        End-Host Mobility and Multihoming with the Host Identity Protocol

Status of This Memo

Abstract

   This document defines mobility and multihoming extensions to the Host
   Identity Protocol (HIP). Specifically, this document defines a
   general "LOCATOR" parameter for HIP messages that allows for a HIP
   host to notify peers about alternate addresses at which it may be
   reached. This document also defines elements of procedure for
   mobility of a HIP host -- the process by which a host dynamically
   changes the primary locator that it uses to receive packets. While
   the same LOCATOR parameter can also be used to support end-host
   multihoming, detailed procedures are left for further study.

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1. Introduction and Scope

    The Host Identity Protocol [RFC4423] (HIP) supports an architecture
    that decouples the transport layer (TCP, UDP, etc.) from the
    internetworking layer (IPv4 and IPv6) by using public/private key
    pairs, instead of IP addresses, as host identities. When a host uses
    HIP, the overlying protocol sublayers (e.g., transport layer sockets
    and Encapsulating Security Payload (ESP) Security Associations (SAs))
    are instead bound to representations of these host identities, and
    the IP addresses are only used for packet forwarding. However, each
    host must also know at least one IP address at which its peers are
    reachable. Initially, these IP addresses are the ones used during
    the HIP base exchange [RFC5201].

One consequence of such a decoupling is that new solutions to
network-layer mobility and host multihoming are possible. There are
potentially many variations of mobility and multihoming possible.
The scope of this document encompasses messaging and elements of
procedure for basic network-level mobility and simple multihoming,
leaving more complicated scenarios and other variations for further
study. More specifically:

   This document defines a generalized LOCATOR parameter for use in
   HIP messages. The LOCATOR parameter allows a HIP host to notify a
   peer about alternate addresses at which it is reachable. The
   LOCATORs may be merely IP addresses, or they may have additional
   multiplexing and demultiplexing context to aid the packet handling
   in the lower layers. For instance, an IP address may need to be
   paired with an ESP Security Parameter Index (SPI) so that packets
   are sent on the correct SA for a given address.

   This document also specifies the messaging and elements of
   procedure for end-host mobility of a HIP host -- the sequential
   change in the preferred IP address used to reach a host. In
   particular, message flows to enable successful host mobility,
   including address verification methods, are defined herein.

   However, while the same LOCATOR parameter is intended to support
   host multihoming (parallel support of a number of addresses), and
   experimentation is encouraged, detailed elements of procedure for
   host multihoming are left for further study.

While HIP can potentially be used with transports other than the ESP
transport format [RFC5202], this document largely assumes the use of
ESP and leaves other transport formats for further study.

There are a number of situations where the simple end-to-end
readdressing functionality is not sufficient. These include the
initial reachability of a mobile host, location privacy, simultaneous
mobility of both hosts, and some modes of NAT traversal. In these
situations, there is a need for some helper functionality in the
network, such as a HIP rendezvous server [RFC5204]. Such
functionality is out of the scope of this document. We also do not
consider localized mobility management extensions (i.e., mobility
management techniques that do not involve directly signaling the
correspondent node); this document is concerned with end-to-end
mobility. Finally, making underlying IP mobility transparent to the
transport layer has implications on the proper response of transport
congestion control, path MTU selection, and Quality of Service (QoS).
Transport-layer mobility triggers, and the proper transport response
to a HIP mobility or multihoming address change, are outside the
scope of this document.

2. Terminology and Conventions

   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 RFC 2119 [RFC2119].

   LOCATOR. The name of a HIP parameter containing zero or more Locator
      fields. This parameter's name is distinguished from the Locator
      fields embedded within it by the use of all capital letters.

   Locator. A name that controls how the packet is routed through the
      network and demultiplexed by the end host. It may include a
      concatenation of traditional network addresses such as an IPv6
      address and end-to-end identifiers such as an ESP SPI. It may
      also include transport port numbers or IPv6 Flow Labels as
      demultiplexing context, or it may simply be a network address.

   Address. A name that denotes a point-of-attachment to the network.
      The two most common examples are an IPv4 address and an IPv6
      address. The set of possible addresses is a subset of the set of
      possible locators.

   Preferred locator. A locator on which a host prefers to receive
      data. With respect to a given peer, a host always has one active
      Preferred locator, unless there are no active locators. By
      default, the locators used in the HIP base exchange are the
      Preferred locators.

   Credit Based Authorization. A host must verify a mobile or
      multihomed peer's reachability at a new locator. Credit-Based
      Authorization authorizes the peer to receive a certain amount of
      data at the new locator before the result of such verification is
      known.

3. Protocol Model

   This section is an overview; more detailed specification follows this
   section.

3.1. Operating Environment

   The Host Identity Protocol (HIP) [RFC5201] is a key establishment and
   parameter negotiation protocol. Its primary applications are for
   authenticating host messages based on host identities, and
   establishing security associations (SAs) for the ESP transport format
   [RFC5202] and possibly other protocols in the future.

```
   +--------------------+                 +--------------------+
   |                    |                 |                    |
   |   +-----------+    |                 |   +-----------+    |
   |   |   Key     |    |      HIP         |   |   Key     |    |
   |   | Management| <-+---------------------+-> | Management|    |
   |   | Process   |    |                 |   | Process   |    |
   |   +-----------+    |                 |   +-----------+    |
   |        ^          |                 |        ^          |
   |        |          |                 |        |          |
   |        v          |                 |        v          |
   |   +-----------+    |                 |   +-----------+    |
   |   |  IPsec    |    |      ESP         |   |  IPsec    |    |
   |   |  Stack    | <-+---------------------+-> |  Stack    |    |
   |   |           |    |                 |   |           |    |
   |   +-----------+    |                 |   +-----------+    |
   |                    |                 |                    |
   |                    |                 |                    |
   |     Initiator      |                 |     Responder      |
   +--------------------+                 +--------------------+
```
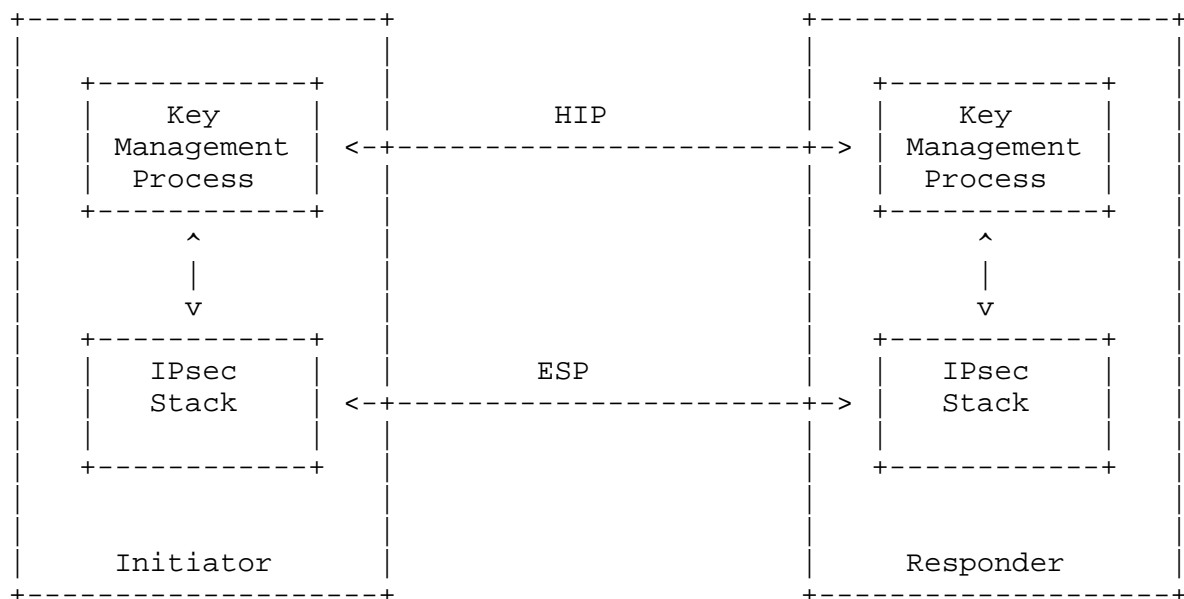
                     Figure 1: HIP Deployment Model

   The general deployment model for HIP is shown above, assuming
   operation in an end-to-end fashion. This document specifies
   extensions to the HIP protocol to enable end-host mobility and basic
   multihoming. In summary, these extensions to the HIP base protocol
   enable the signaling of new addressing information to the peer in HIP
   messages. The messages are authenticated via a signature or keyed
   hash message authentication code (HMAC) based on its Host Identity.
   This document specifies the format of this new addressing (LOCATOR)
   parameter, the procedures for sending and processing this parameter
   to enable basic host mobility, and procedures for a concurrent
   address verification mechanism.

```
                ---------
                | TCP   |  (sockets bound to HITs)
                ---------
                    |
                ---------
      ----> | ESP   |  {HIT_s, HIT_d} <-> SPI
      |         ---------
      |         |    |
    ----    ---------
   | MH |-> | HIP   |  {HIT_s, HIT_d, SPI} <-> {IP_s, IP_d, SPI}
    ----    ---------
                    |
                ---------
                | IP    |
                ---------
```

          Figure 2: Architecture for HIP Mobility and Multihoming (MH)

Figure 2 depicts a layered architectural view of a HIP-enabled stack
using the ESP transport format. In HIP, upper-layer protocols
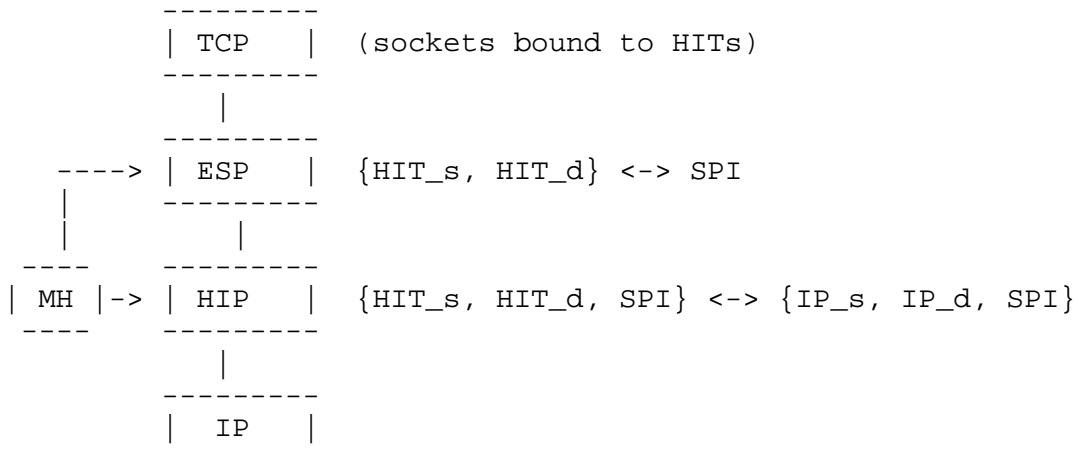(including TCP and ESP in this figure) are bound to Host Identity
Tags (HITs) and not IP addresses. The HIP sublayer is responsible
for maintaining the binding between HITs and IP addresses. The SPI
is used to associate an incoming packet with the right HITs. The
block labeled "MH" is introduced below.

Consider first the case in which there is no mobility or multihoming,
as specified in the base protocol specification [RFC5201]. The HIP
base exchange establishes the HITs in use between the hosts, the SPIs
to use for ESP, and the IP addresses (used in both the HIP signaling
packets and ESP data packets). Note that there can only be one such
set of bindings in the outbound direction for any given packet, and
the only fields used for the binding at the HIP layer are the fields
exposed by ESP (the SPI and HITs). For the inbound direction, the
SPI is all that is required to find the right host context. ESP
rekeying events change the mapping between the HIT pair and SPI, but
do not change the IP addresses.

Consider next a mobility event, in which a host is still single-homed
but moves to another IP address. Two things must occur in this case.
First, the peer must be notified of the address change using a HIP
UPDATE message. Second, each host must change its local bindings at
the HIP sublayer (new IP addresses). It may be that both the SPIs
and IP addresses are changed simultaneously in a single UPDATE; the
protocol described herein supports this. However, simultaneous
movement of both hosts, notification of transport layer protocols of
the path change, and procedures for possibly traversing middleboxes
are not covered by this document.

   Finally, consider the case when a host is multihomed (has more than
   one globally routable address) and has multiple addresses available
   at the HIP layer as alternative locators for fault tolerance.
   Examples include the use of (possibly multiple) IPv4 and IPv6
   addresses on the same interface, or the use of multiple interfaces
   attached to different service providers. Such host multihoming
   generally necessitates that a separate ESP SA is maintained for each
   interface in order to prevent packets that arrive over different
   paths from falling outside of the ESP anti-replay window [RFC4303].
   Multihoming thus makes it possible that the bindings shown on the
   right side of Figure 2 are one to many (in the outbound direction,
   one HIT pair to multiple SPIs, and possibly then to multiple IP
   addresses). However, only one SPI and address pair can be used for
   any given packet, so the job of the "MH" block depicted above is to
   dynamically manipulate these bindings. Beyond locally managing such
   multiple bindings, the peer-to-peer HIP signaling protocol needs to
   be flexible enough to define the desired mappings between HITs, SPIs,
   and addresses, and needs to ensure that UPDATE messages are sent
   along the right network paths so that any HIP-aware middleboxes can
   observe the SPIs. This document does not specify the "MH" block, nor
   does it specify detailed elements of procedure for how to handle
   various multihoming (perhaps combined with mobility) scenarios. The
   "MH" block may apply to more general problems outside of HIP.
   However, this document does describe a basic multihoming case (one
   host adds one address to its initial address and notifies the peer)
   and leave more complicated scenarios for experimentation and future
   documents.

3.1.1. Locator

   This document defines a generalization of an address called a
   "locator". A locator specifies a point-of-attachment to the network
   but may also include additional end-to-end tunneling or per-host
   demultiplexing context that affects how packets are handled below the
   logical HIP sublayer of the stack. This generalization is useful
   because IP addresses alone may not be sufficient to describe how
   packets should be handled below HIP. For example, in a host
   multihoming context, certain IP addresses may need to be associated
   with certain ESP SPIs to avoid violating the ESP anti-replay window.
   Addresses may also be affiliated with transport ports in certain
   tunneling scenarios. Locators may simply be traditional network
   addresses. The format of the locator fields in the LOCATOR parameter
   is defined in Section 4.

3.1.2. Mobility Overview

   When a host moves to another address, it notifies its peer of the new
   address by sending a HIP UPDATE packet containing a LOCATOR
   parameter. This UPDATE packet is acknowledged by the peer. For
   reliability in the presence of packet loss, the UPDATE packet is
   retransmitted as defined in the HIP protocol specification [RFC5201].
   The peer can authenticate the contents of the UPDATE packet based on
   the signature and keyed hash of the packet.

   When using ESP Transport Format [RFC5202], the host may at the same
   time decide to rekey its security association and possibly generate a
   new Diffie-Hellman key; all of these actions are triggered by
   including additional parameters in the UPDATE packet, as defined in
   the base protocol specification [RFC5201] and ESP extension
   [RFC5202].

   When using ESP (and possibly other transport modes in the future),
   the host is able to receive packets that are protected using a HIP
   created ESP SA from any address. Thus, a host can change its IP
   address and continue to send packets to its peers without necessarily
   rekeying. However, the peers are not able to send packets to these
   new addresses before they can reliably and securely update the set of
   addresses that they associate with the sending host. Furthermore,
   mobility may change the path characteristics in such a manner that
   reordering occurs and packets fall outside the ESP anti-replay window
   for the SA, thereby requiring rekeying.

3.1.3. Multihoming Overview

   A related operational configuration is host multihoming, in which a
   host has multiple locators simultaneously rather than sequentially,
   as in the case of mobility. By using the LOCATOR parameter defined
   herein, a host can inform its peers of additional (multiple) locators
   at which it can be reached, and can declare a particular locator as a
   "preferred" locator. Although this document defines a basic
   mechanism for multihoming, it does not define detailed policies and
   procedures, such as which locators to choose when more than one pair
   is available, the operation of simultaneous mobility and multihoming,
   source address selection policies (beyond those specified in
   [RFC3484]), and the implications of multihoming on transport
   protocols and ESP anti-replay windows. Additional definitions of
   HIP-based multihoming are expected to be part of future documents.

3.2. Protocol Overview

   In this section, we briefly introduce a number of usage scenarios for
   HIP mobility and multihoming. These scenarios assume that HIP is
   being used with the ESP transform [RFC5202], although other scenarios
   may be defined in the future. To understand these usage scenarios,
   the reader should be at least minimally familiar with the HIP
   protocol specification [RFC5201]. However, for the (relatively)
   uninitiated reader, it is most important to keep in mind that in HIP
   the actual payload traffic is protected with ESP, and that the ESP
   SPI acts as an index to the right host-to-host context. More
   specification details are found later in Section 4 and Section 5.

   The scenarios below assume that the two hosts have completed a single
   HIP base exchange with each other. Both of the hosts therefore have
   one incoming and one outgoing SA. Further, each SA uses the same
   pair of IP addresses, which are the ones used in the base exchange.

   The readdressing protocol is an asymmetric protocol where a mobile or
   multihomed host informs a peer host about changes of IP addresses on
   affected SPIs. The readdressing exchange is designed to be
   piggybacked on existing HIP exchanges. The majority of the packets
   on which the LOCATOR parameters are expected to be carried are UPDATE
   packets. However, some implementations may want to experiment with
   sending LOCATOR parameters also on other packets, such as R1, I2, and
   NOTIFY.

   The scenarios below at times describe addresses as being in either an
   ACTIVE, VERIFIED, or DEPRECATED state. From the perspective of a
   host, newly-learned addresses of the peer must be verified before put
   into active service, and addresses removed by the peer are put into a
   deprecated state. Under limited conditions described below
   (Section 5.6), an UNVERIFIED address may be used. The addressing
   states are defined more formally in Section 5.1.

   Hosts that use link-local addresses as source addresses in their HIP
   handshakes may not be reachable by a mobile peer. Such hosts SHOULD
   provide a globally routable address either in the initial handshake
   or via the LOCATOR parameter.

3.2.1. Mobility with a Single SA Pair (No Rekeying)

   A mobile host must sometimes change an IP address bound to an
   interface. The change of an IP address might be needed due to a
   change in the advertised IPv6 prefixes on the link, a reconnected PPP
   link, a new DHCP lease, or an actual movement to another subnet. In
   order to maintain its communication context, the host must inform its
   peers about the new IP address. This first example considers the

case in which the mobile host has only one interface, IP address, a
single pair of SAs (one inbound, one outbound), and no rekeying
occurs on the SAs. We also assume that the new IP addresses are
within the same address family (IPv4 or IPv6) as the first address.
This is the simplest scenario, depicted in Figure 3.

```
   Mobile Host                             Peer Host

          UPDATE(ESP_INFO, LOCATOR, SEQ)
      ------------------------------------>
          UPDATE(ESP_INFO, SEQ, ACK, ECHO_REQUEST)
      <------------------------------------
          UPDATE(ACK, ECHO_RESPONSE)
      ------------------------------------>
```
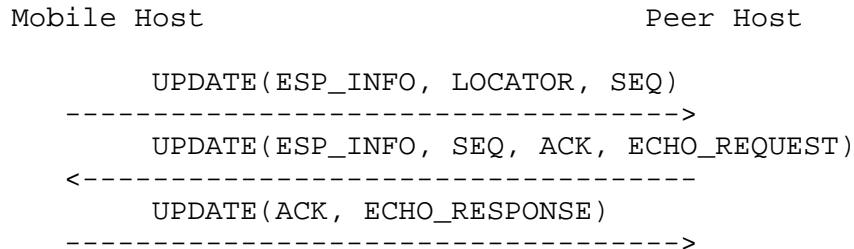
       Figure 3: Readdress without Rekeying, but with Address Check

   The steps of the packet processing are as follows:

   1. The mobile host is disconnected from the peer host for a brief
       period of time while it switches from one IP address to another.
       Upon obtaining a new IP address, the mobile host sends a LOCATOR
       parameter to the peer host in an UPDATE message. The UPDATE
       message also contains an ESP_INFO parameter containing the values
       of the old and new SPIs for a security association. In this
       case, the OLD SPI and NEW SPI parameters both are set to the
       value of the preexisting incoming SPI; this ESP_INFO does not
       trigger a rekeying event but is instead included for possible
       parameter-inspecting middleboxes on the path. The LOCATOR
       parameter contains the new IP address (Locator Type of "1",
       defined below) and a locator lifetime. The mobile host waits for
       this UPDATE to be acknowledged, and retransmits if necessary, as
       specified in the base specification [RFC5201].

   2. The peer host receives the UPDATE, validates it, and updates any
       local bindings between the HIP association and the mobile host's
       destination address. The peer host MUST perform an address
       verification by placing a nonce in the ECHO_REQUEST parameter of
       the UPDATE message sent back to the mobile host. It also
       includes an ESP_INFO parameter with the OLD SPI and NEW SPI
       parameters both set to the value of the preexisting incoming SPI,
       and sends this UPDATE (with piggybacked acknowledgment) to the
       mobile host at its new address. The peer MAY use the new address
       immediately, but it MUST limit the amount of data it sends to the
       address until address verification completes.

3. The mobile host completes the readdress by processing the UPDATE
    ACK and echoing the nonce in an ECHO_RESPONSE. Once the peer
    host receives this ECHO_RESPONSE, it considers the new address to
    be verified and can put the address into full use.

While the peer host is verifying the new address, the new address is
marked as UNVERIFIED in the interim, and the old address is
DEPRECATED. Once the peer host has received a correct reply to its
UPDATE challenge, it marks the new address as ACTIVE and removes the
old address.

3.2.2. Mobility with a Single SA Pair (Mobile-Initiated Rekey)

The mobile host may decide to rekey the SAs at the same time that it
notifies the peer of the new address. In this case, the above
procedure described in Figure 3 is slightly modified. The UPDATE
message sent from the mobile host includes an ESP_INFO with the OLD
SPI set to the previous SPI, the NEW SPI set to the desired new SPI
value for the incoming SA, and the KEYMAT Index desired. Optionally,
the host may include a DIFFIE_HELLMAN parameter for a new Diffie-
Hellman key. The peer completes the request for a rekey as is
normally done for HIP rekeying, except that the new address is kept
as UNVERIFIED until the UPDATE nonce challenge is received as
described above. Figure 4 illustrates this scenario.

```
   Mobile Host                               Peer Host

         UPDATE(ESP_INFO, LOCATOR, SEQ, [DIFFIE_HELLMAN])
       ----------------------------------->
         UPDATE(ESP_INFO, SEQ, ACK, [DIFFIE_HELLMAN,] ECHO_REQUEST)
       <-----------------------------------
         UPDATE(ACK, ECHO_RESPONSE)
       ----------------------------------->
```

           Figure 4: Readdress with Mobile-Initiated Rekey

3.2.3. Host Multihoming

A (mobile or stationary) host may sometimes have more than one
interface or global address. The host may notify the peer host of
the additional interface or address by using the LOCATOR parameter.
To avoid problems with the ESP anti-replay window, a host SHOULD use
a different SA for each interface or address used to receive packets
from the peer host when multiple locator pairs are being used
simultaneously rather than sequentially.

When more than one locator is provided to the peer host, the host
SHOULD indicate which locator is preferred (the locator on which the
host prefers to receive traffic). By default, the addresses used in
the base exchange are preferred until indicated otherwise.

In the multihoming case, the sender may also have multiple valid
locators from which to source traffic. In practice, a HIP
association in a multihoming configuration may have both a preferred
peer locator and a preferred local locator, although rules for source
address selection should ultimately govern the selection of the
source locator based on the destination locator.

Although the protocol may allow for configurations in which there is
an asymmetric number of SAs between the hosts (e.g., one host has two
interfaces and two inbound SAs, while the peer has one interface and
one inbound SA), it is RECOMMENDED that inbound and outbound SAs be
created pairwise between hosts. When an ESP_INFO arrives to rekey a
particular outbound SA, the corresponding inbound SA should be also
rekeyed at that time. Although asymmetric SA configurations might be
experimented with, their usage may constrain interoperability at this
time. However, it is recommended that implementations attempt to
support peers that prefer to use non-paired SAs. It is expected that
this section and behavior will be modified in future revisions of
this protocol, once the issue and its implications are better
understood.

Consider the case between two hosts, one single-homed and one
multihomed. The multihomed host may decide to inform the single-
homed host about its other address. It is RECOMMENDED that the
multihomed host set up a new SA pair for use on this new address. To
do this, the multihomed host sends a LOCATOR with an ESP_INFO,
indicating the request for a new SA by setting the OLD SPI value to
zero, and the NEW SPI value to the newly created incoming SPI. A
Locator Type of "1" is used to associate the new address with the new
SPI. The LOCATOR parameter also contains a second Type "1" locator,
that of the original address and SPI. To simplify parameter
processing and avoid explicit protocol extensions to remove locators,
each LOCATOR parameter MUST list all locators in use on a connection
(a complete listing of inbound locators and SPIs for the host). The
multihomed host waits for an ESP_INFO (new outbound SA) from the peer
and an ACK of its own UPDATE. As in the mobility case, the peer host
must perform an address verification before actively using the new
address. Figure 5 illustrates this scenario.

```
   Multi-homed Host                          Peer Host

          UPDATE(ESP_INFO, LOCATOR, SEQ, [DIFFIE_HELLMAN])
       ----------------------------------->
          UPDATE(ESP_INFO, SEQ, ACK, [DIFFIE_HELLMAN,] ECHO_REQUEST)
       <-----------------------------------
          UPDATE(ACK, ECHO_RESPONSE)
       ----------------------------------->
```

                  Figure 5: Basic Multihoming Scenario

   In multihoming scenarios, it is important that hosts receiving
   UPDATEs associate them correctly with the destination address used in
   the packet carrying the UPDATE. When processing inbound LOCATORs
   that establish new security associations on an interface with
   multiple addresses, a host uses the destination address of the UPDATE
   containing the LOCATOR as the local address to which the LOCATOR plus
   ESP_INFO is targeted. This is because hosts may send UPDATEs with
   the same (locator) IP address to different peer addresses -- this has
   the effect of creating multiple inbound SAs implicitly affiliated
   with different peer source addresses.

3.2.4. Site Multihoming

   A host may have an interface that has multiple globally routable IP
   addresses. Such a situation may be a result of the site having
   multiple upper Internet Service Providers, or just because the site
   provides all hosts with both IPv4 and IPv6 addresses. The host
   should stay reachable at all or any subset of the currently available
   global routable addresses, independent of how they are provided.

   This case is handled the same as if there were different IP
   addresses, described above in Section 3.2.3. Note that a single
   interface may experience site multihoming while the host itself may
   have multiple interfaces.

   Note that a host may be multihomed and mobile simultaneously, and
   that a multihomed host may want to protect the location of some of
   its interfaces while revealing the real IP address of some others.

   This document does not presently specify additional site multihoming
   extensions to HIP; further alignment with the IETF shim6 working
   group may be considered in the future.

3.2.5. Dual host multihoming

   Consider the case in which both hosts would like to add an additional
   address after the base exchange completes. In Figure 6, consider
   that host1, which used address addr1a in the base exchange to set up
   SPI1a and SPI2a, wants to add address addr1b. It would send an
   UPDATE with LOCATOR (containing the address addr1b) to host2, using
   destination address addr2a, and a new set of SPIs would be added
   between hosts 1 and 2 (call them SPI1b and SPI2b -- not shown in the
   figure). Next, consider host2 deciding to add addr2b to the
   relationship. Host2 must select one of host1's addresses towards
   which to initiate an UPDATE. It may choose to initiate an UPDATE to
   addr1a, addr1b, or both. If it chooses to send to both, then a full
   mesh (four SA pairs) of SAs would exist between the two hosts. This
   is the most general case; it often may be the case that hosts
   primarily establish new SAs only with the peer's Preferred locator.
   The readdressing protocol is flexible enough to accommodate this
   choice.

```
              -<- SPI1a --                         -- SPI2a ->-
      host1 <               > addr1a <---> addr2a <             > host2
              ->- SPI2a --                         -- SPI1a -<-

                           addr1b <---> addr2a  (second SA pair)
                           addr1a <---> addr2b  (third SA pair)
                           addr1b <---> addr2b  (fourth SA pair)
```

        Figure 6: Dual Multihoming Case in Which Each Host Uses LOCATOR to
                         Add a Second Address

3.2.6. Combined Mobility and Multihoming

   It looks likely that in the future, many mobile hosts will be
   simultaneously mobile and multihomed, i.e., have multiple mobile
   interfaces. Furthermore, if the interfaces use different access
   technologies, it is fairly likely that one of the interfaces may
   appear stable (retain its current IP address) while some other(s) may
   experience mobility (undergo IP address change).

   The use of LOCATOR plus ESP_INFO should be flexible enough to handle
   most such scenarios, although more complicated scenarios have not
   been studied so far.

3.2.7. Using LOCATORs across Addressing Realms

   It is possible for HIP associations to migrate to a state in which
   both parties are only using locators in different addressing realms.
   For example, the two hosts may initiate the HIP association when both

are using IPv6 locators, then one host may loose its IPv6
connectivity and obtain an IPv4 address. In such a case, some type
of mechanism for interworking between the different realms must be
employed; such techniques are outside the scope of the present text.
The basic problem in this example is that the host readdressing to
IPv4 does not know a corresponding IPv4 address of the peer. This
may be handled (experimentally) by possibly configuring this address
information manually or in the DNS, or the hosts exchange both IPv4
and IPv6 addresses in the locator.

3.2.8. Network Renumbering

It is expected that IPv6 networks will be renumbered much more often
than most IPv4 networks. From an end-host point of view, network
renumbering is similar to mobility.

3.2.9. Initiating the Protocol in R1 or I2

A Responder host MAY include a LOCATOR parameter in the R1 packet
that it sends to the Initiator. This parameter MUST be protected by
the R1 signature. If the R1 packet contains LOCATOR parameters with
a new Preferred locator, the Initiator SHOULD directly set the new
Preferred locator to status ACTIVE without performing address
verification first, and MUST send the I2 packet to the new Preferred
locator. The I1 destination address and the new Preferred locator
may be identical. All new non-preferred locators must still undergo
address verification once the base exchange completes.

```
          Initiator                                   Responder

                        R1 with LOCATOR
                <-----------------------------------
    record additional addresses
    change responder address
                I2 sent to newly indicated preferred address
                ----------------------------------->
                                             (process normally)
                              R2
                <-----------------------------------
    (process normally, later verification of non-preferred locators)
```
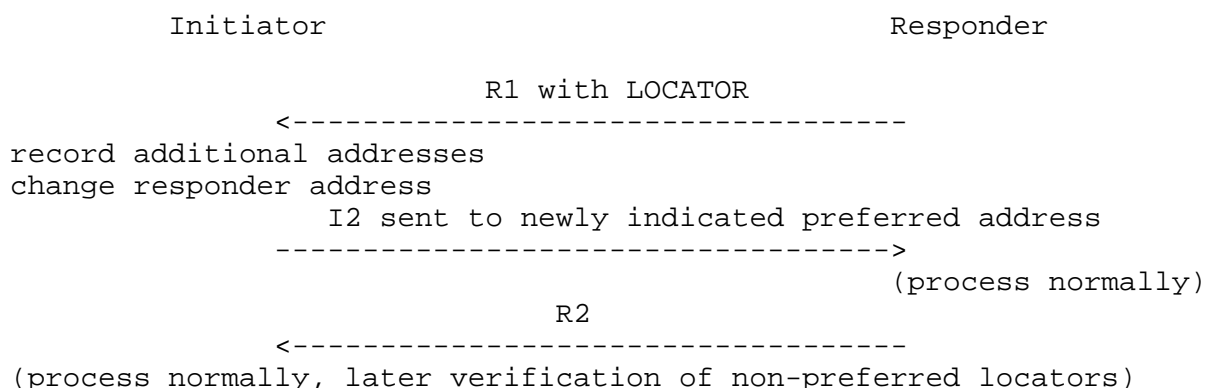
              Figure 7: LOCATOR Inclusion in R1

An Initiator MAY include one or more LOCATOR parameters in the I2
packet, independent of whether or not there was a LOCATOR parameter
in the R1. These parameters MUST be protected by the I2 signature.
Even if the I2 packet contains LOCATOR parameters, the Responder MUST
still send the R2 packet to the source address of the I2. The new

Preferred locator SHOULD be identical to the I2 source address. If
the I2 packet contains LOCATOR parameters, all new locators must
undergo address verification as usual, and the ESP traffic that
subsequently follows should use the Preferred locator.

```
         Initiator                                Responder

                      I2 with LOCATOR
          ---------------------------------->
                                             (process normally)
                                        record additional addresses
                  R2 sent to source address of I2
            <----------------------------------
(process normally)
```
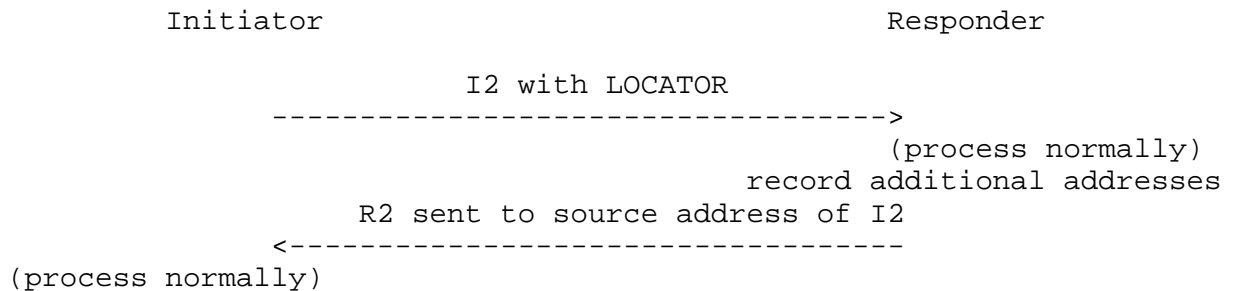
                   Figure 8: LOCATOR Inclusion in I2

The I1 and I2 may be arriving from different source addresses if the
LOCATOR parameter is present in R1. In this case, implementations
simultaneously using multiple pre-created R1s, indexed by Initiator
IP addresses, may inadvertently fail the puzzle solution of I2
packets due to a perceived puzzle mismatch. See, for instance, the
example in Appendix A of [RFC5201]. As a solution, the Responder's
puzzle indexing mechanism must be flexible enough to accommodate the
situation when R1 includes a LOCATOR parameter.

3.3. Other Considerations

3.3.1. Address Verification

When a HIP host receives a set of locators from another HIP host in a
LOCATOR, it does not necessarily know whether the other host is
actually reachable at the claimed addresses. In fact, a malicious
peer host may be intentionally giving bogus addresses in order to
cause a packet flood towards the target addresses [RFC4225].
Likewise, viral software may have compromised the peer host,
programming it to redirect packets to the target addresses. Thus,
the HIP host must first check that the peer is reachable at the new
address.

An additional potential benefit of performing address verification is
to allow middleboxes in the network along the new path to obtain the
peer host's inbound SPI.

Address verification is implemented by the challenger sending some
piece of unguessable information to the new address, and waiting for
some acknowledgment from the Responder that indicates reception of
the information at the new address. This may include the exchange of

a nonce, or the generation of a new SPI and observation of data
arriving on the new SPI.

3.3.2. Credit-Based Authorization

Credit-Based Authorization (CBA) allows a host to securely use a new
locator even though the peer's reachability at the address embedded
in the locator has not yet been verified. This is accomplished based
on the following three hypotheses:

1. A flooding attacker typically seeks to somehow multiply the
    packets it generates for the purpose of its attack because
    bandwidth is an ample resource for many victims.

2. An attacker can often cause unamplified flooding by sending
    packets to its victim, either by directly addressing the victim
    in the packets, or by guiding the packets along a specific path
    by means of an IPv6 Routing header, if Routing headers are not
    filtered by firewalls.

3. Consequently, the additional effort required to set up a
    redirection-based flooding attack (without CBA and return
    routability checks) would pay off for the attacker only if
    amplification could be obtained this way.

On this basis, rather than eliminating malicious packet redirection
in the first place, Credit-Based Authorization prevents
amplifications. This is accomplished by limiting the data a host can
send to an unverified address of a peer by the data recently received
from that peer. Redirection-based flooding attacks thus become less
attractive than, for example, pure direct flooding, where the
attacker itself sends bogus packets to the victim.

Figure 9 illustrates Credit-Based Authorization: Host B measures the
amount of data recently received from peer A and, when A readdresses,
sends packets to A's new, unverified address as long as the sum of
the packet sizes does not exceed the measured, received data volume.
When insufficient credit is left, B stops sending further packets to
A until A's address becomes ACTIVE. The address changes may be due
to mobility, multihoming, or any other reason. Not shown in Figure 9
are the results of credit aging (Section 5.6.2), a mechanism used to
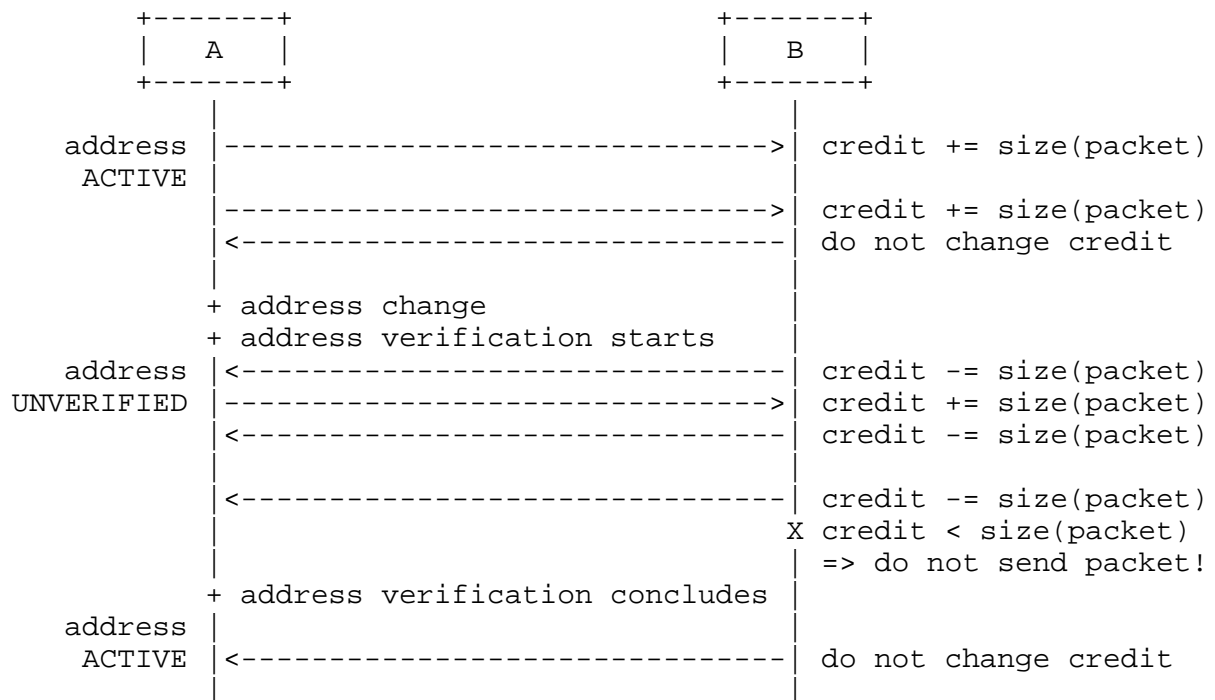dampen possible time-shifting attacks.

```
        +-------+                         +-------+
        |   A   |                         |   B   |
        +-------+                         +-------+
            |                                 |
  address   |-------------------------------->| credit += size(packet)
    ACTIVE  |                                 |
            |-------------------------------->| credit += size(packet)
            |<--------------------------------| do not change credit
            |                                 |
            + address change                 |
            + address verification starts    |
  address   |<--------------------------------| credit -= size(packet)
  UNVERIFIED|-------------------------------->| credit += size(packet)
            |<--------------------------------| credit -= size(packet)
            |                                 |
            |<--------------------------------| credit -= size(packet)
            |                               X credit < size(packet)
            |                                 | => do not send packet!
            |                                 |
            + address verification concludes |
  address   |                                 |
    ACTIVE  |<--------------------------------| do not change credit
            |                                 |
```

Figure 9: Readdressing Scenario

3.3.3. Preferred Locator

   When a host has multiple locators, the peer host must decide which to
   use for outbound packets. It may be that a host would prefer to
   receive data on a particular inbound interface. HIP allows a
   particular locator to be designated as a Preferred locator and
   communicated to the peer (see Section 4).

   In general, when multiple locators are used for a session, there is
   the question of using multiple locators for failover only or for
   load-balancing. Due to the implications of load-balancing on the
   transport layer that still need to be worked out, this document
   assumes that multiple locators are used primarily for failover. An
   implementation may use ICMP interactions, reachability checks, or
   other means to detect the failure of a locator.

3.3.4. Interaction with Security Associations

   This document specifies a new HIP protocol parameter, the LOCATOR
   parameter (see Section 4), that allows the hosts to exchange
   information about their locator(s) and any changes in their
   locator(s). The logical structure created with LOCATOR parameters

has three levels: hosts, Security Associations (SAs) indexed by
Security Parameter Indices (SPIs), and addresses.

The relation between these levels for an association constructed as
defined in the base specification [RFC5201] and ESP transform
[RFC5202] is illustrated in Figure 10.

```
          -<- SPI1a --                             -- SPI2a ->-
     host1 <           > addr1a <---> addr2a <           > host2
          ->- SPI2a --                             -- SPI1a -<-
```

            Figure 10: Relation between Hosts, SPIs,
               and Addresses (Base Specification)

In Figure 10, host1 and host2 negotiate two unidirectional SAs, and
each host selects the SPI value for its inbound SA. The addresses
addr1a and addr2a are the source addresses that the hosts use in the
base HIP exchange. These are the "preferred" (and only) addresses
conveyed to the peer for use on each SA. That is, although packets
sent to any of the hosts' interfaces may be accepted on the inbound
SA, the peer host in general knows of only the single destination
address learned in the base exchange (e.g., for host1, it sends a
packet on SPI2a to addr2a to reach host2), unless other mechanisms
exist to learn of new addresses.

In general, the bindings that exist in an implementation
corresponding to this document can be depicted as shown in Figure 11.
In this figure, a host can have multiple inbound SPIs (and, not
shown, multiple outbound SPIs) associated with another host.
Furthermore, each SPI may have multiple addresses associated with it.
These addresses that are bound to an SPI are not used to lookup the
incoming SA. Rather, the addresses are those that are provided to
the peer host, as hints for which addresses to use to reach the host
on that SPI. The LOCATOR parameter is used to change the set of
addresses that a peer associates with a particular SPI.

```
                             address11
                            /
              SPI1    - address12
            /
           /              address21
    host -- SPI2    <
           \              address22
            \
              SPI3    - address31
                         \
                            address32
```
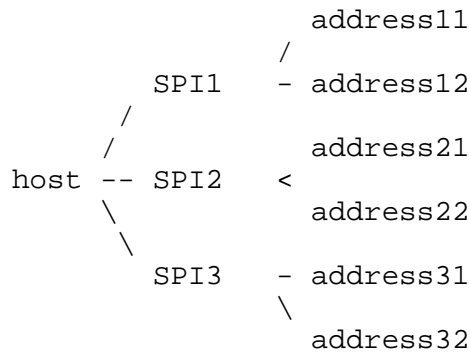
Figure 11: Relation between Hosts, SPIs, and Addresses (General Case)

A host may establish any number of security associations (or SPIs)
with a peer. The main purpose of having multiple SPIs with a peer is
to group the addresses into collections that are likely to experience
fate sharing. For example, if the host needs to change its addresses
on SPI2, it is likely that both address21 and address22 will
simultaneously become obsolete. In a typical case, such SPIs may
correspond with physical interfaces; see below. Note, however, that
especially in the case of site multihoming, one of the addresses may
become unreachable while the other one still works. In the typical
case, however, this does not require the host to inform its peers
about the situation, since even the non-working address still
logically exists.

A basic property of HIP SAs is that the inbound IP address is not
used to lookup the incoming SA. Therefore, in Figure 11, it may seem
unnecessary for address31, for example, to be associated only with
SPI3 -- in practice, a packet may arrive to SPI1 via destination
address address31 as well. However, the use of different source and
destination addresses typically leads to different paths, with
different latencies in the network, and if packets were to arrive via
an arbitrary destination IP address (or path) for a given SPI, the
reordering due to different latencies may cause some packets to fall
outside of the ESP anti-replay window. For this reason, HIP provides
a mechanism to affiliate destination addresses with inbound SPIs,
when there is a concern that anti-replay windows might be violated.
In this sense, we can say that a given inbound SPI has an "affinity"
for certain inbound IP addresses, and this affinity is communicated
to the peer host. Each physical interface SHOULD have a separate SA,
unless the ESP anti-replay window is loose.

Moreover, even when the destination addresses used for a particular
SPI are held constant, the use of different source interfaces may
also cause packets to fall outside of the ESP anti-replay window,
since the path traversed is often affected by the source address or

interface used. A host has no way to influence the source interface
on which a peer sends its packets on a given SPI. A host SHOULD
consistently use the same source interface and address when sending
to a particular destination IP address and SPI. For this reason, a
host may find it useful to change its SPI or at least reset its ESP
anti-replay window when the peer host readdresses.

An address may appear on more than one SPI. This creates no
ambiguity since the receiver will ignore the IP addresses during SA
lookup anyway. However, this document does not specify such cases.

When the LOCATOR parameter is sent in an UPDATE packet, then the
receiver will respond with an UPDATE acknowledgment. When the
LOCATOR parameter is sent in an R1 or I2 packet, the base exchange
retransmission mechanism will confirm its successful delivery.
LOCATORs may experimentally be used in NOTIFY packets; in this case,
the recipient MUST consider the LOCATOR as informational and not
immediately change the current preferred address, but can test the
additional locators when the need arises. The use of the LOCATOR in
a NOTIFY message may not be compatible with middleboxes.

4. LOCATOR Parameter Format

The LOCATOR parameter is a critical parameter as defined by
[RFC5201]. It consists of the standard HIP parameter Type and Length
fields, plus zero or more Locator sub-parameters. Each Locator sub-
parameter contains a Traffic Type, Locator Type, Locator Length,
Preferred locator bit, Locator Lifetime, and a Locator encoding. A
LOCATOR containing zero Locator fields is permitted but has the
effect of deprecating all addresses.

```
      0                   1                   2                   3
      0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |             Type              |             Length            |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     | Traffic Type  | Locator Type | Locator Length | Reserved   |P|
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |                       Locator Lifetime                       |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |                            Locator                           |
     |                                                              |
     |                                                              |
     |                                                              |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     .                                                              .
     .                                                              .
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     | Traffic Type  | Locator Type | Locator Length | Reserved   |P|
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |                       Locator Lifetime                       |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |                            Locator                           |
     |                                                              |
     |                                                              |
     |                                                              |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
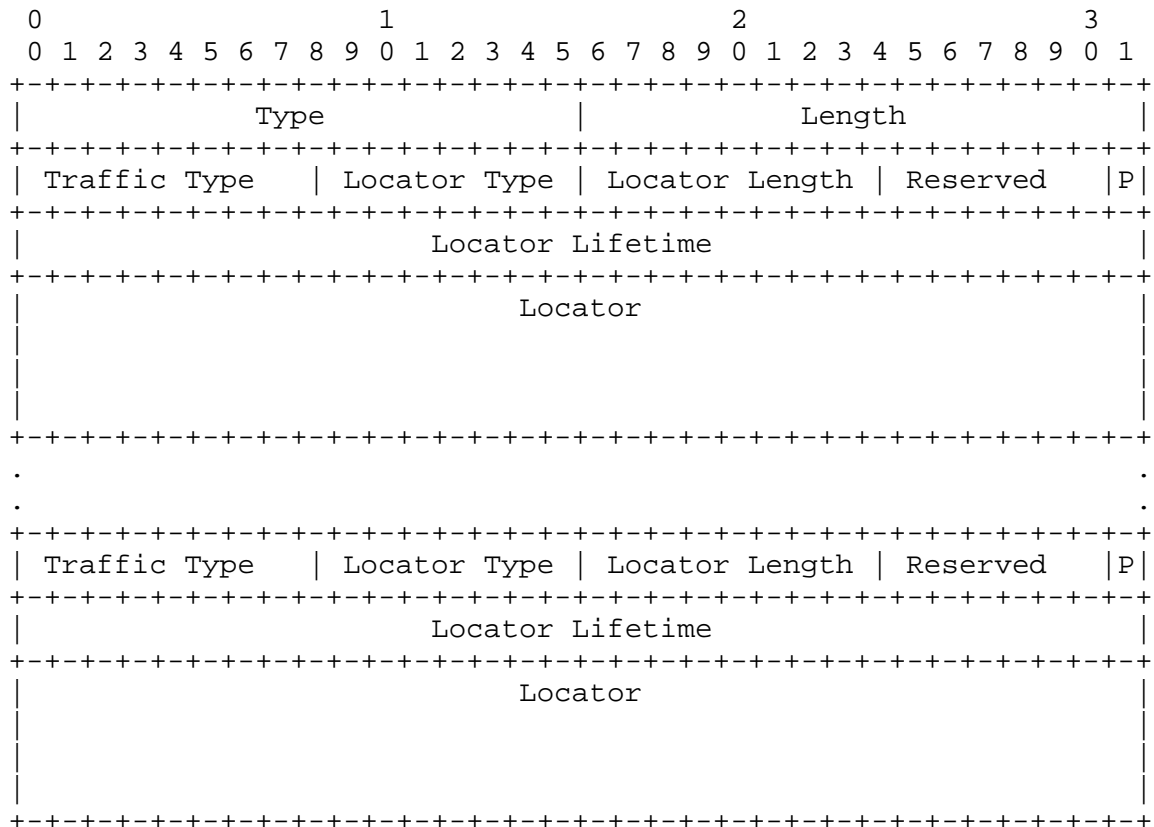
                  Figure 12: LOCATOR Parameter Format

   Type: 193

   Length: Length in octets, excluding Type and Length fields, and
      excluding padding.

   Traffic Type: Defines whether the locator pertains to HIP signaling,
      user data, or both.

   Locator Type: Defines the semantics of the Locator field.

   Locator Length: Defines the length of the Locator field, in units of
      4-byte words (Locators up to a maximum of 4*255 octets are
      supported).

   Reserved: Zero when sent, ignored when received.

      P: Preferred locator. Set to one if the locator is preferred for
         that Traffic Type; otherwise, set to zero.

      Locator Lifetime: Locator lifetime, in seconds.

      Locator: The locator whose semantics and encoding are indicated by
         the Locator Type field. All Locator sub-fields are integral
         multiples of four octets in length.

   The Locator Lifetime indicates how long the following locator is
   expected to be valid. The lifetime is expressed in seconds. Each
   locator MUST have a non-zero lifetime. The address is expected to
   become deprecated when the specified number of seconds has passed
   since the reception of the message. A deprecated address SHOULD NOT
   be used as a destination address if an alternate (non-deprecated) is
   available and has sufficient scope.

4.1. Traffic Type and Preferred Locator

   The following Traffic Type values are defined:

   0: Both signaling (HIP control packets) and user data.

   1: Signaling packets only.

   2: Data packets only.

   The "P" bit, when set, has scope over the corresponding Traffic Type.
   That is, when a "P" bit is set for Traffic Type "2", for example, it
   means that the locator is preferred for data packets. If there is a
   conflict (for example, if the "P" bit is set for an address of Type
   "0" and a different address of Type "2"), the more specific Traffic
   Type rule applies (in this case, "2"). By default, the IP addresses
   used in the base exchange are Preferred locators for both signaling
   and user data, unless a new Preferred locator supersedes them. If no
   locators are indicated as preferred for a given Traffic Type, the
   implementation may use an arbitrary locator from the set of active
   locators.

4.2. Locator Type and Locator

   The following Locator Type values are defined, along with the
   associated semantics of the Locator field:

   0: An IPv6 address or an IPv4-in-IPv6 format IPv4 address [RFC4291]
       (128 bits long). This locator type is defined primarily for non-
       ESP-based usage.

   1: The concatenation of an ESP SPI (first 32 bits) followed by an
       IPv6 address or an IPv4-in-IPv6 format IPv4 address (an
       additional 128 bits). This IP address is defined primarily for
       ESP-based usage.

4.3. UPDATE Packet with Included LOCATOR

   A number of combinations of parameters in an UPDATE packet are
   possible (e.g., see Section 3.2). In this document, procedures are
   defined only for the case in which one LOCATOR and one ESP_INFO
   parameter is used in any HIP packet. Furthermore, the LOCATOR SHOULD
   list all of the locators that are active on the HIP association
   (including those on SAs not covered by the ESP_INFO parameter). Any
   UPDATE packet that includes a LOCATOR parameter SHOULD include both
   an HMAC and a HIP_SIGNATURE parameter. The relationship between the
   announced Locators and any ESP_INFO parameters present in the packet
   is defined in Section 5.2. The sending of multiple LOCATOR and/or
   ESP_INFO parameters is for further study; receivers may wish to
   experiment with supporting such a possibility.

5. Processing Rules

   This section describes rules for sending and receiving the LOCATOR
   parameter, testing address reachability, and using Credit-Based
   Authorization (CBA) on UNVERIFIED locators.

5.1. Locator Data Structure and Status

   In a typical implementation, each outgoing locator is represented by
   a piece of state that contains the following data:

   o the actual bit pattern representing the locator,

   o the lifetime (seconds),

   o the status (UNVERIFIED, ACTIVE, DEPRECATED),

   o the Traffic Type scope of the locator, and

   o whether the locator is preferred for any particular scope.

The status is used to track the reachability of the address embedded within the LOCATOR parameter:

UNVERIFIED indicates that the reachability of the address has not been verified yet,

ACTIVE indicates that the reachability of the address has been verified and the address has not been deprecated,

DEPRECATED indicates that the locator lifetime has expired.

The following state changes are allowed:

UNVERIFIED to ACTIVE The reachability procedure completes successfully.

UNVERIFIED to DEPRECATED The locator lifetime expires while the locator is UNVERIFIED.

ACTIVE to DEPRECATED The locator lifetime expires while the locator is ACTIVE.

ACTIVE to UNVERIFIED There has been no traffic on the address for some time, and the local policy mandates that the address reachability must be verified again before starting to use it again.

DEPRECATED to UNVERIFIED The host receives a new lifetime for the locator.

A DEPRECATED address MUST NOT be changed to ACTIVE without first verifying its reachability.

Note that the state of whether or not a locator is preferred is not necessarily the same as the value of the Preferred bit in the Locator sub-parameter received from the peer. Peers may recommend certain locators to be preferred, but the decision on whether to actually use a locator as a preferred locator is a local decision, possibly influenced by local policy.

5.2. Sending LOCATORs

The decision of when to send LOCATORs is basically a local policy issue. However, it is RECOMMENDED that a host send a LOCATOR whenever it recognizes a change of its IP addresses in use on an active HIP association, and assumes that the change is going to last at least for a few seconds. Rapidly sending LOCATORs that force the peer to change the preferred address SHOULD be avoided.

When a host decides to inform its peers about changes in its IP
addresses, it has to decide how to group the various addresses with
SPIs. The grouping should consider also whether middlebox
interaction requires sending the same LOCATOR in separate UPDATEs on
different paths. Since each SPI is associated with a different
Security Association, the grouping policy may also be based on ESP
anti-replay protection considerations. In the typical case, simply
basing the grouping on actual kernel level physical and logical
interfaces may be the best policy. Grouping policy is outside of the
scope of this document.

Note that the purpose of announcing IP addresses in a LOCATOR is to
provide connectivity between the communicating hosts. In most cases,
tunnels or virtual interfaces such as IPsec tunnel interfaces or
Mobile IP home addresses provide sub-optimal connectivity.
Furthermore, it should be possible to replace most tunnels with HIP
based "non-tunneling", therefore making most virtual interfaces
fairly unnecessary in the future. Therefore, virtual interfaces
SHOULD NOT be announced in general. On the other hand, there are
clearly situations where tunnels are used for diagnostic and/or
testing purposes. In such and other similar cases announcing the IP
addresses of virtual interfaces may be appropriate.

Hosts MUST NOT announce broadcast or multicast addresses in LOCATORs.
Link-local addresses MAY be announced to peers that are known to be
neighbors on the same link, such as when the IP destination address
of a peer is also link-local. The announcement of link-local
addresses in this case is a policy decision; link-local addresses
used as Preferred locators will create reachability problems when the
host moves to another link. In any case, link-local addresses MUST
NOT be announced to a peer unless that peer is known to be on the
same link.

Once the host has decided on the groups and assignment of addresses
to the SPIs, it creates a LOCATOR parameter that serves as a complete
representation of the addresses and affiliated SPIs intended for
active use. We now describe a few cases introduced in Section 3.2.
We assume that the Traffic Type for each locator is set to "0" (other
values for Traffic Type may be specified in documents that separate
the HIP control plane from data plane traffic). Other mobility and
multihoming cases are possible but are left for further
experimentation.

1. Host mobility with no multihoming and no rekeying. The mobile
    host creates a single UPDATE containing a single ESP_INFO with a
    single LOCATOR parameter. The ESP_INFO contains the current
    value of the SPI in both the OLD SPI and NEW SPI fields. The
    LOCATOR contains a single Locator with a "Locator Type" of "1";

the SPI must match that of the ESP_INFO. The Preferred bit
SHOULD be set and the "Locator Lifetime" is set according to
local policy. The UPDATE also contains a SEQ parameter as usual.
This packet is retransmitted as defined in the HIP protocol
specification [RFC5201]. The UPDATE should be sent to the peer's
preferred IP address with an IP source address corresponding to
the address in the LOCATOR parameter.

2. Host mobility with no multihoming but with rekeying. The mobile
    host creates a single UPDATE containing a single ESP_INFO with a
    single LOCATOR parameter (with a single address). The ESP_INFO
    contains the current value of the SPI in the OLD SPI and the new
    value of the SPI in the NEW SPI, and a KEYMAT Index as selected
    by local policy. Optionally, the host may choose to initiate a
    Diffie Hellman rekey by including a DIFFIE_HELLMAN parameter.
    The LOCATOR contains a single Locator with "Locator Type" of "1";
    the SPI must match that of the NEW SPI in the ESP_INFO.
    Otherwise, the steps are identical to the case in which no
    rekeying is initiated.

3. Host multihoming (addition of an address). We only describe the
    simple case of adding an additional address to a (previously)
    single-homed, non-mobile host. The host SHOULD set up a new SA
    pair between this new address and the preferred address of the
    peer host. To do this, the multihomed host creates a new inbound
    SA and creates a new SPI. For the outgoing UPDATE message, it
    inserts an ESP_INFO parameter with an OLD SPI field of "0", a NEW
    SPI field corresponding to the new SPI, and a KEYMAT Index as
    selected by local policy. The host adds to the UPDATE message a
    LOCATOR with two Type "1" Locators: the original address and SPI
    active on the association, and the new address and new SPI being
    added (with the SPI matching the NEW SPI contained in the
    ESP_INFO). The Preferred bit SHOULD be set depending on the
    policy to tell the peer host which of the two locators is
    preferred. The UPDATE also contains a SEQ parameter and
    optionally a DIFFIE_HELLMAN parameter, and follows rekeying
    procedures with respect to this new address. The UPDATE message
    SHOULD be sent to the peer's Preferred address with a source
    address corresponding to the new locator.

The sending of multiple LOCATORs, locators with Locator Type "0", and
multiple ESP_INFO parameters is for further study. Note that the
inclusion of LOCATOR in an R1 packet requires the use of Type "0"
locators since no SAs are set up at that point.

5.3. Handling Received LOCATORs

   A host SHOULD be prepared to receive a LOCATOR parameter in the
   following HIP packets: R1, I2, UPDATE, and NOTIFY.

   This document describes sending both ESP_INFO and LOCATOR parameters
   in an UPDATE. The ESP_INFO parameter is included when there is a
   need to rekey or key a new SPI, and is otherwise included for the
   possible benefit of HIP-aware middleboxes. The LOCATOR parameter
   contains a complete map of the locators that the host wishes to make
   or keep active for the HIP association.

   In general, the processing of a LOCATOR depends upon the packet type
   in which it is included. Here, we describe only the case in which
   ESP_INFO is present and a single LOCATOR and ESP_INFO are sent in an
   UPDATE message; other cases are for further study. The steps below
   cover each of the cases described in Section 5.2.

   The processing of ESP_INFO and LOCATOR parameters is intended to be
   modular and support future generalization to the inclusion of
   multiple ESP_INFO and/or multiple LOCATOR parameters. A host SHOULD
   first process the ESP_INFO before the LOCATOR, since the ESP_INFO may
   contain a new SPI value mapped to an existing SPI, while a Type "1"
   locator will only contain a reference to the new SPI.

   When a host receives a validated HIP UPDATE with a LOCATOR and
   ESP_INFO parameter, it processes the ESP_INFO as follows. The
   ESP_INFO parameter indicates whether an SA is being rekeyed, created,
   deprecated, or just identified for the benefit of middleboxes. The
   host examines the OLD SPI and NEW SPI values in the ESP_INFO
   parameter:

   1. (no rekeying) If the OLD SPI is equal to the NEW SPI and both
       correspond to an existing SPI, the ESP_INFO is gratuitous
       (provided for middleboxes) and no rekeying is necessary.

   2. (rekeying) If the OLD SPI indicates an existing SPI and the NEW
       SPI is a different non-zero value, the existing SA is being
       rekeyed and the host follows HIP ESP rekeying procedures by
       creating a new outbound SA with an SPI corresponding to the NEW
       SPI, with no addresses bound to this SPI. Note that locators in
       the LOCATOR parameter will reference this new SPI instead of the
       old SPI.

   3. (new SA) If the OLD SPI value is zero and the NEW SPI is a new
       non-zero value, then a new SA is being requested by the peer.
       This case is also treated like a rekeying event; the receiving
       host must create a new SA and respond with an UPDATE ACK.

   4.   (deprecating the SA) If the OLD SPI indicates an existing SPI and
        the NEW SPI is zero, the SA is being deprecated and all locators
        uniquely bound to the SPI are put into the DEPRECATED state.

   If none of the above cases apply, a protocol error has occurred and
   the processing of the UPDATE is stopped.

   Next, the locators in the LOCATOR parameter are processed. For each
   locator listed in the LOCATOR parameter, check that the address
   therein is a legal unicast or anycast address. That is, the address
   MUST NOT be a broadcast or multicast address. Note that some
   implementations MAY accept addresses that indicate the local host,
   since it may be allowed that the host runs HIP with itself.

   The below assumes that all locators are of Type "1" with a Traffic
   Type of "0"; other cases are for further study.

   For each Type "1" address listed in the LOCATOR parameter, the host
   checks whether the address is already bound to the SPI indicated. If
   the address is already bound, its lifetime is updated. If the status
   of the address is DEPRECATED, the status is changed to UNVERIFIED.
   If the address is not already bound, the address is added, and its
   status is set to UNVERIFIED. Mark all addresses corresponding to the
   SPI that were NOT listed in the LOCATOR parameter as DEPRECATED.

   As a result, at the end of processing, the addresses listed in the
   LOCATOR parameter have either a state of UNVERIFIED or ACTIVE, and
   any old addresses on the old SA not listed in the LOCATOR parameter
   have a state of DEPRECATED.

   Once the host has processed the locators, if the LOCATOR parameter
   contains a new Preferred locator, the host SHOULD initiate a change
   of the Preferred locator. This requires that the host first verifies
   reachability of the associated address, and only then changes the
   Preferred locator; see Section 5.5.

   If a host receives a locator with an unsupported Locator Type, and
   when such a locator is also declared to be the Preferred locator for
   the peer, the host SHOULD send a NOTIFY error with a Notify Message
   Type of LOCATOR_TYPE_UNSUPPORTED, with the Notification Data field
   containing the locator(s) that the receiver failed to process.
   Otherwise, a host MAY send a NOTIFY error if a (non-preferred)
   locator with an unsupported Locator Type is received in a LOCATOR
   parameter.

5.4. Verifying Address Reachability

   A host MUST verify the reachability of an UNVERIFIED address. The
   status of a newly learned address MUST initially be set to UNVERIFIED
   unless the new address is advertised in a R1 packet as a new
   Preferred locator. A host MAY also want to verify the reachability
   of an ACTIVE address again after some time, in which case it would
   set the status of the address to UNVERIFIED and reinitiate address
   verification.

   A host typically starts the address-verification procedure by sending
   a nonce to the new address. For example, when the host is changing
   its SPI and sending an ESP_INFO to the peer, the NEW SPI value SHOULD
   be random and the value MAY be copied into an ECHO_REQUEST sent in
   the rekeying UPDATE. However, if the host is not changing its SPI,
   it MAY still use the ECHO_REQUEST parameter in an UPDATE message sent
   to the new address. A host MAY also use other message exchanges as
   confirmation of the address reachability.

   Note that in the case of receiving a LOCATOR in an R1 and replying
   with an I2 to the new address in the LOCATOR, receiving the
   corresponding R2 is sufficient proof of reachability for the
   Responder's preferred address. Since further address verification of
   such an address can impede the HIP-base exchange, a host MUST NOT
   separately verify reachability of a new Preferred locator that was
   received on an R1.

   In some cases, it MAY be sufficient to use the arrival of data on a
   newly advertised SA as implicit address reachability verification as
   depicted in Figure 13, instead of waiting for the confirmation via a
   HIP packet. In this case, a host advertising a new SPI as part of
   its address reachability check SHOULD be prepared to receive traffic
   on the new SA.

```
   Mobile host                                     Peer host


                                             prepare incoming SA
                      NEW SPI in ESP_INFO (UPDATE)
               <----------------------------------
   switch to new outgoing SA
                          data on new SA
               ---------------------------------->
                                             mark address ACTIVE
```
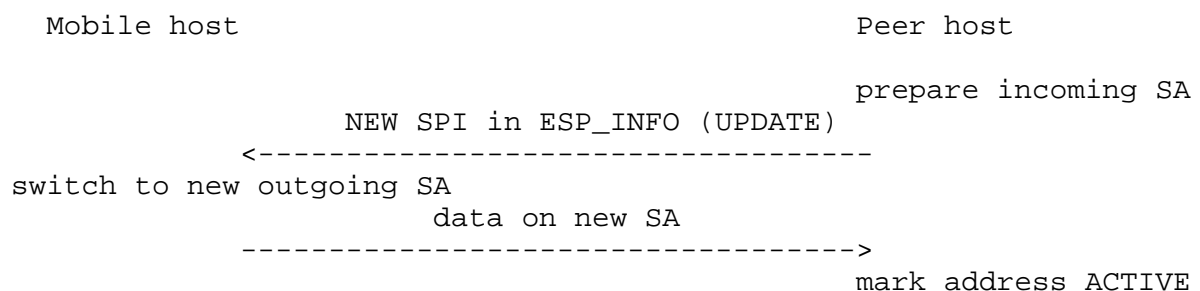
                Figure 13: Address Activation Via Use of a New SA

   When address verification is in progress for a new Preferred locator,
   the host SHOULD select a different locator listed as ACTIVE, if one

such locator is available, to continue communications until address
verification completes. Alternatively, the host MAY use the new
Preferred locator while in UNVERIFIED status to the extent Credit-
Based Authorization permits. Credit-Based Authorization is explained
in Section 5.6. Once address verification succeeds, the status of
the new Preferred locator changes to ACTIVE.

5.5. Changing the Preferred Locator

   A host MAY want to change the Preferred outgoing locator for
   different reasons, e.g., because traffic information or ICMP error
   messages indicate that the currently used preferred address may have
   become unreachable. Another reason may be due to receiving a LOCATOR
   parameter that has the "P" bit set.

   To change the Preferred locator, the host initiates the following
   procedure:

   1. If the new Preferred locator has ACTIVE status, the Preferred
       locator is changed and the procedure succeeds.

   2. If the new Preferred locator has UNVERIFIED status, the host
       starts to verify its reachability. The host SHOULD use a
       different locator listed as ACTIVE until address verification
       completes if one such locator is available. Alternatively, the
       host MAY use the new Preferred locator, even though in UNVERIFIED
       status, to the extent Credit-Based Authorization permits. Once
       address verification succeeds, the status of the new Preferred
       locator changes to ACTIVE and its use is no longer governed by
       Credit-Based Authorization.

   3. If the peer host has not indicated a preference for any address,
       then the host picks one of the peer's ACTIVE addresses randomly
       or according to policy. This case may arise if, for example,
       ICMP error messages that deprecate the Preferred locator arrive,
       but the peer has not yet indicated a new Preferred locator.

   4. If the new Preferred locator has DEPRECATED status and there is
       at least one non-deprecated address, the host selects one of the
       non-deprecated addresses as a new Preferred locator and
       continues. If the selected address is UNVERIFIED, the address
       verification procedure described above will apply.

5.6. Credit-Based Authorization

   To prevent redirection-based flooding attacks, the use of a Credit-
   Based Authorization (CBA) approach is mandatory when a host sends
   data to an UNVERIFIED locator. The following algorithm meets the
   security considerations for prevention of amplification and time-
   shifting attacks. Other forms of credit aging, and other values for
   the CreditAgingFactor and CreditAgingInterval parameters in
   particular, are for further study, and so are the advanced CBA
   techniques specified in [CBA-MIPv6].

5.6.1. Handling Payload Packets

   A host maintains a "credit counter" for each of its peers. Whenever
   a packet arrives from a peer, the host SHOULD increase that peer's
   credit counter by the size of the received packet. When the host has
   a packet to be sent to the peer, and when the peer's Preferred
   locator is listed as UNVERIFIED and no alternative locator with
   status ACTIVE is available, the host checks whether it can send the
   packet to the UNVERIFIED locator. The packet SHOULD be sent if the
   value of the credit counter is higher than the size of the outbound
   packet. If the credit counter is too low, the packet MUST be
   discarded or buffered until address verification succeeds. When a
   packet is sent to a peer at an UNVERIFIED locator, the peer's credit
   counter MUST be reduced by the size of the packet. The peer's credit
   counter is not affected by packets that the host sends to an ACTIVE
   locator of that peer.

   Figure 14 depicts the actions taken by the host when a packet is
   received. Figure 15 shows the decision chain in the event a packet
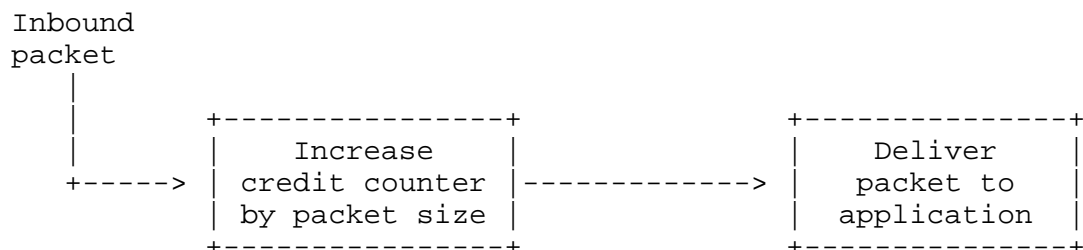   is sent.

```
     Inbound
     packet
       |
       |        +----------------+           +---------------+
       |        |    Increase    |           |    Deliver    |
     +-----> | credit counter |-------------> |   packet to   |
                | by packet size |           |  application  |
                +----------------+           +---------------+
```

        Figure 14: Receiving Packets with Credit-Based Authorization

```
Outbound
 packet
   |               _____
   |              /                \              +--------------+
   |             /  Is the preferred \      No    |  Send packet |
 +-----> |  destination address  |------------> |  to preferred |
   |             \    UNVERIFIED?    /             |    address    |
                  _____/              +--------------+
                          |
                          | Yes
                          |
                          v
                 _____
                /                \              +--------------+
               /   Does an ACTIVE \      Yes    |  Send packet |
              | destination address |------------> |  to ACTIVE    |
               \      exist?       /             |    address    |
                _____/              +--------------+
                          |
                          | No
                          |
                          v
                 _____
                /                \              +--------------+
               /  Credit counter  \      No     |              |
              |        >=          |------------> |  Drop packet  |
               \   packet size?   /             |              |
                _____/              +--------------+
                          |
                          | Yes
                          |
                          v
         +--------------+                       +--------------+
         | Reduce credit|                       |  Send packet |
         |  counter by  |---------------------> |  to preferred |
         |  packet size |                       |    address    |
         +--------------+                       +--------------+
```
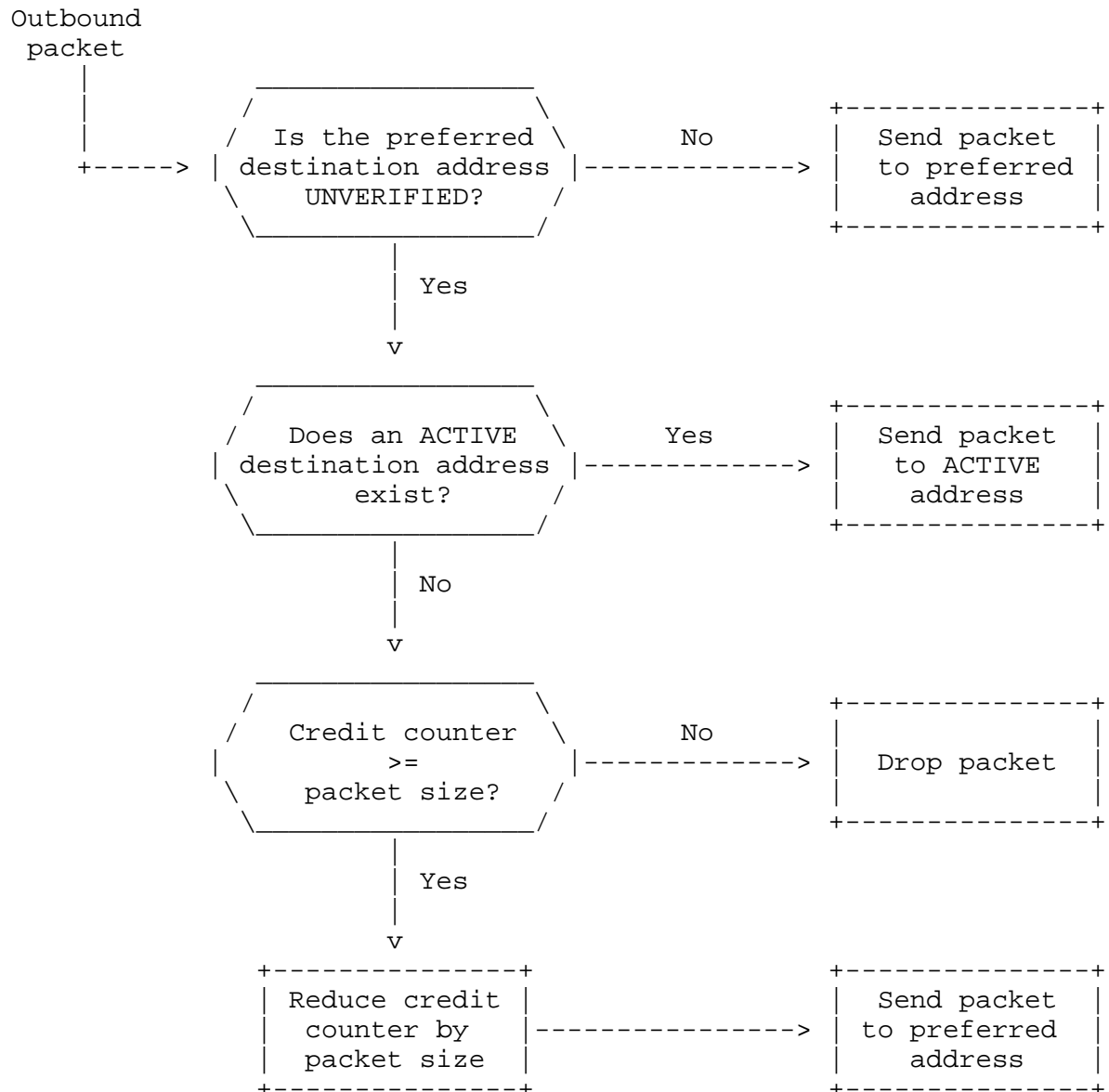
Figure 15: Sending Packets with Credit-Based Authorization

5.6.2. Credit Aging

   A host ensures that the credit counters it maintains for its peers
   gradually decrease over time. Such "credit aging" prevents a
   malicious peer from building up credit at a very slow speed and using
   this, all at once, for a severe burst of redirected packets.

Credit aging may be implemented by multiplying credit counters with a factor, CreditAgingFactor (a fractional value less than one), in fixed time intervals of CreditAgingInterval length. Choosing appropriate values for CreditAgingFactor and CreditAgingInterval is important to ensure that a host can send packets to an address in state UNVERIFIED even when the peer sends at a lower rate than the host itself. When CreditAgingFactor or CreditAgingInterval are too small, the peer's credit counter might be too low to continue sending packets until address verification concludes.

The parameter values proposed in this document are as follows:

```
CreditAgingFactor        7/8
CreditAgingInterval      5 seconds
```

These parameter values work well when the host transfers a file to the peer via a TCP connection and the end-to-end round-trip time does not exceed 500 milliseconds. Alternative credit-aging algorithms may use other parameter values or different parameters, which may even be dynamically established.

6. Security Considerations

The HIP mobility mechanism provides a secure means of updating a host's IP address via HIP UPDATE packets. Upon receipt, a HIP host cryptographically verifies the sender of an UPDATE, so forging or replaying a HIP UPDATE packet is very difficult (see [RFC5201]). Therefore, security issues reside in other attack domains. The two we consider are malicious redirection of legitimate connections as well as redirection-based flooding attacks using this protocol. This can be broken down into the following:

    Impersonation attacks

        - direct conversation with the misled victim

        - man-in-the-middle attack

    DoS attacks

        - flooding attacks (== bandwidth-exhaustion attacks)

            * tool 1: direct flooding

            * tool 2: flooding by zombies

            * tool 3: redirection-based flooding

- memory-exhaustion attacks

- computational-exhaustion attacks

We consider these in more detail in the following sections.

In Section 6.1 and Section 6.2, we assume that all users are using
HIP. In Section 6.3 we consider the security ramifications when we
have both HIP and non-HIP users. Security considerations for Credit-
Based Authorization are discussed in [SIMPLE-CBA].

6.1. Impersonation Attacks

An attacker wishing to impersonate another host will try to mislead
its victim into directly communicating with them, or carry out a man-
in-the-middle (MitM) attack between the victim and the victim's
desired communication peer. Without mobility support, both attack
types are possible only if the attacker resides on the routing path
between its victim and the victim's desired communication peer, or if
the attacker tricks its victim into initiating the connection over an
incorrect routing path (e.g., by acting as a router or using spoofed
DNS entries).

The HIP extensions defined in this specification change the situation
in that they introduce an ability to redirect a connection (like
IPv6), both before and after establishment. If no precautionary
measures are taken, an attacker could misuse the redirection feature
to impersonate a victim's peer from any arbitrary location. The
authentication and authorization mechanisms of the HIP base exchange
[RFC5201] and the signatures in the UPDATE message prevent this
attack. Furthermore, ownership of a HIP association is securely
linked to a HIP HI/HIT. If an attacker somehow uses a bug in the
implementation or weakness in some protocol to redirect a HIP
connection, the original owner can always reclaim their connection
(they can always prove ownership of the private key associated with
their public HI).

MitM attacks are always possible if the attacker is present during
the initial HIP base exchange and if the hosts do not authenticate
each other's identities. However, once the opportunistic base
exchange has taken place, even a MitM cannot steal the HIP connection
anymore because it is very difficult for an attacker to create an
UPDATE packet (or any HIP packet) that will be accepted as a
legitimate update. UPDATE packets use HMAC and are signed. Even
when an attacker can snoop packets to obtain the SPI and HIT/HI, they
still cannot forge an UPDATE packet without knowledge of the secret
keys.

6.2. Denial-of-Service Attacks

6.2.1. Flooding Attacks

   The purpose of a denial-of-service attack is to exhaust some resource
   of the victim such that the victim ceases to operate correctly. A
   denial-of-service attack can aim at the victim's network attachment
   (flooding attack), its memory, or its processing capacity. In a
   flooding attack, the attacker causes an excessive number of bogus or
   unwanted packets to be sent to the victim, which fills their
   available bandwidth. Note that the victim does not necessarily need
   to be a node; it can also be an entire network. The attack basically
   functions the same way in either case.

   An effective DoS strategy is distributed denial of service (DDoS).
   Here, the attacker conventionally distributes some viral software to
   as many nodes as possible. Under the control of the attacker, the
   infected nodes, or "zombies", jointly send packets to the victim.
   With such an 'army', an attacker can take down even very high
   bandwidth networks/victims.

   With the ability to redirect connections, an attacker could realize a
   DDoS attack without having to distribute viral code. Here, the
   attacker initiates a large download from a server, and subsequently
   redirects this download to its victim. The attacker can repeat this
   with multiple servers. This threat is mitigated through reachability
   checks and credit-based authorization. Both strategies do not
   eliminate flooding attacks per se, but they preclude: (i) their use
   from a location off the path towards the flooded victim; and (ii) any
   amplification in the number and size of the redirected packets. As a
   result, the combination of a reachability check and credit-based
   authorization lowers a HIP redirection-based flooding attack to the
   level of a direct flooding attack in which the attacker itself sends
   the flooding traffic to the victim.

6.2.2. Memory/Computational-Exhaustion DoS Attacks

   We now consider whether or not the proposed extensions to HIP add any
   new DoS attacks (consideration of DoS attacks using the base HIP
   exchange and updates is discussed in [RFC5201]). A simple attack is
   to send many UPDATE packets containing many IP addresses that are not
   flagged as preferred. The attacker continues to send such packets
   until the number of IP addresses associated with the attacker's HI
   crashes the system. Therefore, there SHOULD be a limit to the number
   of IP addresses that can be associated with any HI. Other forms of
   memory/computationally exhausting attacks via the HIP UPDATE packet
   are handled in the base HIP document [RFC5201].

A central server that has to deal with a large number of mobile
clients may consider increasing the SA lifetimes to try to slow down
the rate of rekeying UPDATEs or increasing the cookie difficulty to
slow down the rate of attack-oriented connections.

6.3. Mixed Deployment Environment

We now assume an environment with both HIP and non-HIP aware hosts.
Four cases exist.

   1. A HIP host redirects its connection onto a non-HIP host. The
       non-HIP host will drop the reachability packet, so this is not a
       threat unless the HIP host is a MitM that could somehow respond
       successfully to the reachability check.

   2. A non-HIP host attempts to redirect their connection onto a HIP
       host. This falls into IPv4 and IPv6 security concerns, which are
       outside the scope of this document.

   3. A non-HIP host attempts to steal a HIP host's session (assume
       that Secure Neighbor Discovery is not active for the following).
       The non-HIP host contacts the service that a HIP host has a
       connection with and then attempts to change its IP address to
       steal the HIP host's connection. What will happen in this case
       is implementation dependent but such a request should fail by
       being ignored or dropped. Even if the attack were successful,
       the HIP host could reclaim its connection via HIP.

   4. A HIP host attempts to steal a non-HIP host's session. A HIP
       host could spoof the non-HIP host's IP address during the base
       exchange or set the non-HIP host's IP address as its preferred
       address via an UPDATE. Other possibilities exist, but a simple
       solution is to prevent the use of HIP address check information
       to influence non-HIP sessions.

7. IANA Considerations

   This document defines a LOCATOR parameter for the Host Identity
   Protocol [RFC5201]. This parameter is defined in Section 4 with a
   Type of 193.

   This document also defines a LOCATOR_TYPE_UNSUPPORTED Notify Message
   Type as defined in the Host Identity Protocol specification
   [RFC5201]. This parameter is defined in Section 5.3 with a value of
   46.

8. Authors and Acknowledgments

   Pekka Nikander and Jari Arkko originated this document, and Christian
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   Jokela was a co-author of the initial individual submission.

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9. References

9.1. Normative references

   [RFC2119]   Bradner, S., "Key words for use in RFCs to Indicate
                  Requirement Levels", BCP 14, RFC 2119, March 1997.

   [RFC3484]   Draves, R., "Default Address Selection for Internet
                  Protocol version 6 (IPv6)", RFC 3484, February 2003.

   [RFC4291]   Hinden, R. and S. Deering, "IP Version 6 Addressing
                  Architecture", RFC 4291, February 2006.

   [RFC4303]   Kent, S., "IP Encapsulating Security Payload (ESP)",
                  RFC 4303, December 2005.

   [RFC4423]   Moskowitz, R. and P. Nikander, "Host Identity Protocol
                  (HIP) Architecture", RFC 4423, May 2006.

   [RFC5201]   Moskowitz, R., Nikander, P., Jokela, P., Ed., and T.
                  Henderson, "Host Identity Protocol", RFC 5201,
                  April 2008.

   [RFC5202]   Jokela, P., Moskowitz, R., and P. Nikander, "Using the
                  ESP Transport Format with the Host Identity Protocol
                  (HIP)", RFC 5202, April 2008.

   [RFC5204]   Laganier, J. and L. Eggert, "Host Identity Protocol
                  (HIP) Rendezvous Extension", RFC 5204, April 2008.

9.2. Informative references

   [CBA-MIPv6]   Vogt, C. and J. Arkko, "Credit-Based Authorization for
                  Mobile IPv6 Early Binding Updates", Work in Progress,
                  February 2005.

   [RFC4225]   Nikander, P., Arkko, J., Aura, T., Montenegro, G., and
                E. Nordmark, "Mobile IP Version 6 Route Optimization
                Security Design Background", RFC 4225, December 2005.

   [SIMPLE-CBA] Vogt, C. and J. Arkko, "Credit-Based Authorization for
                Concurrent Reachability Verification", Work
                in Progress, February 2006.

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