security Association has expired. Key management applications should use receipt of a soft lifetime SADB_EXPIRE message as a hint to negotiate a replacement SA so the replacement SA will be ready and in the kernel before it is needed.

A SADB_DUMP message is also defined, but this is primarily intended for PF_KEY implementor debugging and is not used in ordinary operation of PF_KEY.

1.6 Differences Between PF_KEY and PF_ROUTE

The following bullets are points of difference between the routing socket and PF_KEY. Programmers who are used to the routing socket semantics will find some differences in PF_KEY.

* PF_KEY message errors are usually returned in PF_KEY messages instead of causing write() operations to fail and returning the error number in errno. This means that other listeners on a PF_KEY socket can be aware that requests from another process failed, which can be useful for auditing purposes. This also means that applications that fail to read PF_KEY messages cannot do error checking.

  An implementation MAY return the errors EINVAL, ENOMEM, and ENOBUFS by causing write() operations to fail and returning the error number in errno. This is an optimization for common error cases in which it does not make sense for any other process to receive the error. An application MUST NOT depend on such errors being set by the write() call, but it SHOULD check for such errors, and handle them in an appropriate manner.

* The entire message isn't always reflected in the reply. A SADB_ADD message is an example of this.

* The PID is not set by the kernel. The process that originates the message MUST set the sadb_msg_pid to its own PID. If the kernel ORIGINATES a message, it MUST set the sadb_msg_pid to 0. A reply to an original message SHOULD have the pid of the original message. (E.g. the kernel's response to an SADB_ADD SHOULD have its pid set to the pid value of the original SADB_ADD message.)

1.7 Name Space

All PF_KEYv2 preprocessor symbols and structure definitions are defined as a result of including the header file <net/pfkeyv2.h>. There is exactly one exception to this rule: the symbol "PF_KEY" (two exceptions if "AF_KEY" is also counted), which is defined as a result of including the header file <sys/socket.h>. All PF_KEYv2 preprocessor symbols start with the prefix "SADB_" and all structure names start with "sadb_". There are exactly two exceptions to this rule: the symbol "PF_KEY_V2" and the symbol "PFKEYV2_REVISION".

The symbol "PFKEYV2_REVISION" is a date-encoded value not unlike certain values defined by POSIX and X/Open. The current value for PFKEYV2_REVISION is 199806L, where 1998 is the year and 06 is the month.

Inclusion of the file <net/pfkeyv2.h> MUST NOT define symbols or structures in the PF_KEYv2 name space that are not described in this document without the explicit prior permission of the authors. Any symbols or structures in the PF_KEYv2 name space that are not described in this document MUST start with "SADB_X_" or "sadb_x_". An implementation that fails to obey these rules IS NOT COMPLIANT WITH THIS SPECIFICATION and MUST NOT make any claim to be. These rules also apply to any files that might be included as a result of including the file <net/pfkeyv2.h>. This rule provides implementors with some assurance that they will not encounter namespace-related surprises.

1.8 On Manual Keying

Not unlike the 4.4-Lite BSD PF_ROUTE socket, this interface allows an application full-reign over the security associations in a kernel that implements PF_KEY. A PF_KEY implementation MUST have some sort of manual interface to PF_KEY, which SHOULD allow all of the functionality of the programmatic interface described here.

2. PF_KEY Message Format

PF_KEY messages consist of a base header followed by additional data fields, some of which may be optional. The format of the additional data is dependent on the type of message.

PF_KEY messages currently do not mandate any specific ordering for non-network multi-octet fields. Unless otherwise specified (e.g. SPI values), fields MUST be in host-specific byte order.

2.1 Base Message Header Format

PF_KEY messages consist of the base message header followed by security association specific data whose types and lengths are specified by a generic type-length encoding.

This base header is shown below, using POSIX types. The fields are arranged primarily for alignment, and where possible, for reasons of clarity.

```
struct sadb_msg {
        uint8_t sadb_msg_version;
        uint8_t sadb_msg_type;
        uint8_t sadb_msg_errno;
        uint8_t sadb_msg_satype;
        uint16_t sadb_msg_len;
        uint16_t sadb_msg_reserved;
        uint32_t sadb_msg_seq;
        uint32_t sadb_msg_pid;
};
/* sizeof(struct sadb_msg) == 16 */
```

sadb_msg_version
: The version field of this PF_KEY message. This MUST be set to PF_KEY_V2. If this is not set to PF_KEY_V2, the write() call MAY fail and return EINVAL. Otherwise, the behavior is undetermined, given that the application might not understand the formatting of the messages arriving from the kernel.

sadb_msg_type
: Identifies the type of message. The valid message types are described later in this document.

sadb_msg_errno
: Should be set to zero by the sender. The responder stores the error code in this field if an error has occurred. This includes the case where the responder is in user space. (e.g. user-space negotiation fails, an errno can be returned.)

sadb_msg_satype
: Indicates the type of security association(s). Valid Security Association types are declared in the file <net/pfkeyv2.h>. The current set of Security Association types is enumerated later in this document.

sadb_msg_len Contains the total length, in 64-bit words, of all data in the PF_KEY message including the base header length and additional data after the base header, if any. This length includes any padding or extra space that might exist. Unless otherwise stated, all other length fields are also measured in 64-bit words.

On user to kernel messages, this field MUST be verified against the length of the inbound message. EMSGSIZE MUST be returned if the verification fails. On kernel to user messages, a size mismatch is most likely the result of the user not providing a large enough buffer for the message. In these cases, the user application SHOULD drop the message, but it MAY try and extract what information it can out of the message.

sadb_msg_reserved
Reserved value. It MUST be zeroed by the sender. All fields labeled reserved later in the document have the same semantics as this field.

sadb_msg_seq Contains the sequence number of this message. This field, along with sadb_msg_pid, MUST be used to uniquely identify requests to a process. The sender is responsible for filling in this field. This responsibility also includes matching the sadb_msg_seq of a request (e.g. SADB_ACQUIRE).

This field is similar to a transaction ID in a remote procedure call implementation.

sadb_msg_pid Identifies the process which originated this message, or which process a message is bound for. For example, if process id 2112 sends an SADB_UPDATE message to the kernel, the process MUST set this field to 2112 and the kernel will set this field to 2112 in its reply to that SADB_UPDATE message. This field, along with sadb_msg_seq, can be used to uniquely identify requests to a process.

It is currently assumed that a 32-bit quantity will hold an operating system’s process ID space.

2.2 Alignment of Headers and Extension Headers

The base message header is a multiple of 64 bits and fields after it in memory will be 64 bit aligned if the base itself is 64 bit aligned. Some of the subsequent extension headers have 64 bit fields in them, and as a consequence need to be 64 bit aligned in an environment where 64 bit quantities need to be 64 bit aligned.

The basic unit of alignment and length in PF_KEY Version 2 is 64 bits. Therefore:

* All extension headers, inclusive of the sadb_ext overlay fields, MUST be a multiple of 64 bits long.

* All variable length data MUST be padded appropriately such that its length in a message is a multiple of 64 bits.

* All length fields are, unless otherwise specified, in units of 64 bits.

* Implementations may safely access quantities of between 8 and 64 bits directly within a message without risk of alignment faults.

All PF_KEYv2 structures are packed and already have all intended padding. Implementations MUST NOT insert any extra fields, including hidden padding, into any structure in this document. This forbids implementations from "extending" or "enhancing" existing headers without changing the extension header type. As a guard against such insertion of silent padding, each structure in this document is labeled with its size in bytes. The size of these structures in an implementation MUST match the size listed.

2.3 Additional Message Fields

The additional data following the base header consists of various length-type-values fields. The first 32-bits are of a constant form:

```
struct sadb_ext {
        uint16_t sadb_ext_len;
        uint16_t sadb_ext_type;
};
/* sizeof(struct sadb_ext) == 4 */
```

sadb_ext_len Length of the extension header in 64 bit words, inclusive.

sadb_ext_type The type of extension header that follows. Values for this field are detailed later. The value zero is reserved.

Types of extension headers include: Association, Lifetime(s), Address(s), Key(s), Identity(ies), Sensitivity, Proposal, and Supported. There MUST be only one instance of a extension type in a message. (e.g. Base, Key, Lifetime, Key is forbidden). An EINVAL will be returned if there are duplicate extensions within a message. Implementations MAY enforce ordering of extensions in the order presented in the EXTENSION HEADER VALUES section.

If an unknown extension type is encountered, it MUST be ignored. Applications using extension headers not specified in this document MUST be prepared to work around other system components not processing those headers. Likewise, if an application encounters an unknown extension from the kernel, it must be prepared to work around it. Also, a kernel that generates extra extension header types MUST NOT _depend_ on applications also understanding extra extension header types.

All extension definitions include these two fields (len and exttype) because they are instances of a generic extension (not unlike sockaddr_in and sockaddr_in6 are instances of a generic sockaddr). The sadb_ext header MUST NOT ever be present in a message without at least four bytes of extension header data following it, and, therefore, there is no problem with it being only four bytes long.

All extensions documented in this section MUST be implemented by a PF_KEY implementation.

2.3.1 Association Extension

The Association extension specifies data specific to a single security association. The only times this extension is not present is when control messages (e.g. SADB_FLUSH or SADB_REGISTER) are being passed and on the SADB_ACQUIRE message.

```
struct sadb_sa {
        uint16_t sadb_sa_len;
        uint16_t sadb_sa_exttype;
        uint32_t sadb_sa_spi;
        uint8_t sadb_sa_replay;
        uint8_t sadb_sa_state;
        uint8_t sadb_sa_auth;
        uint8_t sadb_sa_encrypt;
        uint32_t sadb_sa_flags;
};
```

```
        /* sizeof(struct sadb_sa) == 16 */
```

sadb_sa_spi	The Security Parameters Index value for the security association. Although this is a 32-bit field, some types of security associations might have an SPI or key identifier that is less than 32-bits long. In this case, the smaller value shall be stored in the least significant bits of this field and the unneeded bits shall be zero. This field MUST be in network byte order.
sadb_sa_replay	The size of the replay window, if not zero. If zero, then no replay window is in use.
sadb_sa_state	The state of the security association. The currently defined states are described later in this document.
sadb_sa_auth	The authentication algorithm to be used with this security association. The valid authentication algorithms are described later in this document. A value of zero means that no authentication is used for this security association.
sadb_sa_encrypt	The encryption algorithm to be used with this security association. The valid encryption algorithms are described later in this document. A value of zero means that no encryption is used for this security association.
sadb_sa_flags	A bitmap of options defined for the security association. The currently defined flags are described later in this document.

The kernel MUST check these values where appropriate. For example, IPsec AH with no authentication algorithm is probably an error.

When used with some messages, the values in some fields in this header should be ignored.

2.3.2 Lifetime Extension

The Lifetime extension specifies one or more lifetime variants for this security association. If no Lifetime extension is present the association has an infinite lifetime. An association SHOULD have a lifetime of some sort associated with it. Lifetime variants come in three varieties, HARD - indicating the hard-limit expiration, SOFT - indicating the soft-limit expiration, and CURRENT - indicating the current state of a given security association. The Lifetime

extension looks like:

```
        struct sadb_lifetime {
                uint16_t sadb_lifetime_len;
                uint16_t sadb_lifetime_exttype;
                uint32_t sadb_lifetime_allocations;
                uint64_t sadb_lifetime_bytes;
                uint64_t sadb_lifetime_addtime;
                uint64_t sadb_lifetime_usetime;
        };
        /* sizeof(struct sadb_lifetime) == 32 */
```

sadb_lifetime_allocations
: For CURRENT, the number of different connections, endpoints, or flows that the association has been allocated towards. For HARD and SOFT, the number of these the association may be allocated towards before it expires. The concept of a connection, flow, or endpoint is system specific.

sadb_lifetime_bytes
: For CURRENT, how many bytes have been processed using this security association. For HARD and SOFT, the number of bytes that may be processed using this security association before it expires.

sadb_lifetime_addtime
: For CURRENT, the time, in seconds, when the association was created. For HARD and SOFT, the number of seconds after the creation of the association until it expires.

  For such time fields, it is assumed that 64-bits is sufficiently large to hold the POSIX time_t value. If this assumption is wrong, this field will have to be revisited.

sadb_lifetime_usetime
: For CURRENT, the time, in seconds, when association was first used. For HARD and SOFT, the number of seconds after the first use of the association until it expires.

The semantics of lifetimes are inclusive-OR, first-to-expire. This means that if values for bytes and time, or multiple times, are passed in, the first of these values to be reached will cause a lifetime expiration.

2.3.3 Address Extension

The Address extension specifies one or more addresses that are associated with a security association. Address extensions for both source and destination MUST be present when an Association extension is present. The format of an Address extension is:

```
struct sadb_address {
        uint16_t sadb_address_len;
        uint16_t sadb_address_exttype;
        uint8_t sadb_address_proto;
        uint8_t sadb_address_prefixlen;
        uint16_t sadb_address_reserved;
};
/* sizeof(struct sadb_address) == 8 */

/* followed by some form of struct sockaddr */
```

The sockaddr structure SHOULD conform to the sockaddr structure of the system implementing PF_KEY. If the system has an sa_len field, so SHOULD the sockaddrs in the message. If the system has NO sa_len field, the sockaddrs SHOULD NOT have an sa_len field. All non-address information in the sockaddrs, such as sin_zero for AF_INET sockaddrs, and sin6_flowinfo for AF_INET6 sockaddrs, MUST be zeroed out. The zeroing of ports (e.g. sin_port and sin6_port) MUST be done for all messages except for originating SADB_ACQUIRE messages, which SHOULD fill them in with ports from the relevant TCP or UDP session which generates the ACQUIRE message. If the ports are non-zero, then the sadb_address_proto field, normally zero, MUST be filled in with the transport protocol's number. If the sadb_address_prefixlen is non-zero, then the address has a prefix (often used in KM access control decisions), with length specified in sadb_address_prefixlen. These additional fields may be useful to KM applications.

The SRC and DST addresses for a security association MUST be in the same protocol family and MUST always be present or absent together in a message. The PROXY address MAY be in a different protocol family, and for most security protocols, represents an actual originator of a packet. (For example, the inner-packets's source address in a tunnel.)

The SRC address MUST be a unicast or unspecified (e.g., INADDR_ANY) address. The DST address can be any valid destination address (unicast, multicast, or even broadcast). The PROXY address SHOULD be a unicast address (there are experimental security protocols where PROXY semantics may be different than described above).

2.3.4 Key Extension

The Key extension specifies one or more keys that are associated with a security association. A Key extension will not always be present with messages, because of security risks. The format of a Key extension is:

```
struct sadb_key {
        uint16_t sadb_key_len;
        uint16_t sadb_key_exttype;
        uint16_t sadb_key_bits;
        uint16_t sadb_key_reserved;
};
/* sizeof(struct sadb_key) == 8 */

/* followed by the key data */
```

sadb_key_bits The length of the valid key data, in bits. A value of zero in sadb_key_bits MUST cause an error.

The key extension comes in two varieties. The AUTH version is used with authentication keys (e.g. IPsec AH, OSPF MD5) and the ENCRYPT version is used with encryption keys (e.g. IPsec ESP). PF_KEY deals only with fully formed cryptographic keys, not with "raw key material". For example, when ISAKMP/Oakley is in use, the key management daemon is always responsible for transforming the result of the Diffie-Hellman computation into distinct fully formed keys PRIOR to sending those keys into the kernel via PF_KEY. This rule is made because PF_KEY is designed to support multiple security protocols (not just IP Security) and also multiple key management schemes including manual keying, which does not have the concept of "raw key material". A clean, protocol-independent interface is important for portability to different operating systems as well as for portability to different security protocols.

If an algorithm defines its key to include parity bits (e.g. DES) then the key used with PF_KEY MUST also include those parity bits. For example, this means that a single DES key is always a 64-bit quantity.

When a particular security protocol only requires one authentication and/or one encryption key, the fully formed key is transmitted using the appropriate key extension. When a particular security protocol requires more than one key for the same function (e.g. Triple-DES using 2 or 3 keys, and asymmetric algorithms), then those two fully formed keys MUST be concatenated together in the order used for outbound packet processing. In the case of multiple keys, the algorithm MUST be able to determine the lengths of the individual

keys based on the information provided. The total key length (when combined with knowledge of the algorithm in use) usually provides sufficient information to make this determination.

Keys are always passed through the PF_KEY interface in the order that they are used for outbound packet processing. For inbound processing, the correct order that keys are used might be different from this canonical concatenation order used with the PF_KEY interface. It is the responsibility of the implementation to use the keys in the correct order for both inbound and outbound processing.

For example, consider a pair of nodes communicating unicast using an ESP three-key Triple-DES Security Association. Both the outbound SA on the sender node, and the inbound SA on the receiver node will contain key-A, followed by key-B, followed by key-C in their respective ENCRYPT key extensions. The outbound SA will use key-A first, followed by key-B, then key-C when encrypting. The inbound SA will use key-C, followed by key-B, then key-A when decrypting. (NOTE: We are aware that 3DES is actually encrypt-decrypt-encrypt.) The canonical ordering of key-A, key-B, key-C is used for 3DES, and should be documented. The order of "encryption" is the canonical order for this example. [Sch96]

The key data bits are arranged most-significant to least significant. For example, a 22-bit key would take up three octets, with the least significant two bits not containing key material. Five additional octets would then be used for padding to the next 64-bit boundary.

While not directly related to PF_KEY, there is a user interface issue regarding odd-digit hexadecimal representation of keys. Consider the example of the 16-bit number:

```
0x123
```

That will require two octets of storage. In the absence of other information, however, unclear whether the value shown is stored as:

```
01 23          OR          12 30
```

It is the opinion of the authors that the former (0x123 == 0x0123) is the better way to interpret this ambiguity. Extra information (for example, specifying 0x0123 or 0x1230, or specifying that this is only a twelve-bit number) would solve this problem.

2.3.5 Identity Extension

The Identity extension contains endpoint identities. This information is used by key management to select the identity certificate that is used in negotiations. This information may also be provided by a kernel to network security aware applications to identify the remote entity, possibly for access control purposes. If this extension is not present, key management MUST assume that the addresses in the Address extension are the only identities for this Security Association. The Identity extension looks like:

```
struct sadb_ident {
        uint16_t sadb_ident_len;
        uint16_t sadb_ident_exttype;
        uint16_t sadb_ident_type;
        uint16_t sadb_ident_reserved;
        uint64_t sadb_ident_id;
};
/* sizeof(struct sadb_ident) == 16 */

/* followed by the identity string, if present */
```

sadb_ident_type The type of identity information that follows. Currently defined identity types are described later in this document.

sadb_ident_id An identifier used to aid in the construction of an identity string if none is present. A POSIX user id value is one such identifier that will be used in this field. Use of this field is described later in this document.

A C string containing a textual representation of the identity information optionally follows the sadb_ident extension. The format of this string is determined by the value in sadb_ident_type, and is described later in this document.

2.3.6 Sensitivity Extension

The Sensitivity extension contains security labeling information for a security association. If this extension is not present, no sensitivity-related data can be obtained from this security association. If this extension is present, then the need for explicit security labeling on the packet is obviated.

```
struct sadb_sens {
        uint16_t sadb_sens_len;
        uint16_t sadb_sens_exttype;
```

```
                uint32_t sadb_sens_dpd;
                uint8_t sadb_sens_sens_level;
                uint8_t sadb_sens_sens_len;
                uint8_t sadb_sens_integ_level;
                uint8_t sadb_sens_integ_len;
                uint32_t sadb_sens_reserved;
        };
        /* sizeof(struct sadb_sens) == 16 */

        /* followed by:
                uint64_t sadb_sens_bitmap[sens_len];
                uint64_t sadb_integ_bitmap[integ_len]; */
```

sadb_sens_dpd Describes the protection domain, which allows interpretation of the levels and compartment bitmaps.

sadb_sens_sens_level
The sensitivity level.

sadb_sens_sens_len
The length, in 64 bit words, of the sensitivity bitmap.

sadb_sens_integ_level
The integrity level.

sadb_sens_integ_len
The length, in 64 bit words, of the integrity bitmap.

This sensitivity extension is designed to support the Bell-LaPadula [BL74] security model used in compartmented-mode or multi-level secure systems, the Clark-Wilson [CW87] commercial security model, and/or the Biba integrity model [Biba77]. These formal models can be used to implement a wide variety of security policies. The definition of a particular security policy is outside the scope of this document. Each of the bitmaps MUST be padded to a 64-bit boundary if they are not implicitly 64-bit aligned.

2.3.7 Proposal Extension

The Proposal extension contains a "proposed situation" of algorithm preferences. It looks like:

```
        struct sadb_prop {
                uint16_t sadb_prop_len;
                uint16_t sadb_prop_exttype;
                uint8_t sadb_prop_replay;
                uint8_t sadb_prop_reserved[3];
        };
        /* sizeof(struct sadb_prop) == 8 */
```

```
        /* followed by:
           struct sadb_comb sadb_combs[(sadb_prop_len *
               sizeof(uint64_t) - sizeof(struct sadb_prop)) /
               sizeof(struct sadb_comb)]; */
```

Following the header is a list of proposed parameter combinations in preferential order. The values in these fields have the same definition as the fields those values will move into if the combination is chosen.

NOTE: Some algorithms in some security protocols will have variable IV lengths per algorithm. Variable length IVs are not supported by PF_KEY v2. If they were, however, proposed IV lengths would go in the Proposal Extension.

These combinations look like:

```
        struct sadb_comb {
                uint8_t sadb_comb_auth;
                uint8_t sadb_comb_encrypt;
                uint16_t sadb_comb_flags;
                uint16_t sadb_comb_auth_minbits;
                uint16_t sadb_comb_auth_maxbits;
                uint16_t sadb_comb_encrypt_minbits;
                uint16_t sadb_comb_encrypt_maxbits;
                uint32_t sadb_comb_reserved;
                uint32_t sadb_comb_soft_allocations;
                uint32_t sadb_comb_hard_allocations;
                uint64_t sadb_comb_soft_bytes;
                uint64_t sadb_comb_hard_bytes;
                uint64_t sadb_comb_soft_addtime;
                uint64_t sadb_comb_hard_addtime;
                uint64_t sadb_comb_soft_usetime;
                uint64_t sadb_comb_hard_usetime;
        };

        /* sizeof(struct sadb_comb) == 72 */
```

sadb_comb_auth If this combination is accepted, this will be the value of sadb_sa_auth.

sadb_comb_encrypt
If this combination is accepted, this will be the value of sadb_sa_encrypt.

sadb_comb_auth_minbits;
sadb_comb_auth_maxbits;
: The minimum and maximum acceptable authentication key lengths, respectably, in bits. If sadb_comb_auth is zero, both of these values MUST be zero. If sadb_comb_auth is nonzero, both of these values MUST be nonzero. If this combination is accepted, a value between these (inclusive) will be stored in the sadb_key_bits field of KEY_AUTH. The minimum MUST NOT be greater than the maximum.

sadb_comb_encrypt_minbits;
sadb_comb_encrypt_maxbits;
: The minimum and maximum acceptable encryption key lengths, respectably, in bits. If sadb_comb_encrypt is zero, both of these values MUST be zero. If sadb_comb_encrypt is nonzero, both of these values MUST be nonzero. If this combination is accepted, a value between these (inclusive) will be stored in the sadb_key_bits field of KEY_ENCRYPT. The minimum MUST NOT be greater than the maximum.

sadb_comb_soft_allocations
sadb_comb_hard_allocations
: If this combination is accepted, these are proposed values of sadb_lifetime_allocations in the SOFT and HARD lifetimes, respectively.

sadb_comb_soft_bytes
sadb_comb_hard_bytes
: If this combination is accepted, these are proposed values of sadb_lifetime_bytes in the SOFT and HARD lifetimes, respectively.

sadb_comb_soft_addtime
sadb_comb_hard_addtime
: If this combination is accepted, these are proposed values of sadb_lifetime_addtime in the SOFT and HARD lifetimes, respectively.

sadb_comb_soft_usetime
sadb_comb_hard_usetime
: If this combination is accepted, these are proposed values of sadb_lifetime_usetime in the SOFT and HARD lifetimes, respectively.

Each combination has an authentication and encryption algorithm, which may be 0, indicating none. A combination's flags are the same as the flags in the Association extension. The minimum and maximum key lengths (which are in bits) are derived from possible a priori policy decisions, along with basic properties of the algorithm. Lifetime attributes are also included in a combination, as some algorithms may know something about their lifetimes and can suggest lifetime limits.

2.3.8 Supported Algorithms Extension

The Supported Algorithms extension contains a list of all algorithms supported by the system. This tells key management what algorithms it can negotiate. Available authentication algorithms are listed in the SUPPORTED_AUTH extension and available encryption algorithms are listed in the SUPPORTED_ENCRYPT extension. The format of these extensions is:

```
struct sadb_supported {
        uint16_t sadb_supported_len;
        uint16_t sadb_supported_exttype;
        uint32_t sadb_supported_reserved;
};
/* sizeof(struct sadb_supported) == 8 */

/* followed by:
   struct sadb_alg sadb_algs[(sadb_supported_len *
       sizeof(uint64_t) - sizeof(struct sadb_supported)) /
       sizeof(struct sadb_alg)]; */
```

This header is followed by one or more algorithm descriptions. An algorithm description looks like:

```
struct sadb_alg {
        uint8_t sadb_alg_id;
        uint8_t sadb_alg_ivlen;
        uint16_t sadb_alg_minbits;
        uint16_t sadb_alg_maxbits;
        uint16_t sadb_alg_reserved;
};
/* sizeof(struct sadb_alg) == 8 */
```

sadb_alg_id The algorithm identification value for this algorithm. This is the value that is stored in sadb_sa_auth or sadb_sa_encrypt if this algorithm is selected.

sadb_alg_ivlen The length of the initialization vector to be used for the algorithm. If an IV is not needed, this value MUST be set to zero.

sadb_alg_minbits
The minimum acceptable key length, in bits. A value of zero is invalid.

sadb_alg_maxbits
The maximum acceptable key length, in bits. A value of zero is invalid. The minimum MUST NOT be greater than the maximum.

2.3.9 SPI Range Extension

One PF_KEY message, SADB_GETSPI, might need a range of acceptable SPI values. This extension performs such a function.

```
struct sadb_spirange {
        uint16_t sadb_spirange_len;
        uint16_t sadb_spirange_exttype;
        uint32_t sadb_spirange_min;
        uint32_t sadb_spirange_max;
        uint32_t sadb_spirange_reserved;
};
/* sizeof(struct sadb_spirange) == 16 */
```

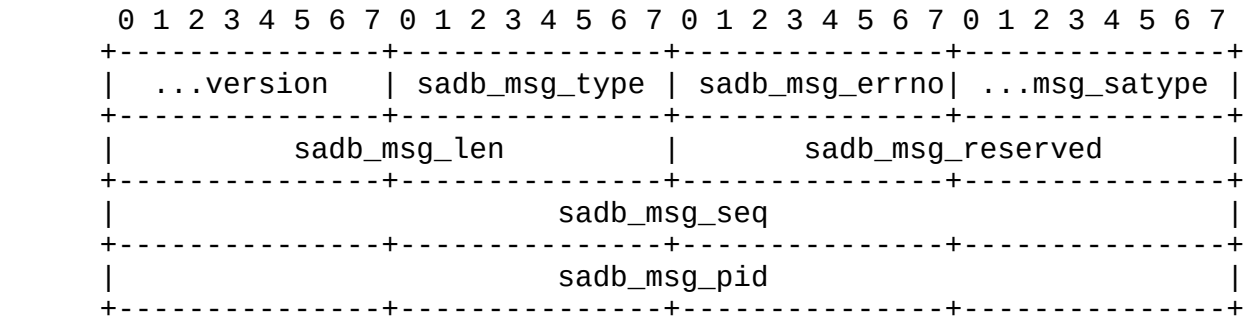
sadb_spirange_min
The minimum acceptable SPI value.

sadb_spirange_max
The maximum acceptable SPI value. The maximum MUST be greater than or equal to the minimum.

2.4 Illustration of Message Layout

The following shows how the octets are laid out in a PF_KEY message. Optional fields are indicated as such.

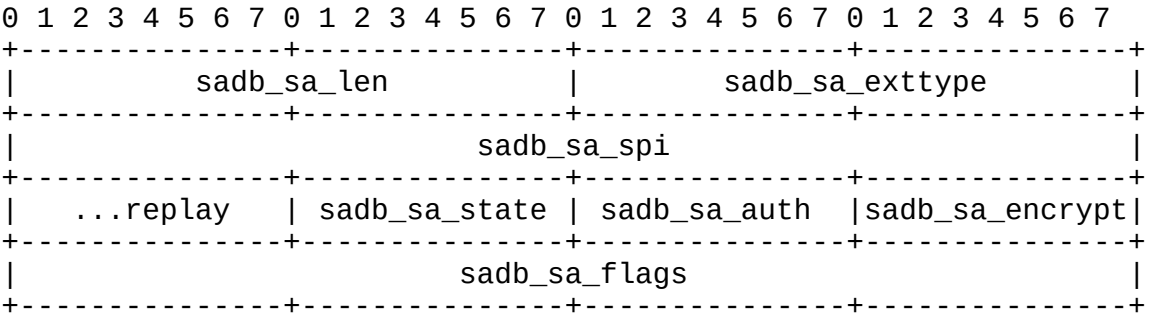
The base header is as follows:



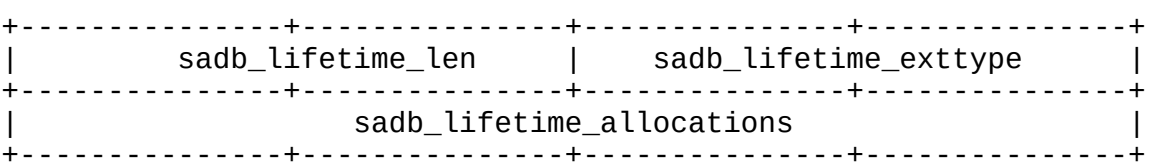
The base header may be followed by one or more of the following extension fields, depending on the values of various base header fields. The following fields are ordered such that if they appear, they SHOULD appear in the order presented below.

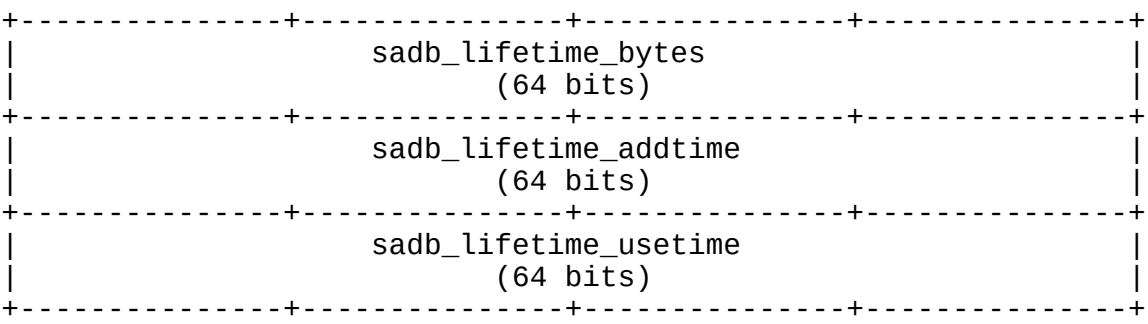
An extension field MUST not be repeated. If there is a situation where an extension MUST be repeated, it should be brought to the attention of the authors.

The Association extension

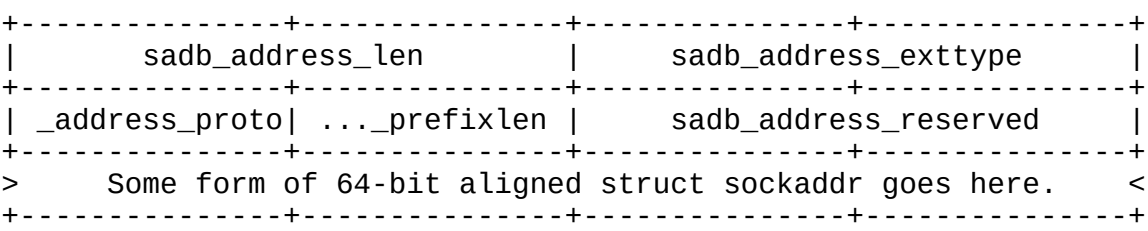


The Lifetime extension

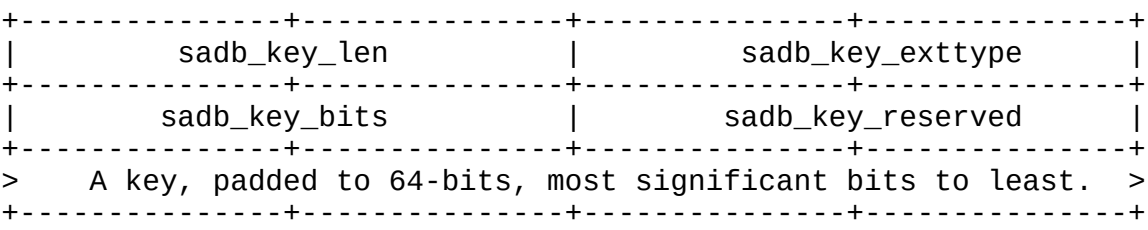




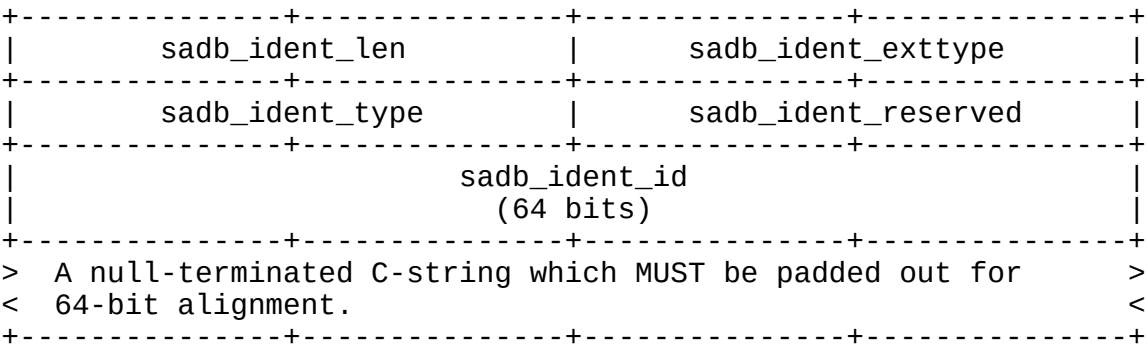
The Address extension



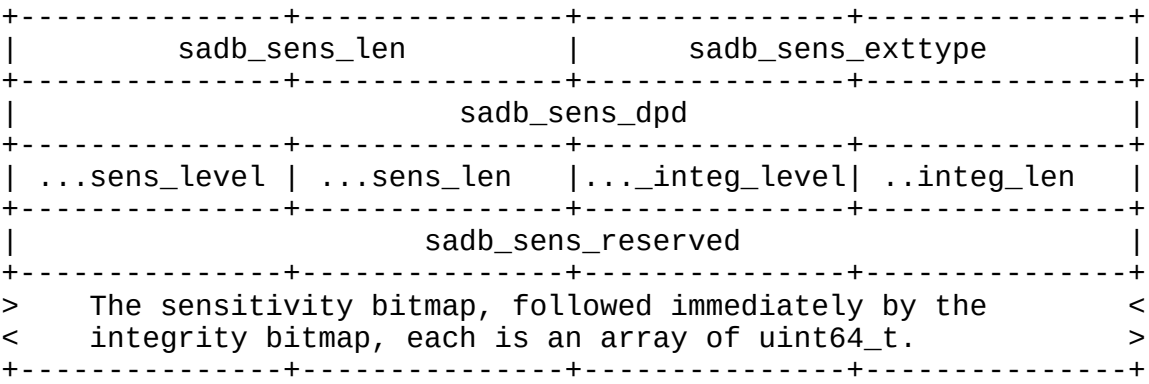
The Key extension



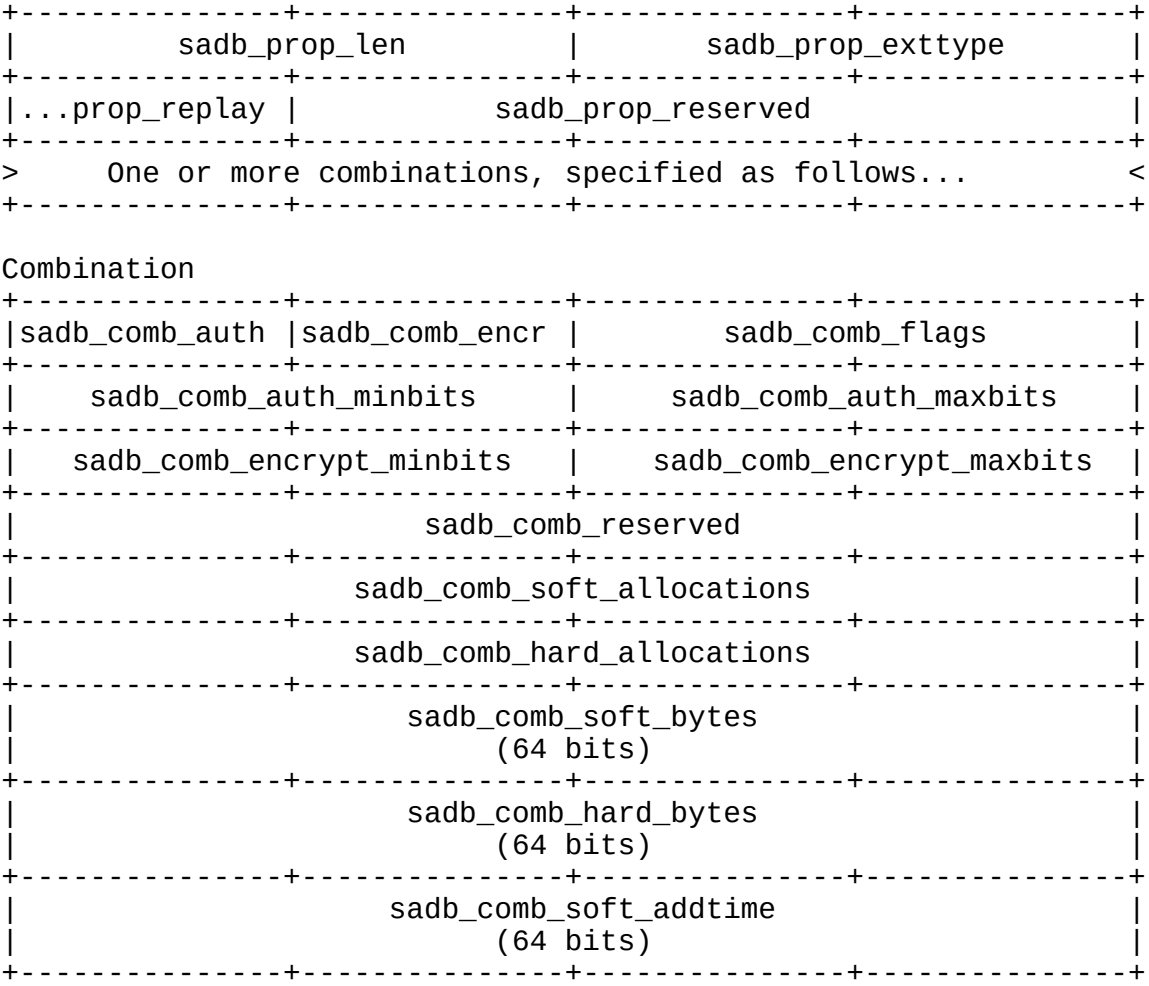
The Identity extension

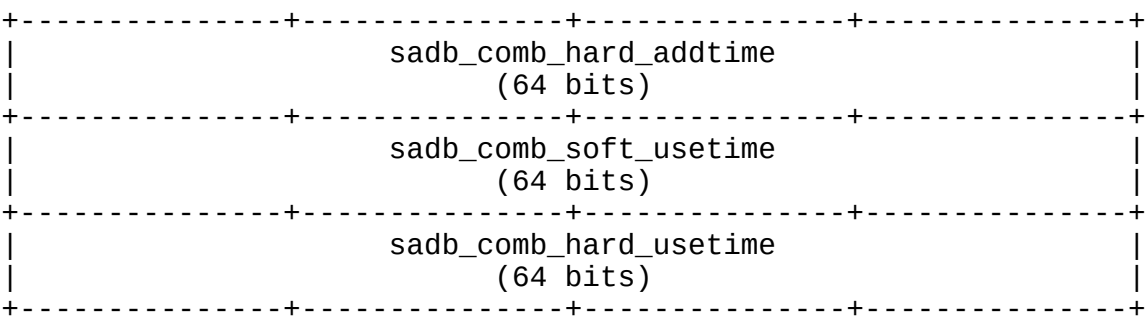


The Sensitivity extension

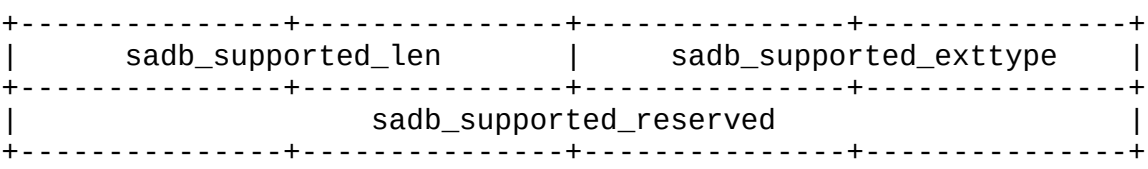


The Proposal extension

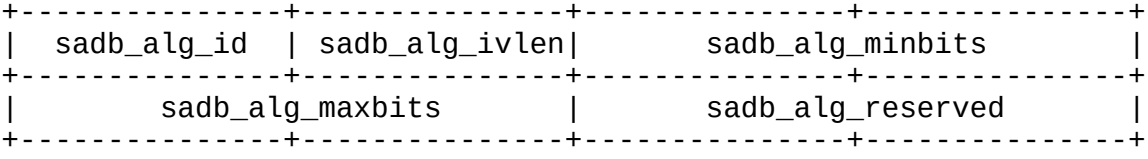




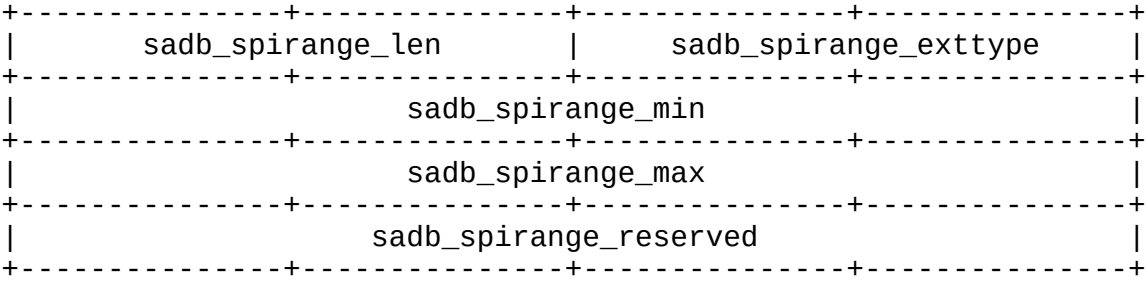
The Supported Algorithms extension



Followed by one or more Algorithm Descriptors



The SPI Range extension



3 Symbolic Names

This section defines various symbols used with PF_KEY and the semantics associated with each symbol. Applications MUST use the symbolic names in order to be portable. The numeric definitions shown are for illustrative purposes, unless explicitly stated otherwise. The numeric definition MAY vary on other systems. The symbolic name MUST be kept the same for all conforming implementations.

3.1 Message Types

The following message types are used with PF_KEY. These are defined in the file <net/pfkeyv2.h>.

```
#define SADB_RESERVED    0
#define SADB_GETSPI      1
#define SADB_UPDATE      2
#define SADB_ADD         3
#define SADB_DELETE      4
#define SADB_GET         5
#define SADB_ACQUIRE     6
#define SADB_REGISTER    7
#define SADB_EXPIRE      8
#define SADB_FLUSH       9

#define SADB_DUMP        10   /* not used normally */

#define SADB_MAX         10
```

Each message has a behavior. A behavior is defined as where the initial message travels (e.g. user to kernel), and what subsequent actions are expected to take place. Contents of messages are illustrated as:

<base, REQUIRED EXTENSION, REQ., (OPTIONAL EXT.,) (OPT)>

The SA extension is sometimes used only for its SPI field. If all other fields MUST be ignored, this is represented by "SA(*)".

The lifetime extensions are represented with one to three letters after the word "lifetime," representing (H)ARD, (S)OFT, and (C)URRENT.

The address extensions are represented with one to three letters after the word "address," representing (S)RC, (D)ST, (P)ROXY.

NOTE: Some security association types do not use a source address for SA identification, where others do. This may cause EEXIST errors for some SA types where others do not report collisions. It is expected that application authors know enough about the underlying security association types to understand these differences.

The key extensions are represented with one or two letters after the word "key," representing (A)UTH and (E)NCRYPT.

The identity extensions are represented with one or two letters after the word "identity," representing (S)RC and (D)ST.

In the case of an error, only the base header is returned.

Note that any standard error could be returned for any message.

Typically, they will be either one of the errors specifically listed in the description for a message or one of the following:

EINVAL	Various message improprieties, including SPI ranges that are malformed.
ENOMEM	Needed memory was not available.
ENOBUFS	Needed memory was not available.
EMSGSIZ	The message exceeds the maximum length allowed.

3.1.1 SADB_GETSPI

The SADB_GETSPI message allows a process to obtain a unique SPI value for given security association type, source address, and destination address. This message followed by an SADB_UPDATE is one way to create a security association (SADB_ADD is the other method). The process specifies the type in the base header, the source and destination address in address extension. If the SADB_GETSPI message is in response to a kernel-generated SADB_ACQUIRE, the sadb_msg_seq MUST be the same as the SADB_ACQUIRE message. The application may also specify the SPI. This is done by having the kernel select within a range of SPI values by using the SPI range extension. To specify a single SPI value to be verified, the application sets the high and low values to be equal. Permitting range specification is important because the kernel can allocate an SPI value based on what it knows about SPI values already in use. The kernel returns the same message with the allocated SPI value stored in the spi field of an association extension. The allocate SPI (and destination address) refer to a LARVAL security association. An SADB_UPDATE message can later be used to add an entry with the requested SPI value.

It is recommended that associations that are created with SADB_GETSPI SHOULD be automatically deleted within a fixed amount of time if they are not updated by an SADB_UPDATE message. This allows SA storage not to get cluttered with larval associations.

The message behavior of the SADB_GETSPI message is:

Send an SADB_GETSPI message from a user process to the kernel.

<base, address, SPI range>

The kernel returns the SADB_GETSPI message to all listening processes.

<base, SA(*), address(SD)>

Errors:

EEXIST Requested SPI or SPI range is not available or already used.

3.1.2 SADB_UPDATE Message

The SADB_UPDATE message allows a process to update the information in an existing Security Association. Since SADB_GETSPI does not allow setting of certain parameters, this message is needed to fully form the SADB_SASTATE_LARVAL security association created with SADB_GETSPI. The format of the update message is a base header, followed by an association header and possibly by several extension headers. The kernel searches for the security association with the same type, spi, source address and destination address specified in the message and updates the Security Association information using the content of the SADB_UPDATE message.

The kernel MAY disallow SADB_UPDATE to succeed unless the message is issued from the same socket that created the security association. Such enforcement significantly reduces the chance of accidental changes to an in-use security association. Malicious trusted parties could still issue an SADB_FLUSH or SADB_DELETE message, but deletion of associations is more easily detected and less likely to occur accidentally than an erroneous SADB_UPDATE. The counter argument to supporting this behavior involves the case where a user-space key management application fails and is restarted. The new instance of the application will not have the same socket as the creator of the security association.

The kernel MUST sanity check all significant values submitted in an SADB_UPDATE message before changing the SA in its database and MUST return EINVAL if any of the values are invalid. Examples of checks that should be performed are DES key parity bits, key length checking, checks for keys known to be weak for the specified algorithm, and checks for flags or parameters known to be incompatible with the specified algorithm.

Only SADB_SASTATE_MATURE SAs may be submitted in an SADB_UPDATE message. If the original SA is an SADB_SASTATE_LARVAL SA, then any value in the SA may be changed except for the source address, destination address, and SPI. If the original SA is an SADB_SASTATE_DEAD SA, any attempt to perform an SADB_UPDATE on the SA

MUST return EINVAL. It is not valid for established keying or algorithm information to change without the SPI changing, which would require creation of a new SA rather than a change to an existing SA. Once keying and algorithm information is negotiated, address and identity information is fixed for the SA. Therefore, if the original SA is an SADB_SASTATE_MATURE or DYING SA, only the sadb_sa_state field in the SA header and lifetimes (hard, soft, and current) may be changed and any attempt to change other values MUST result in an error return of EINVAL.

The message behavior of the SADB_UPDATE message is:

Send an SADB_UPDATE message from a user process to the kernel.

<base, SA, (lifetime(HSC),) address(SD), (address(P),) key(AE), (identity(SD),) (sensitivity)>

The kernel returns the SADB_UPDATE message to all listening processes.

<base, SA, (lifetime(HSC),) address(SD), (address(P),) (identity(SD),) (sensitivity)>

The keying material is not returned on the message from the kernel to listening sockets because listeners might not have the privileges to see such keying material.

Errors:

ESRCH	The security association to be updated was not found.
EINVAL	In addition to other possible causes, this error is returned if sanity checking on the SA values (such as the keys) fails.
EACCES	Insufficient privilege to update entry. The socket issuing the SADB_UPDATE is not creator of the entry to be updated.

3.1.3 SADB_ADD

The SADB_ADD message is nearly identical to the SADB_UPDATE message, except that it does not require a previous call to SADB_GETSPI. The SADB_ADD message is used in manual keying applications, and in other cases where the uniqueness of the SPI is known immediately.

An SADB_ADD message is also used when negotiation is finished, and the second of a pair of associations is added. The SPI for this association was determined by the peer machine. The sadb_msg_seq

MUST be set to the value set in a kernel-generated SADB_ACQUIRE so that both associations in a pair are bound to the same ACQUIRE request.

The kernel MUST sanity check all used fields in the SA submitted in an SADB_ADD message before adding the SA to its database and MUST return EINVAL if any of the values are invalid.

Only SADB_SASTATE_MATURE SAs may be submitted in an SADB_ADD message. SADB_SASTATE_LARVAL SAs are created by SADB_GETSPI and it is not sensible to add a new SA in the DYING or SADB_SASTATE_DEAD state. Therefore, the sadb_sa_state field of all submitted SAs MUST be SADB_SASTATE_MATURE and the kernel MUST return an error if this is not true.

The message behavior of the SADB_ADD message is:

Send an SADB_ADD message from a user process to the kernel.

<base, SA, (lifetime(HS),) address(SD), (address(P),)
key(AE), (identity(SD),) (sensitivity)>

The kernel returns the SADB_ADD message to all listening processes.

<base, SA, (lifetime(HS),) address(SD), (identity(SD),)
(sensitivity)>

The keying material is not returned on the message from the kernel to listening sockets because listeners may not have the privileges to see such keying material.

Errors:

EEXIST The security association that was to be added already exists.
EINVAL In addition to other possible causes, this error is returned if sanity checking on the SA values (such as the keys) fails.

3.1.4 SADB_DELETE

The SADB_DELETE message causes the kernel to delete a Security Association from the key table. The delete message consists of the base header followed by the association, and the source and destination sockaddrs in the address extension. The kernel deletes the security association matching the type, spi, source address, and destination address in the message.

The message behavior for SADB_DELETE is as follows:

Send an SADB_DELETE message from a user process to the kernel.

<base, SA(*), address(SD)>

The kernel returns the SADB_DELETE message to all listening processes.

<base, SA(*), address(SD)>

3.1.5 SADB_GET

The SADB_GET message allows a process to retrieve a copy of a Security Association from the kernel's key table. The get message consists of the base header follows by the relevant extension fields. The Security Association matching the type, spi, source address, and destination address is returned.

The message behavior of the SADB_GET message is:

Send an SADB_GET message from a user process to the kernel.

<base, SA(*), address(SD)>

The kernel returns the SADB_GET message to the socket that sent the SADB_GET message.

<base, SA, (lifetime(HSC),) address(SD), (address(P),) key(AE), (identity(SD),) (sensitivity)>

Errors:

ESRCH The sought security association was not found.

3.1.6 SADB_ACQUIRE

The SADB_ACQUIRE message is typically sent only by the kernel to key socket listeners who have registered their key socket (see SADB_REGISTER message). SADB_ACQUIRE messages can be sent by application-level consumers of security associations (such as an OSPFv2 implementation that uses OSPF security). The SADB_ACQUIRE message is a base header along with an address extension, possibly an identity extension, and a proposal extension. The proposed situation contains a list of desirable algorithms that can be used if the algorithms in the base header are not available. The values for the fields in the base header and in the security association data which follows the base header indicate the properties of the Security Association that the listening process should attempt to acquire. If

the message originates from the kernel (i.e. the sadb_msg_pid is 0), the sadb_msg_seq number MUST be used by a subsequent SADB_GETSPI and SADB_UPDATE, or subsequent SADB_ADD message to bind a security association to the request. This avoids the race condition of two TCP connections between two IP hosts that each require unique associations, and having one steal another's security association. The sadb_msg_errno and sadb_msg_state fields should be ignored by the listening process.

The SADB_ACQUIRE message is typically triggered by an outbound packet that needs security but for which there is no applicable Security Association existing in the key table. If the packet can be sufficiently protected by more than one algorithm or combination of options, the SADB_ACQUIRE message MUST order the preference of possibilities in the Proposal extension.

There are three messaging behaviors for SADB_ACQUIRE. The first is where the kernel needs a security association (e.g. for IPsec).

The kernel sends an SADB_ACQUIRE message to registered sockets.

<base, address(SD), (address(P)), (identity(SD),) (sensitivity,) proposal>

NOTE: The address(SD) extensions MUST have the port fields filled in with the port numbers of the session requiring keys if appropriate.

The second is when, for some reason, key management fails, it can send an ACQUIRE message with the same sadb_msg_seq as the initial ACQUIRE with a non-zero errno.

Send an SADB_ACQUIRE to indicate key management failure.

<base>

The third is where an application-layer consumer of security associations (e.g. an OSPFv2 or RIPv2 daemon) needs a security association.

Send an SADB_ACQUIRE message from a user process to the kernel.

<base, address(SD), (address(P),) (identity(SD),) (sensitivity,) proposal>

The kernel returns an SADB_ACQUIRE message to registered sockets.

<base, address(SD), (address(P),) (identity(SD),) (sensitivity,)
proposal>

The user-level consumer waits for an SADB_UPDATE or SADB_ADD message for its particular type, and then can use that association by using SADB_GET messages.

Errors:
EINVAL Invalid acquire request.
EPROTONOSUPPORT No KM application has registered with the Key Engine as being able to obtain the requested SA type, so the requested SA cannot be acquired.

3.1.7 SADB_REGISTER

The SADB_REGISTER message allows an application to register its key socket as able to acquire new security associations for the kernel. SADB_REGISTER allows a socket to receive SADB_ACQUIRE messages for the type of security association specified in sadb_msg_satype. The application specifies the type of security association that it can acquire for the kernel in the type field of its register message. If an application can acquire multiple types of security association, it MUST register each type in a separate message. Only the base header is needed for the register message. Key management applications MAY register for a type not known to the kernel, because the consumer may be in user-space (e.g. OSPFv2 security).

The reply of the SADB_REGISTER message contains a supported algorithm extension. That field contains an array of supported algorithms, one per octet. This allows key management applications to know what algorithm are supported by the kernel.

In an environment where algorithms can be dynamically loaded and unloaded, an asynchronous SADB_REGISTER reply MAY be generated. The list of supported algorithms MUST be a complete list, so the application can make note of omissions or additions.

The messaging behavior of the SADB_REGISTER message is:

Send an SADB_REGISTER message from a user process to the kernel.

<base>

The kernel returns an SADB_REGISTER message to registered sockets, with algorithm types supported by the kernel being indicated in the supported algorithms field.

NOTE: This message may arrive asynchronously due to an algorithm being loaded or unloaded into a dynamically linked kernel.

<base, supported>

3.1.8 SADB_EXPIRE Message

The operating system kernel is responsible for tracking SA expirations for security protocols that are implemented inside the kernel. If the soft limit or hard limit of a Security Association has expired for a security protocol implemented inside the kernel, then the kernel MUST issue an SADB_EXPIRE message to all key socket listeners. If the soft limit or hard limit of a Security Association for a user-level security protocol has expired, the user-level protocol SHOULD issue an SADB_EXPIRE message.

The base header will contain the security association information followed by the source sockaddr, destination sockaddr, (and, if present, internal sockaddr,) (and, if present, one or both compartment bitmaps).

The lifetime extension of an SADB_EXPIRE message is important to indicate which lifetime expired. If a HARD lifetime extension is included, it indicates that the HARD lifetime expired. This means the association MAY be deleted already from the SADB. If a SOFT lifetime extension is included, it indicates that the SOFT lifetime expired. The CURRENT lifetime extension will indicate the current status, and comparisons to the HARD or SOFT lifetime will indicate which limit was reached. HARD lifetimes MUST take precedence over SOFT lifetimes, meaning if the HARD and SOFT lifetimes are the same, the HARD lifetime will appear on the EXPIRE message. The pathological case of HARD lifetimes being shorter than SOFT lifetimes is handled such that the SOFT lifetime will never expire.

The messaging behavior of the SADB_EXPIRE message is:

The kernel sends an SADB_EXPIRE message to all listeners when the soft limit of a security association has been expired.

<base, SA, lifetime(C and one of HS), address(SD)>

Note that the SADB_EXPIRE message is ONLY sent by the kernel to the KMd. It is a one-way informational message that does not have a reply.

3.1.9 SADB_FLUSH

The SADB_FLUSH message causes the kernel to delete all entries in its key table for a certain sadb_msg_satype. Only the base header is required for a flush message. If sadb_msg_satype is filled in with a specific value, only associations of that type are deleted. If it is filled in with SADB_SATYPE_UNSPEC, ALL associations are deleted.

The messaging behavior for SADB_FLUSH is:

Send an SADB_FLUSH message from a user process to the kernel.

<base>

The kernel will return an SADB_FLUSH message to all listening sockets.

<base>

The reply message happens only after the actual flushing of security associations has been attempted.

3.1.10 SADB_DUMP

The SADB_DUMP message causes the kernel to dump the operating system's entire Key Table to the requesting key socket. As in SADB_FLUSH, if a sadb_msg_satype value is in the message, only associations of that type will be dumped. If SADB_SATYPE_UNSPEC is specified, all associations will be dumped. Each Security Association is returned in its own SADB_DUMP message. A SADB_DUMP message with a sadb_seq field of zero indicates the end of the dump transaction. The dump message is used for debugging purposes only and is not intended for production use.

Support for the dump message MAY be discontinued in future versions of PF_KEY. Key management applications MUST NOT depend on this message for basic operation.

The messaging behavior for SADB_DUMP is:

Send an SADB_DUMP message from a user process to the kernel.

<base>

Several SADB_DUMP messages will return from the kernel to the sending socket.

```
<base, SA, (lifetime (HSC),) address(SD), (address(P),)
  key(AE), (identity(SD),) (sensitivity)>
```

3.2 Security Association Flags

The Security Association's flags are a bitmask field. These flags also appear in a combination that is part of a PROPOSAL extension. The related symbolic definitions below should be used in order that applications will be portable:

```
#define SADB_SAFLAGS_PFS 1    /* perfect forward secrecy */
```

The SADB_SAFLAGS_PFS flag indicates to key management that this association should have perfect forward secrecy in its key. (In other words, any given session key cannot be determined by cryptanalysis of previous session keys or some master key.)

3.3 Security Association States

The security association state field is an integer that describes the states of a security association. They are:

```
#define SADB_SASTATE_LARVAL   0
#define SADB_SASTATE_MATURE   1
#define SADB_SASTATE_DYING    2
#define SADB_SASTATE_DEAD     3

#define SADB_SASTATE_MAX      3
```

A SADB_SASTATE_LARVAL security association is one that was created by the SADB_GETSPI message. A SADB_SASTATE_MATURE association is one that was updated with the SADB_UPDATE message or added with the SADB_ADD message. A DYING association is one whose soft lifetime has expired. A SADB_SASTATE_DEAD association is one whose hard lifetime has expired, but hasn't been reaped by system garbage collection. If a consumer of security associations has to extend an association beyond its normal lifetime (e.g. OSPF Security) it MUST only set the soft lifetime for an association.

3.4 Security Association Types

This defines the type of Security Association in this message. The symbolic names are always the same, even on different implementations. Applications SHOULD use the symbolic name in order to have maximum portability across different implementations. These are defined in the file <net/pfkeyv2.h>.

```
#define SADB_SATYPE_UNSPEC        0

#define SADB_SATYPE_AH            2  /* RFC-1826 */
#define SADB_SATYPE_ESP           3  /* RFC-1827 */

#define SADB_SATYPE_RSVP          5  /* RSVP Authentication */
#define SADB_SATYPE_OSPFV2        6  /* OSPFv2 Authentication */
#define SADB_SATYPE_RIPV2         7  /* RIPv2 Authentication */
#define SADB_SATYPE_MIP           8  /* Mobile IP Auth. */

#define SADB_SATYPE_MAX           8
```

SADB_SATYPE_UNSPEC is defined for completeness and means no specific type of security association. This type is never used with PF_KEY SAs.

SADB_SATYPE_AH is for the IP Authentication Header [Atk95b].

SADB_SATYPE_ESP is for the IP Encapsulating Security Payload [Atk95c].

SADB_SATYPE_RSVP is for the RSVP Integrity Object.

SADB_SATYPE_OSPFV2 is for OSPFv2 Cryptographic authentication [Moy98].

SADB_SATYPE_RIPV2 is for RIPv2 Cryptographic authentication [BA97].

SADB_SATYPE_MIP is for Mobile IP's authentication extensions [Per97].

SADB_SATYPE_MAX is always set to the highest valid numeric value.

3.5 Algorithm Types

The algorithm type is interpreted in the context of the Security Association type defined above. The numeric value might vary between implementations, but the symbolic name MUST NOT vary between implementations. Applications should use the symbolic name in order to have maximum portability to various implementations.

Some of the algorithm types defined below might not be standardized or might be deprecated in the future. To obtain an assignment for a symbolic name, contact the authors.

The symbols below are defined in <net/pfkeyv2.h>.

```
/* Authentication algorithms */
#define SADB_AALG_NONE          0
#define SADB_AALG_MD5HMAC       2
#define SADB_AALG_SHA1HMAC      3
#define SADB_AALG_MAX           3

/* Encryption algorithms */
#define SADB_EALG_NONE          0
#define SADB_EALG_DESCBC        2
#define SADB_EALG_3DESCBC       3
#define SADB_EALG_NULL          11
#define SADB_EALG_MAX           11
```

The algorithm for SADB_AALG_MD5_HMAC is defined in [MG98a]. The algorithm for SADB_AALG_SHA1HMAC is defined in [MG98b]. The algorithm for SADB_EALG_DESCBC is defined in [MD98]. SADB_EALG_NULL is the NULL encryption algorithm, defined in [GK98]. The SADB_EALG_NONE value is not to be used in any security association except those which have no possible encryption algorithm in them (e.g. IPsec AH).

3.6 Extension Header Values

To briefly recap the extension header values:

```
#define SADB_EXT_RESERVED          0
#define SADB_EXT_SA                1
#define SADB_EXT_LIFETIME_CURRENT  2
#define SADB_EXT_LIFETIME_HARD     3
#define SADB_EXT_LIFETIME_SOFT     4
#define SADB_EXT_ADDRESS_SRC       5
#define SADB_EXT_ADDRESS_DST       6
#define SADB_EXT_ADDRESS_PROXY     7
#define SADB_EXT_KEY_AUTH          8
#define SADB_EXT_KEY_ENCRYPT       9
#define SADB_EXT_IDENTITY_SRC      10
#define SADB_EXT_IDENTITY_DST      11
#define SADB_EXT_SENSITIVITY       12
#define SADB_EXT_PROPOSAL          13
#define SADB_EXT_SUPPORTED_AUTH    14
#define SADB_EXT_SUPPORTED_ENCRYPT 15
#define SADB_EXT_SPIRANGE          16

#define SADB_EXT_MAX               16
```

3.7 Identity Extension Values

Each identity can have a certain type.

```
#define SADB_IDENTTYPE_RESERVED  0
#define SADB_IDENTTYPE_PREFIX    1
#define SADB_IDENTTYPE_FQDN      2
#define SADB_IDENTTYPE_USERFQDN  3

#define SADB_IDENTTYPE_MAX       3
```

The PREFIX identity string consists of a network address followed by a forward slash and a prefix length. The network address is in a printable numeric form appropriate for the protocol family. The prefix length is a decimal number greater than or equal to zero and less than the number of bits in the network address. It indicates the number of bits in the network address that are significant; all bits in the network address that are not significant MUST be set to zero. Note that implementations MUST parse the contents of the printable address into a binary form for comparison purposes because multiple printable strings are valid representations of the same address in many protocol families (for example, some allow leading zeros and some have letters that are case insensitive). Examples of PREFIX identities are "199.33.248.64/27" and "3ffe::1/128". If the source or destination identity is a PREFIX identity, the source or destination address for the SA (respectively) MUST be within that prefix. The sadb_ident_id field is zeroed for these identity types.

The FQDN identity string contains a fully qualified domain name. An example FQDN identity is "ministry-of-truth.inner.net". The sadb_ident_id field is zeroed for these identity types.

The UserFQDN identity consists of a text string in the format commonly used for Internet-standard electronic mail. The syntax is the text username, followed by the "@" character, followed in turn by the appropriate fully qualified domain name. This identity specifies both a username and an associated FQDN. There is no requirement that this string specify a mailbox valid for SMTP or other electronic mail use. This identity is useful with protocols supporting user-oriented keying. It is a convenient identity form because the DNS Security extensions can be used to distribute signed public key values by associating KEY and SIG records with an appropriate MB DNS record. An example UserFQDN identity is "julia@ministry-of-love.inner.net". The sadb_ident_id field is used to contain a POSIX user id in the absence of an identity string itself so that a user-level application can use the getpwuid{,_r}() routine to obtain a textual user login id. If a string is present, it SHOULD match the numeric value in the sadb_ident_id field. If it does not match, the string SHOULD override

the numeric value.

3.8 Sensitivity Extension Values

The only field currently defined in the sensitivity extension is the sadb_sens_dpd, which represents the data protection domain. The other data in the sensitivity extension is based off the sadb_sens_dpd value.

The DP/DOI is defined to be the same as the "Labeled Domain Identifier Value" of the IP Security DOI specification [Pip98]. As noted in that specification, values in the range 0x80000000 to 0xffffffff (inclusive) are reserved for private use and values in the range 0x00000001 through 0x7fffffff are assigned by IANA. The all-zeros DP/DOI value is permanently reserved to mean that "no DP/DOI is in use".

3.9 Proposal Extension Values

These are already mentioned in the Algorithm Types and Security Association Flags sections.

4 Future Directions

While the current specification for the Sensitivity and Integrity Labels is believed to be general enough, if a case should arise that can’t work with the current specification then this might cause a change in a future version of PF_KEY.

Similarly, PF_KEY might need extensions to work with other kinds of Security Associations in future. It is strongly desirable for such extensions to be made in a backwards-compatible manner should they be needed.

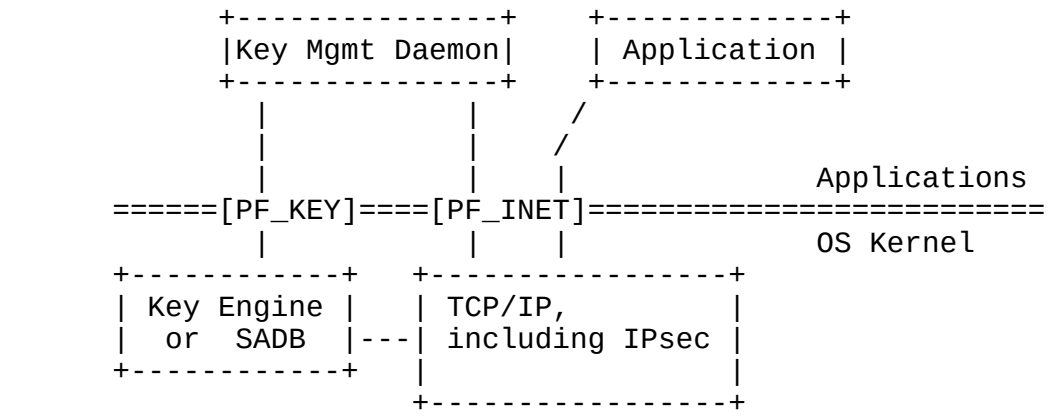
When more experience is gained with certificate management, it is possible that the IDENTITY extension will have to be revisited to allow a finer grained selection of certificate identities.

5. Examples

The following examples illustrate how PF_KEY is used. The first example is an IP Security example, where the consumer of the security associations is inside an operating system kernel. The second example is an OSPF Security example, which illustrates a user-level consumer of security associations. The third example covers things not mentioned by the first two examples. A real system may closely conform to one of these examples, or take parts of them. These examples are purely illustrative, and are not intended to mandate a

particular implementation method.

5.1 Simple IP Security Example



When the Key Management daemon (KMd) begins. It must tell PF_KEY that it is willing to accept message for the two IPsec services, AH and ESP. It does this by sending down two SADB_REGISTER messages.

```
KMd->Kernel:         SADB_REGISTER for ESP
Kernel->Registered:  SADB_REGISTER for ESP, Supported Algorithms
KMd->Kernel:         SADB_REGISTER for AH
Kernel->Registered:  SADB_REGISTER for AH, Supported Algorithms
```

Each REGISTER message will cause a reply to go to all PF_KEY sockets registered for ESP and AH respectively (including the requester).

Assume that no security associations currently exist for IPsec to use. Consider when a network application begins transmitting data (e.g. a TCP SYN). Because of policy, or the application's request, the kernel IPsec module needs an AH security association for this data. Since there is not one present, the following message is generated:

```
Kernel->Registered:  SADB_ACQUIRE for AH, addrs, ID, sens,
                     proposals
```

The KMd reads the ACQUIRE message, especially the sadb_msg_seq number. Before it begins the negotiation, it sends down an SADB_GETSPI message with the sadb_msg_seq number equal to the one received in the ACQUIRE. The kernel returns the results of the GETSPI to all listening sockets.

```
KMd->Kernel:         SADB_GETSPI for AH, addr, SPI range
Kernel->All:         SADB_GETSPI for AH, assoc, addrs
```

The KMd may perform a second GETSPI operation if it needs both directions of IPsec SPI values. Now that the KMd has an SPI for at least one of the security associations, it begins negotiation. After deriving keying material, and negotiating other parameters, it sends down one (or more) SADB_UPDATE messages with the same value in sadb_msg_seq.

If a KMd has any error at all during its negotiation, it can send down:

```
KMd->Kernel:        SADB_ACQUIRE for AH, assoc (with an error)
Kernel->All:        SADB_ACQUIRE for AH, assoc (same error)
```

but if it succeeds, it can instead:

```
KMd->Kernel:        SADB_UPDATE for AH, assoc, addrs, keys,
                    <etc.>
Kernel->All:        SADB_UPDATE for AH, assoc, addrs, <etc.>
```

The results of the UPDATE (minus the actual keys) are sent to all listening sockets. If only one SPI value was determined locally, the other SPI (since IPsec SAs are unidirectional) must be added with an SADB_ADD message.

```
KMd->Kernel:        SADB_ADD for AH, assoc, addrs, keys, <etc.>
Kernel->All:        SADB_ADD for AH, assoc, addrs, <etc.>
```

If one of the extensions passed down was a Lifetime extension, it is possible at some point an SADB_EXPIRE message will arrive when one of the lifetimes has expired.

```
Kernel->All:        SADB_EXPIRE for AH, assoc, addrs,
                    Hard or Soft, Current, <etc.>
```

The KMd can use this as a clue to begin negotiation, or, if it has some say in policy, send an SADB_UPDATE down with a lifetime extension.

5.2 Proxy IP Security Example

Many people are interested in using IP Security in a "proxy" or "firewall" configuration in which an intermediate system provides security services for "inside" hosts. In these environments, the intermediate systems can use PF_KEY to communicate with key management applications almost exactly as they would if they were the actual endpoints. The messaging behavior of PF_KEY in these cases is exactly the same as the previous example, but the address information is slightly different.

Consider this case:

```
A ========= B --------- C
```

Key:

A	"outside" host that implements IPsec
B	"firewall" that implements IPsec
C	"inside" host that does not implement IPsec
===	IP_{A<->B} ESP [IP_{A<->C} ULP]
---	IP_{A<->C} ULP

A is a single system that wishes to communicate with the "inside" system C. B is a "firewall" between C and the outside world that will do ESP and tunneling on C's behalf. A discovers that it needs to send traffic to C via B through methods not described here (Use of the DNS' KX record might be one method for discovering this).

For packets that flow from left to right, A and B need an IPsec Security Association with:

SA type of ESP tunnel-mode
Source Identity that dominates A (e.g. A's address)
Destination Identity that dominates B (e.g. B's address)
Source Address of A
Destination Address of B

For packets to flow from right to left, A and B need an IPsec Security Association with:

SA type of ESP tunnel-mode
Source Identity that dominates C
Destination Identity that dominates A
Source Address of B
Destination Address of A
Proxy Address of C

For this second SA (for packets flowing from C towards A), node A MUST verify that the inner source address is dominated by the Source Identity for the SA used with those packets. If node A does not do this, an adversary could forge packets with an arbitrary Source Identity and defeat the packet origin protections provided by IPsec.

Now consider a slightly more complex case:

```
A_1 --|                  |-- D_1
      |--- B ====== C ---|
A_2 --|                  |-- D_2
```

Key:

A_n	"inside" host on net 1 that does not do IPsec.
B	"firewall" for net 1 that supports IPsec.
C	"firewall" for net 2 that supports IPsec.
D_n	"inside" host on net 2 that does not do IPsec.
===	IP_{B<->C} ESP [IP_{A<->C} ULP]
---	IP_{A<->C} ULP

For A_1 to send a packet to D_1, B and C need an SA with:

SA Type of ESP
Source Identity that dominates A_1
Destination Identity that dominates C
Source Address of B
Destination Address of C
Proxy Address of A_1

For D_1 to send a packet to A_1, C and B need an SA with:
SA Type of ESP Tunnel-mode
Source Identity that dominates D_1
Destination Identity that dominates B
Source Address of C
Destination Address of B
Proxy Address of D_1

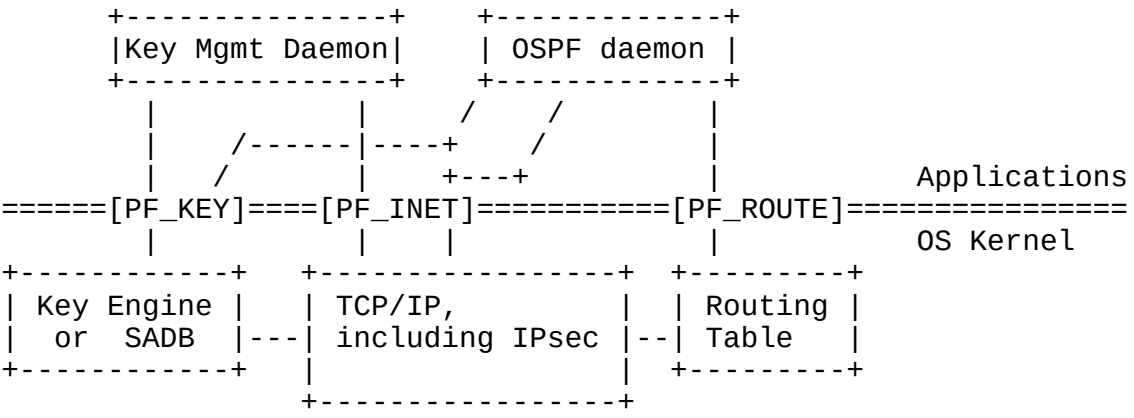
Note that A_2 and D_2 could be substituted for A_1 and D_1 (respectively) here; the association of an SA with a particular pair of ends or group of those pairs is a policy decision on B and/or C and not necessarily a function of key management. The same check of the Source Identity against the inner source IP address MUST also be performed in this case for the same reason.

For a more detailed discussion of the use of IP Security in complex cases, please see [Atk97].

NOTE: The notion of identity domination might be unfamiliar. Let H represent some node. Let Hn represent H's fully qualified domain name. Let Ha represent the IP address of H. Let Hs represent the IP subnet containing Ha. Let Hd represent a fully qualified domain name that is a parent of the fully qualified domain name of H. Let M be a UserFQDN identity that whose right-hand part is Hn or Ha.

Any of M, Hn, Ha, Hs, and Hd is considered to dominate H in the example above. Hs dominates any node having an IP address within the IP address range represented by Hs. Hd dominates any node having a fully qualified domain name within underneath Hd.

5.3 OSPF Security Example



As in the previous examples, the KMd registers itself with the Key Engine via PF_KEY. Even though the consumer of the security associations is in user-space, the PF_KEY and Key Engine implementation knows enough to store SAs and to relay messages.

When the OSPF daemon needs to communicate securely with its peers, it would perform an SADB_GET message and retrieve the appropriate association:

```
OSPFd->Kernel:       SADB_GET of OSPF, assoc, addrs
Kernel->OSPFd:       SADB_GET of OSPF, assoc, addrs, keys, <etc.>
```

If this GET fails, the OSPFd may need to acquire a new security association. This interaction is as follows:

```
OSPFd->Kernel:       SADB_ACQUIRE of OSPF, addrs, <ID, sens,>
                     proposal
Kernel->Registered:  SADB_ACQUIRE of OSPF, <same as sent message>
```

The KMd sees this and performs actions similar to the previous example. One difference, however, is that when the UPDATE message comes back, the OSPFd will then perform a GET of the updated SA to retrieve all of its parameters.

5.4 Miscellaneous

Some messages work well only in system maintenance programs, for debugging, or for auditing. In a system panic situation, such as a detected compromise, an SADB_FLUSH message should be issued for a particular SA type, or for ALL SA types.

```
  Program->Kernel:     SADB_FLUSH for ALL
  <Kernel then flushes all internal SAs>
  Kernel->All:         SADB_FLUSH for ALL
```

Some SAs may need to be explicitly deleted, either by a KMd, or by a system maintenance program.

```
  Program->Kernel:     SADB_DELETE for AH, association, addrs
  Kernel->All:         SADB_DELETE for AH, association, addrs
```

Common usage of the SADB_DUMP message is discouraged. For debugging purposes, however, it can be quite useful. The output of a DUMP message should be read quickly, in order to avoid socket buffer overflows.

```
  Program->Kernel:     SADB_DUMP for ESP
  Kernel->Program:     SADB_DUMP for ESP, association, <all fields>
  Kernel->Program:     SADB_DUMP for ESP, association, <all fields>
  Kernel->Program:     SADB_DUMP for ESP, association, <all fields>
  <ad nauseam...>
```

6 Security Considerations

This memo discusses a method for creating, reading, modifying, and deleting Security Associations from an operating system. Only trusted, privileged users and processes should be able to perform any of these operations. It is unclear whether this mechanism provides any security when used with operating systems not having the concept of a trusted, privileged user.

If an unprivileged user is able to perform any of these operations, then the operating system cannot actually provide the related security services. If an adversary knows the keys and algorithms in use, then cryptography cannot provide any form of protection.

This mechanism is not a panacea, but it does provide an important operating system component that can be useful in creating a secure internetwork.

Users need to understand that the quality of the security provided by an implementation of this specification depends completely upon the overall security of the operating system, the correctness of the PF_KEY implementation, and upon the security and correctness of the applications that connect to PF_KEY. It is appropriate to use high assurance development techniques when implementing PF_KEY and the related security association components of the operating system.

Acknowledgments

The authors of this document are listed primarily in alphabetical order. Randall Atkinson and Ron Lee provided useful feedback on earlier versions of this document.

At one time or other, all of the authors worked at the Center for High Assurance Computer Systems at the U.S. Naval Research Laboratory. This work was sponsored by the Information Security Program Office (PMW-161), U.S. Space and Naval Warfare Systems Command (SPAWAR) and the Computing Systems Technology Office, Defense Advanced Research Projects Agency (DARPA/CSTO). We really appreciate their sponsorship of our efforts and their continued support of PF_KEY development. Without that support, PF_KEY would not exist.

The "CONFORMANCE and COMPLIANCE" wording was taken from [MSST98].

Finally, the authors would like to thank those who sent in comments and questions on the various iterations of this document. This specification and implementations of it are discussed on the PF_KEY mailing list. If you would like to be added to this list, send a note to <pf_key-request@inner.net>.

References

[AMPMC96] Randall J. Atkinson, Daniel L. McDonald, Bao G. Phan, Craig W. Metz, and Kenneth C. Chin, "Implementation of IPv6 in 4.4-Lite BSD", Proceedings of the 1996 USENIX Conference, San Diego, CA, January 1996, USENIX Association.

[Atk95a] Atkinson, R., "IP Security Architecture", RFC 1825, August 1995.

[Atk95b] Atkinson, R., "IP Authentication Header", RFC 1826, August 1995.

[Atk95c] Atkinson, R., "IP Encapsulating Security Payload", RFC 1827, August 1995.

[Atk97] Atkinson, R., "Key Exchange Delegation Record for the Domain Name System", RFC 2230, October 1997.

[BA97] Baker, F., and R. Atkinson, "RIP-2 MD5 Authentication", RFC 2082, January 1997.

[Biba77] K. J. Biba, "Integrity Considerations for Secure Computer Systems", MTR-3153, The MITRE Corporation, June 1975; ESD-TR-76-372, April 1977.

[BL74] D. Elliot Bell and Leonard J. LaPadula, "Secure Computer Systems: Unified Exposition and Multics Interpretation", MTR 2997, The MITRE Corporation, April 1974. (AD/A 020 445)

[Bra97] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, March 1997.

[CW87] D. D. Clark and D. R. Wilson, "A Comparison of Commercial and Military Computer Security Policies", Proceedings of the 1987 Symposium on Security and Privacy, pp. 184-195, IEEE Computer Society, Washington, D.C., 1987.

[DIA] US Defense Intelligence Agency (DIA), "Compartmented Mode Workstation Specification", Technical Report DDS-2600-6243-87.

[GK98] Glenn, R., and S. Kent, "The NULL Encryption Algorithm and Its Use with IPsec", Work in Progress.

[HM97a] Harney, H., and C. Muckenhirn, "Group Key Management Protocol (GKMP) Specification", RFC 2093, July 1997.

[HM97b] Harney, H., and C. Muckenhirn, "Group Key Management Protocol (GKMP) Architecture", RFC 2094, July 1997.

[MD98] Madsen, C., and N. Doraswamy, "The ESP DES-CBC Cipher Algorithm With Explicit IV", Work in Progress.

[MG98a] Madsen, C., and R. Glenn, "The Use of HMAC-MD5-96 within ESP and AH", Work in Progress.

[MG98b] Madsen, C., and R. Glenn, "The Use of HMAC-SHA-1-96 within ESP and AH", Work in Progress.

[MSST98] Maughan, D., Schertler, M., Schneider, M., and J. Turner, "Internet Security Association and Key Management Protocol (ISAKMP)", Work in Progress.

[Moy98] Moy, J., "OSPF Version 2", STD 54, RFC 2328, April 1998.

[Per97] Perkins, C., "IP Mobility Support", RFC 2002, October 1996.

[Pip98] Piper, D., "The Internet IP Security Domain of Interpretation for ISAKMP", Work in Progress.

[Sch96] Bruce Schneier, Applied Cryptography, p. 360, John Wiley & Sons, Inc., 1996.

[Skl91] Keith Sklower, "A Tree-based Packet Routing Table for Berkeley UNIX", Proceedings of the Winter 1991 USENIX Conference, Dallas, TX, USENIX Association. 1991. pp. 93-103.

Disclaimer

The views and specification here are those of the editors and are not necessarily those of their employers. The employers have not passed judgment on the merits, if any, of this work. The editors and their employers specifically disclaim responsibility for any problems arising from correct or incorrect implementation or use of this specification.

Authors' Addresses

Daniel L. McDonald
Sun Microsystems, Inc.
901 San Antonio Road, MS UMPK17-202
Palo Alto, CA 94303

Phone: +1 650 786 6815
EMail: danmcd@eng.sun.com

Craig Metz
(for Code 5544)
U.S. Naval Research Laboratory
4555 Overlook Ave. SW
Washington, DC 20375

Phone: (DSN) 754-8590
EMail: cmetz@inner.net

Bao G. Phan
U. S. Naval Research Laboratory

EMail: phan@itd.nrl.navy.mil

Appendix A: Promiscuous Send/Receive Message Type

A kernel supporting PF_KEY MAY implement the following extension for development and debugging purposes. If it does, it MUST implement the extension as specified here. An implementation MAY require an application to have additional privileges to perform promiscuous send and/or receive operations.

The SADB_X_PROMISC message allows an application to send and receive messages in a "promiscuous mode." There are two forms of this message: control and data. The control form consists of only a message header. This message is used to toggle the promiscuous-receive function. A value of one in the sadb_msg_satype field enables promiscuous message reception for this socket, while a value of zero in that field disables it.

The second form of this message is the data form. This is used to send or receive messages in their raw form. Messages in the data form consist of a message header followed by an entire new message. There will be two message headers in a row: one for the SADB_X_PROMISC message, and one for the payload message.

Data messages sent from the application are sent to either the PF_KEY socket of a single process identified by a nonzero sadb_msg_seq or to all PF_KEY sockets if sadb_msg_seq is zero. These messages are sent without any processing of their contents by the PF_KEY interface (including sanity checking). This promiscuous-send capability allows an application to send messages as if it were the kernel. This also allows it to send erroneous messages.

If the promiscuous-receive function has been enabled, a copy of any message sent via PF_KEY by another application or by the kernel is sent to the promiscuous application. This is done before any processing of the message’s contents by the PF_KEY interface (again, including sanity checking). This promiscuous-receive capability allows an application to receive all messages sent by other parties using PF_KEY.

The messaging behavior of the SADB_X_PROMISC message is:

Send a control-form SADB_X_PROMISC message from a user process to the kernel.

<base>

The kernel returns the SADB_X_PROMISC message to all listening processes.

<base>

Send a data-form SADB_X_PROMISC message from a user process to the kernel.

<base, base(, others)>

The kernel sends the encapsulated message to the target process(s).

<base(, others)>

If promiscuous-receive is enabled, the kernel will encapsulate and send copies of all messages sent via the PF_KEY interface.

<base, base(, others)>

Errors:

EPERM Additional privileges are required to perform the requested operations.

ESRCH (Data form, sending) The target process in sadb_msg_seq does not exist or does not have an open PF_KEY Version 2 socket.

Appendix B: Passive Change Message Type

The SADB_X_PCHANGE message is a passive-side (aka. the "listener" or "receiver") counterpart to the SADB_ACQUIRE message. It is useful for when key management applications wish to more effectively handle incoming key management requests for passive-side sessions that deviate from systemwide default security services. If a passive session requests that only certain levels of security service be allowed, the SADB_X_PCHANGE message expresses this change to any registered PF_KEY sockets. Unlike SADB_ACQUIRE, this message is purely informational, and demands no other PF_KEY interaction.

The SADB_X_PCHANGE message is typically triggered by either a change in an endpoint's requested security services, or when an endpoint that made a special request disappears. In the former case, an SADB_X_PCHANGE looks like an SADB_ACQUIRE, complete with an sadb_proposal extension indicating the preferred algorithms, lifetimes, and other attributes. When a passive session either disappears, or reverts to a default behavior, an SADB_X_PCHANGE will be issued with _no_ sadb_proposal extension, indicating that the exception to systemwide default behavior has disappeared.

There are two messaging behaviors for SADB_X_PCHANGE. The first is the kernel-originated case:

> The kernel sends an SADB_X_PCHANGE message to registered sockets.
>
> <base, address(SD), (identity(SD),) (sensitivity,) (proposal)>
>
> NOTE: The address(SD) extensions MUST have the port fields filled in with the port numbers of the session requiring keys if appropriate.

The second is for a user-level consumer of SAs.

> Send an SADB_X_PCHANGE message from a user process to the kernel.
>
> <base, address(SD), (identity(SD),) (sensitivity,) (proposal)>
>
> The kernel returns an SADB_X_PCHANGE message to registered sockets.
>
> <base, address(SD), (identity(SD),) (sensitivity,) (proposal)>

Appendix C: Key Management Private Data Extension

The Key Management Private Data extension is attached to either an SADB_ADD or an SADB_UPDATE message. It attaches a single piece of arbitrary data to a security association. It may be useful for key managment applications that could use an SADB_DUMP or SADB_GET message to obtain additional state if it needs to restart or recover after a crash. The format of this extension is:

```
#define SADB_X_EXT_KMPRIVATE 17

struct sadb_x_kmprivate {
        uint16_t sadb_x_kmprivate_len;
        uint16_t sadb_x_kmprivate_exttype;
        uint32_t sadb_x_kmprivate_reserved;
};
/* sizeof(struct sadb_x_kmprivate) == 8 */

/* followed by arbitrary data */
```

The data following the sadb_x_kmprivate extension can be anything. It will be stored with the actual security association in the kernel. Like all data, it must be padded to an eight byte boundary.

Appendix D: Sample Header File

```
/*
This file defines structures and symbols for the PF_KEY Version 2
key management interface. It was written at the U.S. Naval Research
Laboratory. This file is in the public domain. The authors ask that
you leave this credit intact on any copies of this file.
*/
#ifndef __PFKEY_V2_H
#define __PFKEY_V2_H 1

#define PF_KEY_V2 2
#define PFKEYV2_REVISION        199806L

#define SADB_RESERVED    0
#define SADB_GETSPI      1
#define SADB_UPDATE      2
#define SADB_ADD         3
#define SADB_DELETE      4
#define SADB_GET         5
#define SADB_ACQUIRE     6
#define SADB_REGISTER    7
#define SADB_EXPIRE      8
#define SADB_FLUSH       9
#define SADB_DUMP        10
#define SADB_X_PROMISC   11
#define SADB_X_PCHANGE   12
#define SADB_MAX         12

struct sadb_msg {
  uint8_t sadb_msg_version;
  uint8_t sadb_msg_type;
  uint8_t sadb_msg_errno;
  uint8_t sadb_msg_satype;
  uint16_t sadb_msg_len;
  uint16_t sadb_msg_reserved;
  uint32_t sadb_msg_seq;
  uint32_t sadb_msg_pid;
};

struct sadb_ext {
  uint16_t sadb_ext_len;
  uint16_t sadb_ext_type;
};

struct sadb_sa {
  uint16_t sadb_sa_len;
  uint16_t sadb_sa_exttype;
```

```
    uint32_t sadb_sa_spi;
    uint8_t sadb_sa_replay;
    uint8_t sadb_sa_state;
    uint8_t sadb_sa_auth;
    uint8_t sadb_sa_encrypt;
    uint32_t sadb_sa_flags;
  };

  struct sadb_lifetime {
    uint16_t sadb_lifetime_len;
    uint16_t sadb_lifetime_exttype;
    uint32_t sadb_lifetime_allocations;
    uint64_t sadb_lifetime_bytes;
    uint64_t sadb_lifetime_addtime;
    uint64_t sadb_lifetime_usetime;
  };

  struct sadb_address {
    uint16_t sadb_address_len;
    uint16_t sadb_address_exttype;
    uint8_t sadb_address_proto;
    uint8_t sadb_address_prefixlen;
    uint16_t sadb_address_reserved;
  };

  struct sadb_key {
    uint16_t sadb_key_len;
    uint16_t sadb_key_exttype;
    uint16_t sadb_key_bits;
    uint16_t sadb_key_reserved;
  };

  struct sadb_ident {
    uint16_t sadb_ident_len;
    uint16_t sadb_ident_exttype;
    uint16_t sadb_ident_type;
    uint16_t sadb_ident_reserved;
    uint64_t sadb_ident_id;
  };

  struct sadb_sens {
    uint16_t sadb_sens_len;
    uint16_t sadb_sens_exttype;
    uint32_t sadb_sens_dpd;
    uint8_t sadb_sens_sens_level;
    uint8_t sadb_sens_sens_len;
    uint8_t sadb_sens_integ_level;
    uint8_t sadb_sens_integ_len;
```

```
  uint32_t sadb_sens_reserved;
};

struct sadb_prop {
  uint16_t sadb_prop_len;
  uint16_t sadb_prop_exttype;
  uint8_t sadb_prop_replay;
  uint8_t sadb_prop_reserved[3];
};

struct sadb_comb {
  uint8_t sadb_comb_auth;
  uint8_t sadb_comb_encrypt;
  uint16_t sadb_comb_flags;
  uint16_t sadb_comb_auth_minbits;
  uint16_t sadb_comb_auth_maxbits;
  uint16_t sadb_comb_encrypt_minbits;
  uint16_t sadb_comb_encrypt_maxbits;
  uint32_t sadb_comb_reserved;
  uint32_t sadb_comb_soft_allocations;
  uint32_t sadb_comb_hard_allocations;
  uint64_t sadb_comb_soft_bytes;
  uint64_t sadb_comb_hard_bytes;
  uint64_t sadb_comb_soft_addtime;
  uint64_t sadb_comb_hard_addtime;
  uint64_t sadb_comb_soft_usetime;
  uint64_t sadb_comb_hard_usetime;
};

struct sadb_supported {
  uint16_t sadb_supported_len;
  uint16_t sadb_supported_exttype;
  uint32_t sadb_supported_reserved;
};

struct sadb_alg {
  uint8_t sadb_alg_id;
  uint8_t sadb_alg_ivlen;
  uint16_t sadb_alg_minbits;
  uint16_t sadb_alg_maxbits;
  uint16_t sadb_alg_reserved;
};

struct sadb_spirange {
  uint16_t sadb_spirange_len;
  uint16_t sadb_spirange_exttype;
  uint32_t sadb_spirange_min;
  uint32_t sadb_spirange_max;
```

```
  uint32_t sadb_spirange_reserved;
};

struct sadb_x_kmprivate {
  uint16_t sadb_x_kmprivate_len;
  uint16_t sadb_x_kmprivate_exttype;
  uint32_t sadb_x_kmprivate_reserved;
};

#define SADB_EXT_RESERVED             0
#define SADB_EXT_SA                   1
#define SADB_EXT_LIFETIME_CURRENT     2
#define SADB_EXT_LIFETIME_HARD        3
#define SADB_EXT_LIFETIME_SOFT        4
#define SADB_EXT_ADDRESS_SRC          5
#define SADB_EXT_ADDRESS_DST          6
#define SADB_EXT_ADDRESS_PROXY        7
#define SADB_EXT_KEY_AUTH             8
#define SADB_EXT_KEY_ENCRYPT          9
#define SADB_EXT_IDENTITY_SRC         10
#define SADB_EXT_IDENTITY_DST         11
#define SADB_EXT_SENSITIVITY          12
#define SADB_EXT_PROPOSAL             13
#define SADB_EXT_SUPPORTED_AUTH       14
#define SADB_EXT_SUPPORTED_ENCRYPT    15
#define SADB_EXT_SPIRANGE             16
#define SADB_X_EXT_KMPRIVATE          17
#define SADB_EXT_MAX                  17
#define SADB_SATYPE_UNSPEC    0
#define SADB_SATYPE_AH        2
#define SADB_SATYPE_ESP       3
#define SADB_SATYPE_RSVP      5
#define SADB_SATYPE_OSPFV2    6
#define SADB_SATYPE_RIPV2     7
#define SADB_SATYPE_MIP       8
#define SADB_SATYPE_MAX       8

#define SADB_SASTATE_LARVAL   0
#define SADB_SASTATE_MATURE   1
#define SADB_SASTATE_DYING    2
#define SADB_SASTATE_DEAD     3
#define SADB_SASTATE_MAX      3

#define SADB_SAFLAGS_PFS      1

#define SADB_AALG_NONE        0
#define SADB_AALG_MD5HMAC     2
#define SADB_AALG_SHA1HMAC    3
```

```
#define SADB_AALG_MAX         3

#define SADB_EALG_NONE        0
#define SADB_EALG_DESCBC      2
#define SADB_EALG_3DESCBC     3
#define SADB_EALG_NULL        11
#define SADB_EALG_MAX         11

#define SADB_IDENTTYPE_RESERVED   0
#define SADB_IDENTTYPE_PREFIX     1
#define SADB_IDENTTYPE_FQDN       2
#define SADB_IDENTTYPE_USERFQDN   3
#define SADB_IDENTTYPE_MAX        3

#define SADB_KEY_FLAGS_MAX 0
#endif /* __PFKEY_V2_H */
```

Appendix E: Change Log

The following changes were made between 05 and 06:

* Last change before becoming an informational RFC. Removed all Internet-Draft references. Also standardized citation strings. Now cite RFC 2119 for MUST, etc.

* New appendix on optional KM private data extension.

* Fixed example to indicate the ACQUIRE messages with errno mean KM failure.

* Added SADB_EALG_NULL.

* Clarified proxy examples to match definition of PROXY address being the inner packet's source address. (Basically a sign-flip. The example still shows how to protect against policy vulnerabilities in tunnel endpoints.)

* Loosened definition of a destination address to include broadcast.

* Recommended that LARVAL security associations have implicit short lifetimes.

The following changes were made between 04 and 05:

* New appendix on Passive Change message.

* New sadb_address_prefixlen field.

* Small clarifications on sadb_ident_id usage.

* New PFKEYV2_REVISION value.

* Small clarification on what a PROXY address is.

* Corrected sadb_spirange_{min,max} language.

* In ADD messages that are in response to an ACQUIRE, the sadb_msg_seq MUST be the same as that of the originating ACQUIRE.

* Corrected ACQUIRE message behavior, ACQUIRE message SHOULD send up PROXY addresses when it needs them.

* Clarification on SADB_EXPIRE and user-level security protocols.

The following changes were made between 03 and 04:

* Stronger language about manual keying.

* PFKEYV2_REVISION, ala POSIX.

* Put in language about sockaddr ports in ACQUIRE messages.

* Mention of asymmetric algorithms.

* New sadb_ident_id field for easier construction of USER_FQDN identity strings.

* Caveat about source addresses not always used for collision detection. (e.g. IPsec)

The following changes were made between 02 and 03:

* Formatting changes.

* Many editorial cleanups, rewordings, clarifications.

* Restrictions that prevent many strange and invalid cases.

* Added definitions section.

* Removed connection identity type (this will reappear when it is more clear what it should look like).

* Removed 5.2.1 (Why involve the kernel?).

* Removed INBOUND, OUTBOUND, and FORWARD flags; they can be computed from src, dst, and proxy and you had to anyway for sanity checking.

* Removed REPLAY flag; sadb_sa_replay==0 means the same thing.

* Renamed bit lengths to "bits" to avoid potential confusion.

* Explicitly listed lengths for structures.

* Reworked identities to always use a string format.

* Removed requirements for support of shutdown() and SO_USELOOPBACK.

* 64 bit alignment and 64 bit lengths instead of 32 bit.

* time_t replaced with uint64 in lifetimes.

* Inserted Appendix A (SADB_X_PROMISC) and Appendix B (SAMPLE HEADER FILE).

* Explicit error if PF_KEY_V2 not set at socket() call.

* More text on SO_USELOOPBACK.

* Made fields names and symbol names more consistent.

* Explicit error if PF_KEY_V2 is not in sadb_msg_version field.

* Bytes lifetime field now a 64-bit quantity.

* Explicit len/exttype wording.

* Flattening out of extensions (LIFETIME_HARD, LIFETIME_SOFT, etc.)

* UI example (0x123 == 0x1230 or 0x0123).

* Cleaned up and fixed some message behavior examples.

The following changes were made between 01 and 02:

* Mentioned that people COULD use these same messages between user progs. (Also mentioned why you still might want to use the actual socket.)

* Various wordsmithing changes.

* Took out netkey/ directory, and make net/pfkeyv2.h

* Inserted PF_KEY_V2 proto argument per C. Metz.

* Mentioned other socket calls and how their PF_KEY behavior is undefined.

* SADB_EXPIRE now communicates both hard and soft lifetime expires.

* New "association" extension, even smaller base header.

* Lifetime extension improvements.

* Length now first in extensions.

* Errors can be sent from kernel to user, also.

* Examples section inserted.

* Some bitfield cleanups, including STATE and SA_OPTIONS cleanup.

* Key splitting now only across auth algorithm and encryption algorithm. Thanks for B. Sommerfeld for clues here.

The following changes were made between 00 and 01:

* Added this change log.

* Simplified TLV header syntax.

* Splitting of algorithms. This may be controversial, but it allows PF_KEY to be used for more than just IPsec. It also allows some kinds of policies to be placed in the KMd easier.

* Added solid definitions and formats for certificate identities, multiple keys, etc.

* Specified how keys are to be layed out (most-to-least bits).

* Changed sequence number semantics to be like an RPC transaction ID number.

F. Full Copyright Statement