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A Bound End-to-End Tunnel (BEET) mode for ESP
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Status of this Memo

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Abstract

This document specifies a new mode, called Bound End-to-End Tunnel (BEET) mode, for IPsec ESP. The new mode augments the existing ESP tunnel and transport modes. For end-to-end tunnels, the new mode provides limited tunnel mode semantics without the regular tunnel mode overhead. The mode is intended to support new uses of ESP, including mobility and multi-address multi-homing.

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1. Introduction

The current IPsec ESP specification [4] defines two modes of operation: tunnel mode and transport mode. The tunnel mode is mainly intended for non-end-to-end use where one or both of the ends of the ESP Security Associations (SAs) are located in security gateways, separate from the actual end-nodes. The transport mode is intended for end-to-end use, where both ends of the security association are terminated at the end-nodes themselves.

This document defines a new mode for ESP, called Bound End-to-End Tunnel (BEET) mode. The purpose of the mode is to provide limited tunnel mode semantics without the overhead associated with the regular tunnel mode. As the name states, the BEET mode is intended solely for end-to-end use. It provides tunnel mode semantics in the sense that the IP addresses seen by the applications and the IP addresses used on the wire are distinct from each other, providing the illusion that the application level IP addresses are tunneled over the network level IP addresses. However, the mode does not support full tunnel semantics. More specifically, the IP addresses as seen by the application are strictly bound, and only one pair of bound addresses can be used on any given BEET mode Security Association. This is in contrast to the regular tunnel mode, where the inner IP addresses can be any addresses from a defined range.

A BEET mode Security Associations records two pairs of IP addresses, called inner addresses and outer addresses. The inner addresses are what the applications see. The outer addresses are what appear on the wire. Since the inner addresses are fixed for the lifetime of the Security Association, they need not to be sent in individual packets. Instead, they are set up as the Security Associations are created, they are verified when packets are sent, and they are restored as packets are received.

This all gives the BEET mode the efficiency of transport mode with a limited set of end-to-end tunnel semantics. The efficiency is accomplished by removing the inner IP header from the packet that is transported on the wire. Due to removal of inner IP header, tunneled packet TTL is reduced by every router on the path. The semantics of BEET mode is limited in the sense that only one fixed pair of inner addresses are allowed. The outer addresses may change over the life time of the SA, but the inner addresses cannot. If a new pair of inner addresses is needed, a new pair of BEET mode Security Associations must be established, or the regular tunnel mode must be used. However, in the cases considered, a single pair of security associations is usually sufficient between any single pair of nodes.

2. Conventions used in this document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC2119 [1].

This document contains both normative and informative sections. The normative sections define the BEET mode. The informative sections provide background information that aim to motivate the need for the new mode. Whenever it may not be clear from the context whether a given major section is normative or informative, it is defined in the beginning of the section.

2.1 Terminology

In this section we define the terms specific to this document. This section is normative.

Inner IP address
: An IP address as seen by applications, stored in TCB or other upper layer data structures, and processed by the IP stack prior to ESP processing in the output side and after ESP processing in the input side.

Outer IP address
: An IP address seen in the wire and processed by the IP stack after ESP processing in the output side and before ESP processing in the input side.

Inner IP header
: An IP header that contains inner IP addresses. In some cases an inner IP header may be represented as an internal data structure containing the data equivalent to an IP header.

Outer IP header
: An IP header that contains outer IP addresses. In some cases an outer IP header may be represented as an internal data structure containing the data equivalent to an IP header.

3. Background

For a number of years people have been talking about using IPsec for other purposes than VPN. In fact, the current specifications do provide support for end-to-end protection of data. However, that mode is rarely used, for a number of reasons [5], [6]. One of the reasons, though, seems to be address agility. That is, due to NAT, mobility, multi-address multi-homing, etc., the addresses that are used actually on the wire do not necessarily match with the addresses that the applications expect to see. In the NAT case the addresses are changed on the fly, thereby invalidating any transport mode checksums (unless, of course, a tunnel is used). Mobile nodes change their addresses periodically, and the existing applications rarely survive the address changes without some help, e.g., Mobile IP. Multi-addressing based multi-homed nodes would prefer to keep their connections active even when the primary (or currently used) IP address becomes unusable in the face of an network outage.

Based on the reasons above, there is clearly a need for a mode of communication where the addresses that the applications see are distinct from the addresses that are actually used in the wire. The current IPsec tunnel mode provides the required functionality, but at the cost of additional overhead in terms of larger packets and more complicated processing.

3.1 Related work

The basic idea captured by this draft has been floating around for a long time. Steven Bellovin's HostNAT talk [7] at the Los Angeles IETF is an early example. After that, basically the same idea has surfaced several times. Perhaps the most concrete current proposal is the Host Identity Protocol (HIP) [10], where BEET mode ESP processing is an integral part of the overall protocol.

4. Use scenarios

In this section we describe a number of possible use scenarios. None of these use scenarios are meant to be complete specifications on how exactly to support the functionality. Separate specifications are needed for that. Instead, the purpose of this section is to discuss the overall benefits of the BEET mode, and to lay out a road map for possible future documents. This section is informative.

4.1 NAT traversal

NAT traversal is currently a major problem in IPsec. It is not sufficient to encapsulate the packets into UDP; additionally, tunnel mode must be used. Tunnel mode is required since the outer IP addresses at the ends of the protected connection differ. If transport mode was used, the differing IP addresses would lead to failing upper layer TCP/UDP checksums.

The BEET mode provides sufficient tunnel mode semantics without the packet overhead of the tunnel mode. A pair of BEET mode SAs can be effectively used to "un-NAT" packets that have been NATed during their travel through the network. Figure 1 illustrates the process.

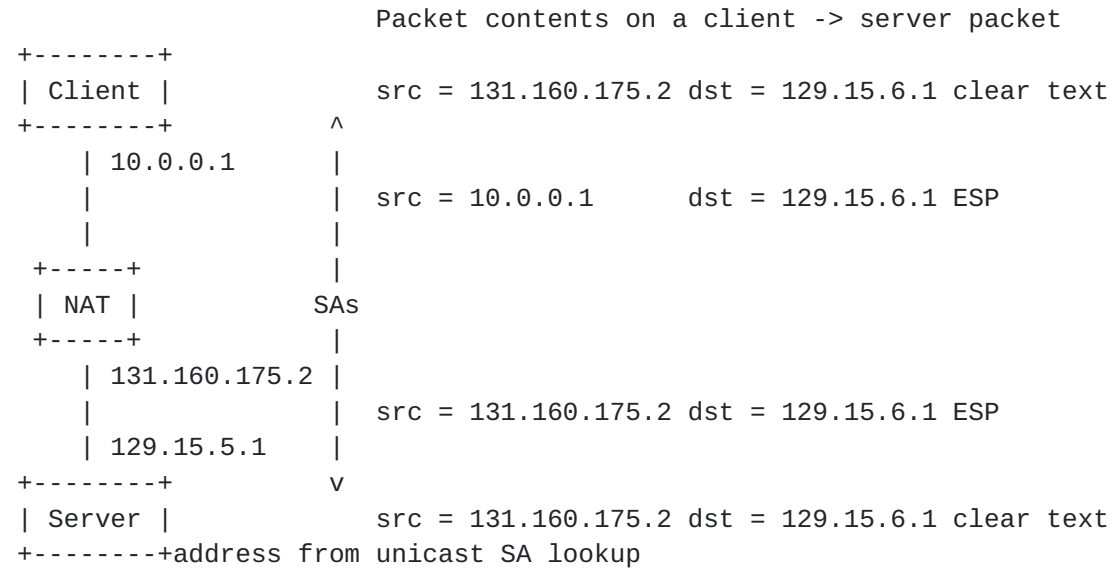


Figure 1

A drawback in this scheme is that the Client must either know its public IP address, or it must rely on the Server to tell what address to use. It must be noticed that if the NAT box is mapping several internal IP addresses into a single public address, the public address cannot be directly used. In that case the client and server need to agree on a unique address, to be used to internally represent

the client. It must be pointed out that such an address is semantically very similar to a Mobile IP home address. The details of such address agreement are beyond the scope of this document.

4.2 Mobile IP

In Mobile IP, the BEET mode could be used instead of the currently defined wire formats. If the hosts would be using end-to-end ESP anyway, this has the benefit of saving the space that would otherwise be taken by the standard Mobile IP wire formats. Furthermore, in BEET the inner IP header does not actually appear in the wire format. Effectively, this makes BEET as space efficient for mobile nodes as the standard ESP transport mode is today between fixed hosts.

Instead of having a separate Binding Cache, the nodes could include the address translation information into a pair of BEET mode security associations.

4.2.1 Mobile IPv4

In the current Mobile IPv4, two different wire formats are used, depending on whether there is a NAT device between the communicating hosts or not. See Figure 2, below.

Mobile IPv4 wire format without NAT traversal

IP(CoA->HA) | IP(HoA->CN) | payload

Mobile IPv4 wire format with NAT traversal

IP(CoA->HA) | UDP(any->434) | MIP header | IP(HoA->CN) | payload

(where the MIP header is a minimal 4 octet header)

[Figure courtesy to Sami Vaarala.]

Figure 2

It is required that the inner address representing the mobile node, as seen by the application, is always the home address. That is, from the application point of view, the packets flow between the home address and the correspondent node address.

If IPsec is used to protect the traffic between the Mobile Node and the Correspondent node, ESP transport mode can be used. However, the transport mode ESP packet is enclosed into an IP-over-IP wrapper at the home agent, see Figure 3.

Current Mobile IPv4 wire format with end-to-end ESP transport mode:

```
  CN -> HA:               IP(CN->HoA) | ESP | payload | ESP trailer
  HA -> MN: IP(HA->CoA) | IP(CN->HoA) | ESP | payload | ESP trailer

  MN -> HA: IP(CoA->HA) | IP(HoA->CN) | ESP | payload | ESP trailer
  HA -> CN:               IP(HoA->CN) | ESP | payload | ESP trailer
```

Proposed Mobile IPv4 wire format with ESP BEET mode:

```
  CN -> HA:               IP(CN->HoA) | ESP | payload | ESP trailer
  HA -> MN: IP(HA->CoA)               | ESP | payload | ESP trailer

  MN -> HA: IP(CoA->HA)               | ESP | payload | ESP trailer
  HA -> CN:               IP(HoA->CN) | ESP | payload | ESP trailer
```

Figure 3

In this scenario, the correspondent node does not need to be aware that the security association is in fact using the BEET mode. If the home agent and the mobile node co-operate, and the mobile node implements the BEET semantics, the change could be implemented transparently to the correspondent node.

The SPI towards the MN MUST be selected so that the HA can differentiate MNs from each other if they are communicating towards the same CN. As the SA is anyway end-to-end the HA MAY check during the key exchange that the selected SPI will not collide with other MNs.

As multiple CNs may choose same SPI for receiving data from HA, the HA must implement SPINAT [8] towards MN. Thus, the SPI used to receive packets from MN at HA would uniquely identify the real destination CN. The SPI must be negotiated per CN basis but as it is assumed that there would be a end-to-end SA anyway the amount of signaling doesn't need to be increased

It should be noticed that the space savings are even larger in the NAT traversal situation, as is illustrated in Figure Figure 4, below.

Current Mobile IPv4 NAT-traversal wire format with end-to-end transport ESP:

```
     CN -> HA:                           IP(CN->HoA) | ESP | payload | ESP
trailer
     HA -> MN: IP(HA->CoA) | UDP | MIP | IP(CN->HoA) | ESP | payload | ESP
trailer

     MN -> HA: IP(CoA->HA) | UDP | MIP | IP(HoA->CN) | ESP | payload | ESP
trailer
     HA -> CN:                           IP(HoA->CN) | ESP | payload | ESP
trailer
```

Proposed Mobile IPv4 NAT-traversal wire format with BEET ESP:

```
     CN -> HA: IP(CN->HoA)       | ESP | payload | ESP trailer
     HA -> MN: IP(HA->CoA) | UDP | ESP | payload | ESP trailer

     MN -> HA: IP(CoA->HA) | UDP | ESP | payload | ESP trailer
     HA -> CN: IP(HoA->CN)       | ESP | payload | ESP trailer
```

Figure 4

In the NAT traversal case the HA doesn't have to implement the SPINAT because the CN MAY be piggy packed in the UDP source and destination IP and port information. Two separate UDP connections MAY not have the same source and destination IP and port pairs thus the UDP connection will identify the CN uniquely.

4.2.2 Mobile IPv4 route optimization

BEET can be used for route optimization purposes as the outer IP address can always be set to as the current CoA of the MN. Likewise the MN can set the outer address as the address of the CN instead of the HA's address, although this would require that both ends support BEET mode. Binding updates would be sent to the CN as well instead of just updating the location on HA. Revealing MN's real location to the CN might not always be desirable.

4.2.3 Mobile IPv6

Triangular routing in Mobile IPv6 is similar to that of Mobile IPv4. However, the tunnel between the home agent and the mobile node is an ESP tunnel instead of being a plain IP-over-IP tunnel. However, if BEET mode was used between the correspondent node and the mobile

node, the ESP tunnel between the home agent and the mobile node would not bring any additional protection to the payload data. Thus, in that case BEET could replace the ESP tunnel, similar to the IPv4

case, illustrated in Figure 3 above.

Mobile IPv6 Route Optimization uses a Type 2 Routing Header (RH) and Home Address Option (HAO) in the packet wire format. However, it can be argued that the semantics of these options is equivalent to a optimized point-to-point tunnel. That is, the Type 2 RH defines the real destination address of a packet, thereby effectively creating a partial tunnel where the inner and outer source addresses are identical but the destination addresses differ. Similarly, the Home Address Option defines the real source address of the packet, again creating a partial tunnel. The only difference is that this time the inner and outer destination addresses are identical but the source addresses differ.

Thus, for Mobile IPv6, BEET mode would define a different wire format for the payload packets. Instead of using Type 2 RH and HAO, the packets could be encapsulated into a BEET mode ESP tunnel. In the case that ESP is used anyway, this has the advantage that the standard Mobile IPv6 extra headers are not needed, thereby saving bytes in the headers. Compared to tunnel mode ESP, BEET mode has the advantage that the inner IP header is not needed.

In Mobile IPv6, mobility management can be implemented just as before, using the HoTI/CoTI, HoT/CoT and Binding Update (BU) messages. The difference would lay in handling Binding Updates. If BEET mode was used, processing Binding Updates would change the outer IP addresses in the BEET mode Security Associations instead of changing the Binding Cache.

4.3 End-node multi-address multi-homing

The BEET mode provides for limited end-node multi-address multi-homing. It semantically provides a tunnel between the end-hosts, with fixed inner IP addresses. This allows a multi-homed host to use different outer IP addresses in different packets, without any notice by the upper layer protocols. The upper layer protocols see the inner IP address at all times. Thus, this limited form of multi-homing has no affect on the applications, which seemingly communicate over fixed IP addresses all the time.

Implementing this kind of limited multi-homing support would require a small change to the current IPsec SPD and SA implementations. Currently the incoming SA selection is based on the SPI and destination address, with the implicit assumption that there is only one possible destination address for each incoming SA. In a multi-homed host it would be desirable to have multiple destination addresses associated with the SA, thereby allowing the same SA to be used independent on the actual destination address in the packets.

Removing the destination address from unicast SA lookup is already being proposed in the current ESP draft [4].

If it is considered undesirable to change the implementations to support multiple alternative destination addresses, it would still be possible to support limited multi-homing by creating several parallel SAs, one for each destination address. Each of these SAs would have identical inner addresses. Effectively, this would distribute the tunnel over multiple SAs.

In this latter implementation, the outgoing SA processing becomes more complex. Selecting the outgoing SA does not depend only on the inner IP addresses but also on the outer destination address. Selecting the outer destination address depends on the current multi-homing situation. This creates a situation where the SA processing must be deferred after selecting the actual outer address to be used. This might be difficult in some implementations.

4.4 Host Identity Protocol

The Host Identity Protocol (HIP) is a piece of more recent development. Its aim is to explore the possibilities created by separating the end-host identifier and locator of IP addresses. There are currently five implementations, and the specifications are being finalized. [9] [10]

In HIP, the TCP and UDP sockets are not bound to IP addresses but to Host Identifiers (HI). The Host Identifiers create a new independent name space.

The BEET mode supports HIP by defining the inner tunnel in terms of Host Identifiers and the outer tunnel in terms of standard IP addresses. In that way all processing prior to outgoing ESP and after incoming ESP uses Host Identifiers. The wire format packets use standard IP addresses and ESP transport packet format.

5. Protocol definition

In this section we define the exact protocol formats and operations. This section is normative.

5.1 Changes to Security Association data structures

A BEET mode Security Association contains the same data as a regular tunnel mode Security Association, with the exception that the inner selectors must be single addresses and cannot be subnets. The data includes the following:

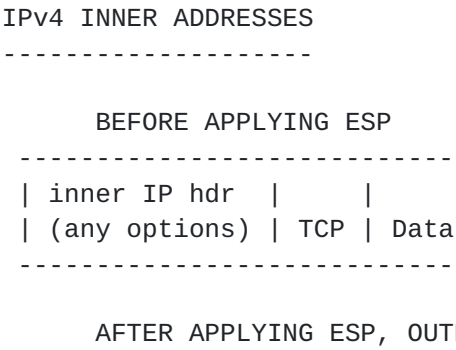
- A pair of inner IP addresses.
- A pair of outer IP addresses.
- Cryptographic keys and other data as defined in RFC2401 [3] Section 4.4.3.

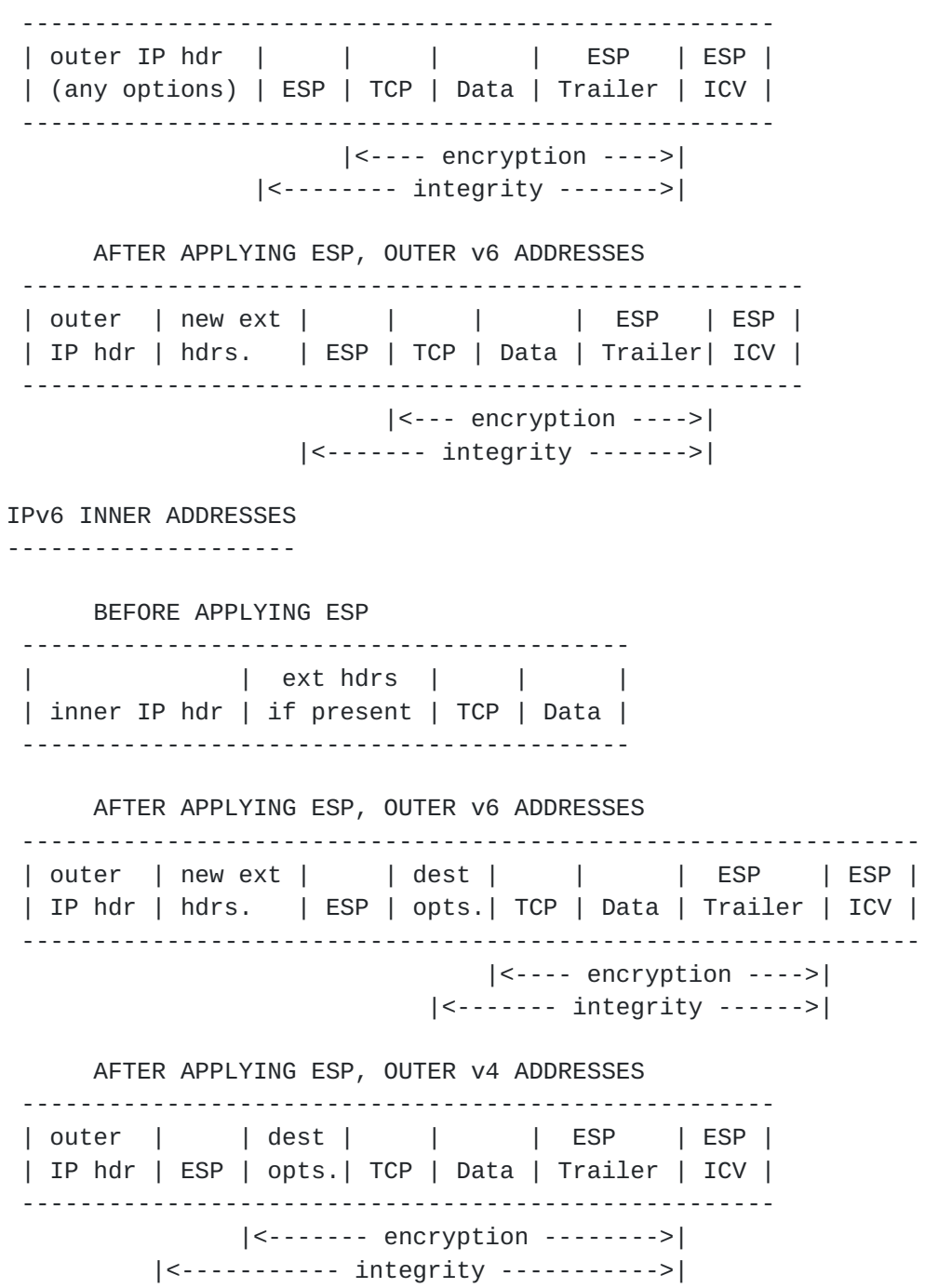
A conforming implementation MAY store the data in a way different than or similar to a regular tunnel mode Security Association.

Note that in a conforming implementation the inner and outer addresses MAY belong to different address families. All implementations that support both IPv4 and IPv6 SHOULD support both IPv4-over-IPv6 and IPv6-over-IPv4 tunneling.

5.2 Packet format

The wire packet format is identical to the ESP transport mode wire format as defined in [4] Section 3.1.1. However, the resulting packet contains outer IP addresses instead of the inner IP addresses received from the upper layer. The construction of the outer headers is defined in RFC2401 [3] Section 5.1.2. The following diagram illustrates ESP BEET mode positioning for typical IPv4 and IPv6 packets.





5.3 Cryptographic processing

The outgoing packets MUST be protected exactly as in ESP transport mode [4]. That is, the upper layer protocol packet is wrapped into an ESP header, encrypted, and authenticated exactly as if regular transport mode was used. The resulting ESP packet is subject to IP header processing as defined in Section 5.4 and Section 5.5. The

incoming ESP protected messages are verified and decrypted exactly as if regular transport mode was used. The resulting clear text packet is subject to IP header processing as defined in Section 5.4 and Section 5.6.

5.4 IP header processing

The biggest difference between the BEET mode and the other two modes is in IP header processing. In the regular transport mode the IP header is kept intact. In the regular tunnel mode an outer IP header is created on output and discarded on input. In the BEET mode the IP header is replaced with another one on both input and output.

On the BEET mode output side, the IP header processing MUST first ensure that the IP addresses in the original IP header contain the inner addresses as specified in the SA. This MAY be ensured by proper policy processing, and it is possible that no checks are needed at the SA processing time. Once the IP header has been verified to contain the right IP inner addresses, it is discarded. A new IP header is created, using the discarded inner header as a hint for other fields but the IP addresses. The IP addresses in the new header MUST be the outer tunnel addresses.

On input side, the received IP header is simply discarded. Since the packet has been decrypted and verified, no further checks are necessary. A new IP header, corresponding to a tunnel mode inner header, is created, using the discarded outer header as a hint for other fields but the IP addresses. The IP addresses in the new header MUST be the inner addresses.

As the outer header fields are used as hint for creating inner header, it must be noted that inner header differs as compared to tunnel-mode inner header. In BEET mode the inner header will have the TTL, DF-bit and other option values from the outer header. The TTL, DF-bit and other option values of the inner header MUST be processed by the stack.

5.5 Handling of outgoing packets

The outgoing BEET mode packets are processed as follows:

1. The system MUST verify that the IP header contains the inner source and destination addresses, exactly as defined in the SA. This verification MAY be explicit, or it MAY be implicit, for example, as a result of prior policy processing. Note that in some implementations there may be no real IP header at this time but the source and destination addresses may be carried out-of-band. In case the source address is still unassigned, it SHOULD

be ensured that the designated inner source address would be selected at a later stage.

2. The IP payload (the contents of the packet beyond the IP header) is wrapped into an ESP header as defined in [4] Section 3.3.

3. A new IP header is constructed, replacing the original one. The new IP header MUST contain the outer source and destination addresses, as defined in the SA. Note that in some implementations there may be no real IP header at this time but the source and destination addresses may be carried out-of-band. In the case where the source address must be left unassigned, it SHOULD be made sure that the right source address is selected at a later stage. Other than the addresses, it is RECOMMENDED that the new IP header copies the fields from the original IP header.

4. If there are any IPv4 header options in the original packet, it is RECOMMENDED that they are discarded. If the inner header contains an option that MUST be transported between the tunnel end-points, sender MAY encapsulate the inner header in to the ESP packet and set the ESP next header as IPv4 (4). Thus, sender MUST encapsulate the whole IP datagram similarly as in tunnel-mode. The inner header contains the BEET mode inner addresses as specified in the SA.

Instead of literally discarding the IP header and constructing a new one a conforming implementation MAY simply replace the addresses in an existing header. However, if the RECOMMENDED feature of allowing the inner and outer addresses from different address families is used, this simple strategy does not work.

5.6 Handling of incoming packets

The incoming BEET mode packets are processed as follows:

1. The system MUST verify and decrypt the incoming packet successfully, as defined in [4] section 3.4. If the verification or decryption fails, the packet MUST be discarded.

2. The original IP header is simply discarded, without any checks. Since the ESP verification succeeded, the packet can be safely assumed to have arrived from the right sender.

3. If the sender has set the ESP next protocol field to IPv4 and included the inner header as previously described, the receiver MUST verify that the inner header contains correct inner addresses. If verification fails, the packet MUST be discarded. The receiver MUST processes the inner header and options as if

the packet would have been received in tunnel-mode and the inner header would have contained the receivers address as destination.

4. A new IP header is constructed, replacing the original one. The new IP header MUST contain the inner source and destination addresses, as defined in the SA. Note that in some implementations the real IP header may have already been discarded and the source and destination addresses are carried out-of-band. In such case the out-of-band addresses MUST be the inner addresses. Other than the addresses, it is RECOMMENDED that the new IP header copies the fields from the original IP header.

Instead of literally discarding the IP header and constructing a new one a conforming implementation MAY simply replace the addresses in an existing header. However, if the RECOMMENDED feature of allowing the inner and outer addresses from different address families is used, this simple strategy does not work.

6. Policy considerations

In this section we describe how the BEET mode affects on IPsec policy processing. This section is normative.

A BEET Security Association SHOULD NOT be used with NULL authentication.

On the output side, the IPsec policy processing mechanism SHOULD take care that only packets with IP addresses matching with the inner addresses of a Security Association are passed to that Security Association. If the policy mechanism do not provide full assurance on this, the SA processing MUST check the addresses. Further policy distinction may be specified based on IP version, upper layer protocol, and ports. If such restrictions are defined, they MUST be enforced.

On the output side, the policy rules SHOULD prevent any packets containing the inner IP addresses pair from escaping to the wire in clear text.

On the input side, there is no policy processing necessary on encrypted packets. The SA is found based on the SPI and destination address. A single SA MAY be associated with several destination addresses. Since the outer IPsec addresses are discarded, and since the packet authenticity and integrity is protected by ESP, there is no need to check the outer addresses. Since the inner addresses are fixed and restored from the SA, there is no need to check them. There MAY be further policy rules specifying allowed upper layer protocols and ports. If such restrictions are defined, they MUST be enforced.

On the input side, there SHOULD be a policy rule that filters out clear text packets that contain the inner addresses.

7. PF_KEY extensions

This section defines the necessary extensions to the PF_KEYv2 API [2] to support the BEET mode. This section is informative.

A BEET mode Security Association is created by specifying the inner IP addresses in the PF_KEYv2 Identity extensions, using two new identity types. The identity types of the source and destination identity extensions MUST be identical, i.e. either IPv4 or IPv6.

```
#define SADB_X_IDENTTYPE_ADDR           4
#define SADB_IDENTTYPE_MAX              4
```

When this new identity type is used, the contents of the identity field in the PF_KEY messages MUST be a socket address.

For SADB_X_IDENTTYPE_ADDR the length of AF_INET type of identity MUST be the length of struct sockaddr_in. Thus the length for AF_INET6 type of identity MUST be the length of struct sockaddr_in6.

Additionally, a new IPsec mode is defined in ipsec.h, and used in the unspecified but commonly used the PF_KEY extension SADB_X_EXT_SA2 field sadb_x_sa2_mode.

```
#define IPSEC_MODE_BEET 4
```

If an SA is specified using SADB_X_EXT_SA2, if the sadb_x_sa2_mode is IPSEC_MODE_BEET, and if the source and destination identities are defined in terms of SADB_IDENTTYPE_ADDR, then the BEET mode MUST be used. If an SA is specified using SADB_X_EXT_SA2, if the sadb_x_sa2_mode is IPSEC_MODE_BEET, and if the identities are defined in terms (other than the new type defined above) that exactly match to single IPv4 or IPv6 addresses, then the BEET mode SHOULD be used.

8. New requirements on Key Management protocols

In this section we discuss the requirements that the new mode places upon existing and new key management protocols. This section is informative.

In order to provide support for the BEET mode, key agreement protocol implementations must understand the existence of such a mode. In some situations it is sufficient that the BEET mode is implemented at the IPsec ESP level only at one end as long as the key management is aware of its usage. For example, the NAT scenario described in Section 4.1 does not require a BEET ESP implementation at the server end. It is sufficient that the client implements the BEET mode; in fact, if the client somehow knows it public IP address it may be able to set up the BEET mode security associations without any explicit concent on the server end. On the other hand, if the client does not know its public IP address, it needs help from the server in order to determine it.

More generally, one can get benefit from the BEET mode only to the extend the key management protocol supports it. If the key management protocol is fully aware of mobility and multi-homing issues, and provides facilities for signaling changes in the current connectivity situation, it is relatively easy to implement end-node mobility and multi-address multi-homing with BEET. An example of such usage is HIP [10].

9. Implementing the functionality with other means

It is currently possible to implement the equivalent of BEET mode by using transport mode ESP and explicit network address translation at the end-hosts themselves. In this section we briefly compare these two alternatives. The purpose of this section is to give background information for security considerations. This section is informative.

In an implementation using the BEET mode, the input side IP address translation is integrated with the decryption and integrity verification processing. The packet is passed and given the inner addresses if and only if it is correctly decrypted and verified. A typical IPsec SPD implementation would prohibit receiving unprotected IP packets that use the inner addresses on the wire, as it is done in the regular tunnel mode. At the same time, any other uses of the outer addresses would be trivial; passing a packet to the SA requires both that the packet has an ESP header and that the SPI matches.

In an implementation based on separate address translation and transport mode ESP, the address translation and cryptographic processing are completely separate. In practise, the host must translate the outer IP address into the inner IP addresses before the packet is passed to IPsec. (The other way around may not be secure, since there would be no way for the address translation process to know if the packet was correctly decrypted and verified or if it was received via some other means.) Using the outer addresses for other purposes may be hard, depending on the implementation of the address translation mechanism. In particular, using the outer addresses on other ESP SAs may be hard, since the typical address translation mechanisms could be only configured with the protocol level (ESP vs. not) and do not understand SPIs.

At the output side, a BEET mode implementation takes care of translating the inner addresses to outer addresses, as a part of the encryption process. The IPsec SPD contains necessary entries that make sure that the inner addresses never leak.

In an implementation based on separate components, the output packets would be passed with inner addresses from IPsec to the address translation mechanism. The address translation mechanism will then translate the inner addresses to outer addresses. While this does not prevent usage of the outer addresses for other purposes, the configuration is brittle and error prone. If there are mistakes at the IPsec configuration, the address translation mechanism may translate unprotected packets, leading to potential confusion. If there are mistakes at the address translation side, the inner addresses may leak to the network.

10. Security Considerations

In this section we discuss the security properties of the BEET mode, discussing some limitations [11]. This section is normative.

There are no known new vulnerabilities that the introduction of the BEET mode would create.

It is currently possible to implement the equivalent of BEET mode by using transport mode ESP and explicit network address translation at the end-hosts themselves. However, such an implementation is more complex, less flexible, and potentially more vulnerable to security problems that are caused by misconfigurations; see Section 9.

The main security benefit is an operational one. To implement the same functionality without the BEET mode typically requires configuring three different, unrelated components in the hosts.

- The transport mode ESP SAs must be configured.

- A host based NAT function must be configured to properly translate between the inner and outer addresses.

- A host firewall must be configured to properly filter out packets so that inner addresses do not leak in or out.

While it may be possible to configure these components to achieve the same functionality, such a configuration is error prone, increasing the probability of security vulnerabilities. An integrated BEET mode implementation is less prone to configuration mistakes. Furthermore, it would be fairly hard to implement portable key management protocols that would be able to configure all of the required components at the same time. On the other hand, it would be easy to provide a portable key management protocol implementation that would be able to configure BEET mode SAs through the specified PF_KEY extensions.

Since the BEET security associations have the semantics of a fixed, point-to-point tunnel between two IP addresses, it is possible to place one or both of the tunnel end points into other nodes but those that actually "possess" the inner IP addresses, i.e., to implement a BEET mode proxy. However, since such usage defeats the security benefits of combined ESP and hostNAT processing, as discussed above, the implementations SHOULD NOT support such usage.

As in the BEET mode the outer header source address is not checked at the input handling, there is the potential possibility a DoS attack where the attacker sends random packets that match with the SPI of some BEET mode SA. This kind of attack would cause the victim to perform unnecessary integrity checks that would result in a failure. If this kind of behaviour is detected, the node may request rekeying from the Key Management Protocol, and after rekeying, if the attacker was not on the path, the new SPI value would not be known by the attacker.

11. IANA Considerations

The PF_KEYv2 interface should probably have an IANA registry.

12. Acknowledgments

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Appendix A. Implementation experiences

We have implemented the BEET mode to the FreeBSD 5.3 KAME stack. Our implementation uses the PF_KEYv2 identity extension, as described in Section 7.

The current implementation is based on four hooks placed at the strategical locations at the ESP and ip_output processing. We support full IPv4/IPv6 conversions, allowing both IPv4-over-IPv6 and IPv6-over-IPv4 tunneling. The number of lines changed in the KAME policy processing is 36 lines; these changes were necessary to fully support the identity extension, which was partly unimplemented in the KAME stack. The hooks themselves take 83 lines, and the protocol processing code is 450 lines long. About 90% of the protocol processing code was copied and pasted from the IPsec tunnel mode and transport mode routines, with minimal changes. About 70% of the code is needed to implement v4-over-v6 and v6-over-v4 tunneling. The number of actual functional lines for the simple v4-over-v4 and v6-over-v6 cases is mere 62 lines. The implementation effort took three days from two programmers, including writing simple test cases and performing rudimentary testing on the implementation to see that it works.

The current implementation is tailored for experimentation. A more proper implementation would implement all of the processing as an integral part of the IPsec processing. The current KAME code supports only two modes. Once the necessary cleanups, such as replacing "if" statements with "switch" statements, we expect the extra protocol processing code required by the BEET mode to take less than 100 lines.

Appendix B. Garden beets

Commonly known as the garden beet, this firm, round root vegetable has leafy green tops, which are also edible and highly nutritious. The most common color for beets (called "beetroots" in the British Isles) is a garnet red. However, they can range in color from deep red to white, the most intriguing being the Chioggia (also called "candy cane"), with its concentric rings of red and white. Beets are available year-round and should be chosen by their firmness and smooth skins.

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