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Host Identity Protocol
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Status of this Memo

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Abstract

This memo specifies the details of the Host Identity Protocol (HIP). HIP allows consenting hosts to securely establish and maintain shared IP-layer state, allowing separation of the identifier and locator

roles of IP addresses, thereby enabling continuity of communications across IP address changes. HIP is based on a Sigma-compliant Diffie-Hellman key exchange, using public-key identifiers from a new Host Identity name space for mutual peer authentication. The protocol is designed to be resistant to Denial-of-Service (DoS) and Man-in-the-middle (MitM) attacks, and when used together with another suitable security protocol, such as Encapsulated Security Payload (ESP), it provides integrity protection and optional encryption for upper layer protocols, suchs as TCP and UDP. Discussion related to this document is going on at the IETF HIP Working Group mailing list.

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1. Introduction

This memo specifies the details of the Host Identity Protocol (HIP). A high-level description of the protocol and the underlying architectural thinking is available in the separate HIP architecture description [26]. Briefly, the HIP architecture proposes an alternative to the dual use of IP addresses as "locators" (routing labels) and "identifiers" (endpoint, or host, identifiers). In HIP, public cryptographic keys, of a public/private key pair, are used as Host Identifiers, to which higher ayer protocols are bound instead of an IP address. By using public keys (and their representations) as host identifiers, dynamic changes to IP address sets can be directly authenticated between hosts and if desired, strong authentication between hosts at the TCP/IP stack level can be obtained.

This memo specifies the base HIP protocol ("base exchange") used between hosts to establish an IP-layer communications context, called HIP association, prior to communications. It also defines a packet format and procedures for updating an active HIP association. Other elements of the HIP architecture are specified in other documents, including how HIP can be combined with a variant of the Encapsulating Security Payload (ESP) for integrity protection and optional encryption, mobility and multi-homing extensions to HIP, extensions to the Domain Name System (DNS) for storing Host Identities there, proposals on added HIP-related infrastructure into the networks, and techniques for NAT traversal.

1.1. A New Name Space and Identifiers

The Host Identity Protocol introduces a new name space, the Host Identity name space. Some ramifications of this new namespace are explained in the HIP architecture description [26].

There are two main representations of the Host Identity, the full Host Identifier (HI) and the Host Identity Tag (HIT The HI is a public key and directly represents the Identity. Since there are different public key algorithms that can be used with different key lengths, the HI is not good for use as a packet identifier, or as an index into the various operational tables needed to support HIP. Consequently, a hash of the HI, the Host Identity Tag (HIT), becomes the operational representation. It is 128 bits long and is used in the HIP payloads and to index the corresponding state in the end hosts. The HIT has an important security property in that it is self-certifying (see Section 3).

1.2. The HIP Base Exchange

The HIP base exchange is a two-party cryptographic protocol used to

establish communications context between hosts. The base exchange is a Sigma-compliant [30] four packet exchange. The first party is called the Initiator and the second party the Responder. The four-packet design helps to make HIP DoS resilient. The protocol exchanges Diffie-Hellman keys in the 2nd and 3rd packets, and authenticates the parties in the 3rd and 4th packets. Additionally, the Responder starts a puzzle exchange in the 2nd packet, with the Initiator completing it in the 3rd packet before the Responder stores any state from the exchange.

The exchange can use the Diffie-Hellman output to encrypt the Host Identity of the Initiator in packet 3 (although Aura et al. [29] notes that such operation may interfere with packet-inspecting middleboxes), or the Host Identity may instead be sent unencrypted. The Responder's Host Identity is not protected. It should be noted, however, that both the Initiator's and the Responder's HITs are transported as such (in cleartext) in the packets, allowing an eavesdropper with a priori knowledge about the parties to verify their identities.

Data packets start to flow after the 4th packet. The 3rd and 4th HIP packets may carry a data payload in the future. However, the details of this are to be defined later as more implementation experience is gained.

An existing HIP association can be updated using the update mechanism defined in this document, and when the association is no longer needed, it can be closed using the defined closing mechanism.

Finally, HIP is designed as an end-to-end authentication and key establishment protocol, to be used with Encapsulated Security Payload (ESP) [24] and other end-to-end security protocols. The base protocol lacks the details for security association management and much of the fine-grained policy control found in Internet Key Exchange IKE RFC2409 [7] that allows IKE to support complex gateway policies. Thus, HIP is not a replacement for IKE.

1.3. Memo structure

The rest of this memo is structured as follows. Section 2 defines the central keywords, notation, and terms used throughout the rest of the document. Section 3 defines the structure of the Host Identity and its various representations. Section 4 gives an overview of the HIP base exchange protocol. Section 5 and Section 6 define the detail packet formats and rules for packet processing. Finally, Section 7, Section 8, and Section 9 discuss policy, security, and IANA considerations, respectively.

2. Terms and Definitions

2.1. Requirements Terminology

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 [5].

2.2. Notation

[x] indicates that x is optional.

{x} indicates that x is encrypted.

X(y) indicates that y is a parameter of X.

<x>i indicates that x exists i times.

--> signifies "Initiator to Responder" communication (requests).

<-- signifies "Responder to Initiator" communication (replies).

| signifies concatenation of information-- e.g. X | Y is the concatenation of X with Y.

Ltrunc (SHA-1(), K) denotes the lowest order K bits of the SHA-1 result.

2.3. Definitions

Unused Association Lifetime (UAL): Implementation-specific time for which, if no packet is sent or received for this time interval, a host MAY begin to tear down an active association.

Maximum Segment Lifetime (MSL): Maximum time that a TCP segment is expected to spend in the network.

Exchange Complete (EC): Time that the host spends at the R2-SENT before it moves to ESTABLISHED state. The time is n * I2 retransmission timeout, where n ~ I2_RETRIES_MAX.

HIT Hash Algorithm: hash algorithm used to generate a Host Identity Tag (HIT) from the Host Identity public key. Currently SHA-1 [25] is used.

Puzzle Hash Algorithm (PHASH): hash algorithm used to calculate the puzzle hash. The algorithm is the same as is used to generate the Responder's HIT.

Opportunistic mode: HIP base exchange where the Responder's HIT is not a priori known to the Initiator.

3. Host Identifier (HI) and its Representations

In this section, the properties of the Host Identifier and Host Identifier Tag are discussed, and the exact format for them is defined. In HIP, public key of an asymmetric key pair is used as the Host Identifier (HI). Correspondingly, the host itself is defined as the entity that holds the private key from the key pair. See the HIP architecture specification [26] for more details about the difference between an identity and the corresponding identifier.

HIP implementations MUST support the Rivest Shamir Adelman (RSA) [15] public key algorithm, and SHOULD support the Digital Signature Algorithm (DSA) [13] algorithm; other algorithms MAY be supported.

A hashed encoding of the HI, the Host Identity Tag (HIT), is used in protocols to represent the Host Identity. The HIT is 128 bits long and has the following three key properties: i) it is the same length as an IPv6 address and can be used in address-sized fields in APIs and protocols, ii) it is self-certifying (i.e., given a HIT, it is computationally hard to find a Host Identity key that matches the HIT), and iii) the probability of HIT collision between two hosts is very low.

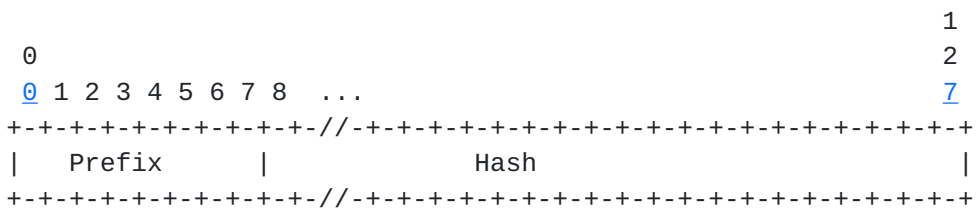
Carrying HIs and HITs in the header of user data packets would increase the overhead of packets. Thus, it is not expected that they are carried in every packet, but other methods are used to map the data packets to the corresponding HIs. In some cases, this makes it possible to use HIP without any additional headers in the user data packets. For example, if ESP is used to protect data traffic, the Security Parameter Index (SPI) carried in the ESP header, can be used to map the encrypted data packet to the correct HIP association.

3.1. Host Identity Tag (HIT)

The Host Identity Tag is a 128 bits long value -- a hashed encoding of the Host Identifier. There are two advantages of using a hashed encoding over the actual Host Identity public key in protocols. Firstly, its fixed length makes for easier protocol coding and also better manages the packet size cost of this technology. Secondly, it presents a consistent format to the protocol whatever underlying identity technology is used.

"A Non-Routable IPv6 Prefix for Keyed Hash Identifiers" [22] has been specified to store 128-bit hash based identifier called Keyed Hash Identifier (KHI) under an 8-bit prefix, proposed to be allocated from the IPv6 address block 1000::/4. The Host Identity Tag is a KHI valid for the Context ID [22] value for HIP, 0xF0EF F02F BFF4 3D0F E793 0C3C 6E61 74EA (The tag value has been generated randomly by the

editor of this specification.) The following figure shows, for informal purposes only, the format of a HIT specified by [22], and used in this document:



Prefix (8 bits) - Fixed prefix, TBD (0x11, TO BE DISCUSSED), as defined per [22].

Encoding (120 bits) - Encoding of the public key and KHI context identifier as defined per [22].

Additional values for the prefix (including different hash algorithms, or other information) may be defined in the future. A host may receive a HIT for which it does not understand the prefix. In such a case, it will not be able to check the mapping between HI and HIT.

3.2. Generating a HIT from a HI

The HIT MUST be generated according to the KHI generation method described in [22] using a context ID value of 0xF0EF F02F BFF4 3D0F E793 0C3C 6E61 74EA, and an input encoding the Host Identity field (see Section 5.2.8) present in a HIP payload packet.

For Identities that are either RSA or DSA public keys, this input consists of the public key encoding as specified in the corresponding DNSSEC document, taking the algorithm specific portion of the RDATA part of the KEY RR. There is currently only two defined public key algorithms: RSA and DSA. Hence, either of the following applies:

The RSA public key is encoded as defined in RFC3110 [15] Section 2, taking the exponent length (e_len), exponent (e) and modulus (n) fields concatenated. The length (n_len) of the modulus (n) can be determined from the total HI Length and the preceding HI fields including the exponent (e). Thus, the data to be hashed has the same length as the HI. The fields MUST be encoded in network byte order, as defined in RFC3110 [15].

The DSA public key is encoded as defined in RFC2536 [13] Section 2, taking the fields T, Q, P, G, and Y, concatenated. Thus, the data to be hashed is 1 + 20 + 3 * 64 + 3 * 8 * T octets long,

where T is the size parameter as defined in RFC2536 [13]. The size parameter T, affecting the field lengths, MUST be selected as the minimum value that is long enough to accommodate P, G, and Y. The fields MUST be encoded in network byte order, as defined in RFC2536 [13].

In Appendix B the public key encoding generation process is illustrated using pseudo-code.

4. Protocol Overview

The following material is an overview of the HIP protocol operation, and does not contain all details of the packet formats or the packet processing steps. Section 5 and Section 6 describe in more detail the packet formats and packet processing steps, respectively, and are normative in case of any conflicts with this section.

The protocol number for Host Identity Protocol will be assigned by IANA. For testing purposes, the protocol number 253 is currently used. This number has been reserved by IANA for experimental use (see [19]).

The HIP payload (Section 5.1) header could be carried in every IP datagram. However, since HIP headers are relatively large (40 bytes), it is desirable to 'compress' the HIP header so that the HIP header only occurs in control packets used to establish or change HIP association state. The actual method for header 'compression' and for matching data packets with existing HIP associations (if any) is defined in separate documents, describing transport formats and methods. All HIP implementations MUST implement, at minimum, the ESP transport format for HIP [24].

4.1. Creating a HIP Association

By definition, the system initiating a HIP exchange is the Initiator, and the peer is the Responder. This distinction is forgotten once the base exchange completes, and either party can become the Initiator in future communications.

The HIP base exchange serves to manage the establishment of state between an Initiator and a Responder. The first packet, I1, initiates the exchange, and the last three packets, R1, I2, and R2, constitute a standard authenticated Diffie-Hellman key exchange for session key generation. During the Diffie-Hellman key exchange, a piece of keying material is generated. The HIP association keys are drawn from this keying material. If other cryptographic keys are needed, e.g., to be used with ESP, they are expected to be drawn from the same keying material.

The Initiator first sends a trigger packet, I1, to the Responder. The packet contains only the HIT of the Initiator and possibly the HIT of the Responder, if it is known. Note that in some cases it may be possible to replace this trigger packet by some other form of a trigger, in which case the protocol starts with the Responder sending the R1 packet.

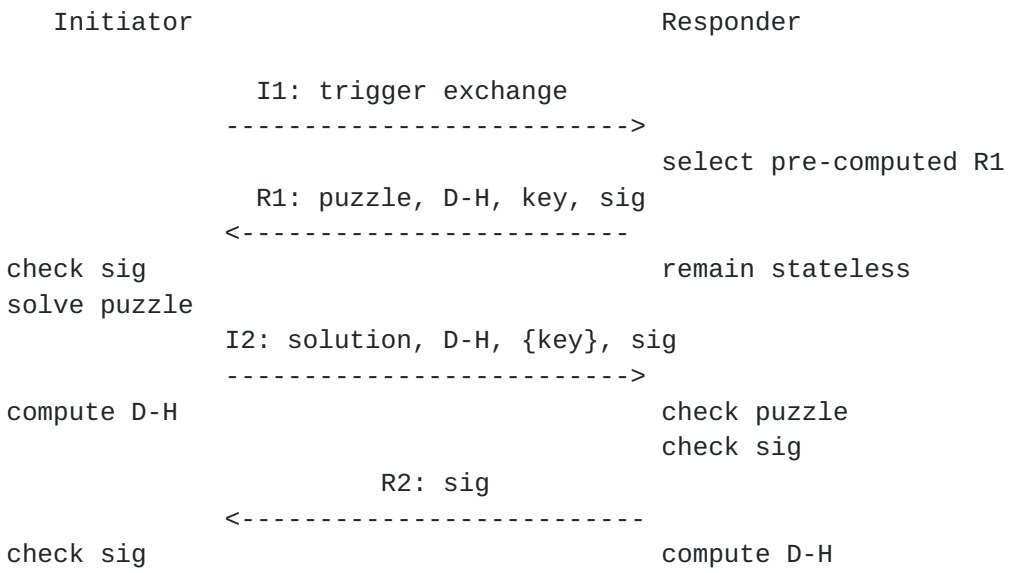
The second packet, R1, starts the actual exchange. It contains a

puzzle-- a cryptographic challenge that the Initiator must solve before continuing the exchange. The level of difficulty of the puzzle can be adjusted based on level of trust with the Initiator, current load, or other factors. In addition, the R1 contains the initial Diffie-Hellman parameters and a signature, covering part of the message. Some fields are left outside the signature to support pre-created R1s.

In the I2 packet, the Initiator must display the solution to the received puzzle. Without a correct solution, the I2 message is discarded. The I2 also contains a Diffie-Hellman parameter that carries needed information for the Responder. The packet is signed by the sender.

The R2 packet finalizes the base exchange. The packet is signed.

The base exchange is illustrated below. The term "key" refers to the host identity public key, and "sig" represents a signature using such a key. The packets contain other parameters not shown in this figure.



4.1.1. HIP Puzzle Mechanism

The purpose of the HIP puzzle mechanism is to protect the Responder from a number of denial-of-service threats. It allows the Responder to delay state creation until receiving I2. Furthermore, the puzzle allows the Responder to use a fairly cheap calculation to check that the Initiator is "sincere" in the sense that it has churned CPU cycles in solving the puzzle.

The Puzzle mechanism has been explicitly designed to give space for various implementation options. It allows a Responder implementation to completely delay session specific state creation until a valid I2 is received. In such a case a correctly formatted I2 can be rejected only once the Responder has checked its validity by computing one hash function. On the other hand, the design also allows a Responder implementation to keep state about received I1s, and match the received I2s against the state, thereby allowing the implementation to avoid the computational cost of the hash function. The drawback of this latter approach is the requirement of creating state. Finally, it also allows an implementation to use other combinations of the space-saving and computation-saving mechanisms.

One possible way for a Responder to remain stateless but drop most spoofed I2s is to base the selection of the puzzle on some function over the Initiator's Host Identity. The idea is that the Responder has a (perhaps varying) number of pre-calculated R1 packets, and it selects one of these based on the information carried in I1. When the Responder then later receives I2, it checks that the puzzle in the I2 matches with the puzzle sent in the R1, thereby making it impractical for the attacker to first exchange one I1/R1, and then generate a large number of spoofed I2s that seemingly come from different IP addresses or use different HITs. The method does not protect from an attacker that uses fixed IP addresses and HITs, though. Against such an attacker a viable approach may be to create a piece of local state, and remember that the puzzle check has previously failed. See Appendix A for one possible implementation. Implementations SHOULD include sufficient randomness to the algorithm so that algorithm complexity attacks become impossible [31].

The Responder can set the puzzle difficulty for Initiator, based on its level of trust of the Initiator. The Responder SHOULD use heuristics to determine when it is under a denial-of-service attack, and set the puzzle difficulty value K appropriately; see below.

4.1.2. Puzzle exchange

The Responder starts the puzzle exchange when it receives an I1. The Responder supplies a random number I, and requires the Initiator to find a number J. To select a proper J, the Initiator must create the concatenation of I, the HITs of the parties, and J, and take a SHA-1 hash over this concatenation. The lowest order K bits of the result MUST be zeros. The value K sets the difficulty of the puzzle.

To generate a proper number J, the Initiator will have to generate a number of Js until one produces the hash target of zero. The Initiator SHOULD give up after exceeding the puzzle lifetime in the PUZZLE parameter (Section 5.2.4). The Responder needs to re-create

the concatenation of I, the HITs, and the provided J, and compute the hash once to prove that the Initiator did its assigned task.

To prevent pre-computation attacks, the Responder MUST select the number I in such a way that the Initiator cannot guess it. Furthermore, the construction MUST allow the Responder to verify that the value was indeed selected by it and not by the Initiator. See Appendix A for an example on how to implement this.

Using the Opaque data field in an ECHO_REQUEST parameter (Section 5.2.17), the Responder can include some data in R1 that the Initiator must copy unmodified in the corresponding I2 packet. The Responder can generate the Opaque data in various ways; e.g. using the sent I, some secret, and possibly other related data. Using this same secret, received I in I2 packet and possible other data, the Receiver can verify that it has itself sent the I to the Initiator. The Responder MUST change such a secret periodically.

It is RECOMMENDED that the Responder generates a new puzzle and a new R1 once every few minutes. Furthermore, it is RECOMMENDED that the Responder remembers an old puzzle at least 2*lifetime seconds after it has been deprecated. These time values allow a slower Initiator to solve the puzzle while limiting the usability that an old, solved puzzle has to an attacker.

NOTE: The protocol developers explicitly considered whether R1 should include a timestamp in order to protect the Initiator from replay attacks. The decision was to NOT include a timestamp.

NOTE: The protocol developers explicitly considered whether a memory bound function should be used for the puzzle instead of a CPU bound function. The decision was not to use memory bound functions. At the time of the decision the idea of memory bound functions was relatively new and their IPR status were unknown. Once there is more experience about memory bound functions and once their IPR status is better known, it may be reasonable to reconsider this decision.

4.1.3. Authenticated Diffie-Hellman Protocol

The packets R1, I2, and R2 implement a standard authenticated Diffie-Hellman exchange. The Responder sends its public Diffie-Hellman key and its public authentication key, i.e., its host identity, in R1. The signature in R1 allows the Initiator to verify that the R1 has been once generated by the Responder. However, since it is precomputed and therefore does not cover all of the packet, it does not protect from replay attacks.

When the Initiator receives an R1, it computes the Diffie-Hellman

session key. It creates a HIP association using keying material from the session key (see Section 6.5), and may use the association to encrypt its public authentication key, i.e., host identity. The resulting I2 contains the Initiator's Diffie-Hellman key and its (optionally encrypted) public authentication key. The signature in I2 covers all of the packet.

The Responder extracts the Initiator Diffie-Hellman public key from the I2, computes the Diffie-Hellman session key, creates a corresponding HIP association, and decrypts the Initiator's public authentication key. It can then verify the signature using the authentication key.

The final message, R2, is needed to protect the Initiator from replay attacks.

4.1.4. HIP Replay Protection

The HIP protocol includes the following mechanisms to protect against malicious replays. Responders are protected against replays of I1 packets by virtue of the stateless response to I1s with presigned R1 messages. Initiators are protected against R1 replays by a monotonically increasing "R1 generation counter" included in the R1. Responders are protected against replays or false I2s by the puzzle mechanism (Section 4.1.1 above), and optional use of opaque data. Hosts are protected against replays to R2s and UPDATEs by use of a less expensive HMAC verification preceding HIP signature verification.

The R1 generation counter is a monotonically increasing 64-bit counter that may be initialized to any value. The scope of the counter MAY be system-wide but SHOULD be per host identity, if there is more than one local host identity. The value of this counter SHOULD be kept across system reboots and invocations of the HIP base exchange. This counter indicates the current generation of puzzles. Implementations MUST accept puzzles from the current generation and MAY accept puzzles from earlier generations. A system's local counter MUST be incremented at least as often as every time old R1s cease to be valid, and SHOULD never be decremented, lest the host expose its peers to the replay of previously generated, higher numbered R1s. Also, the R1 generation counter MUST NOT roll over; if the counter is about to become exhausted, the corresponding HI must be abandoned and replaced with a new one.

A host may receive more than one R1, either due to sending multiple I1s (Section 6.6.1) or due to a replay of an old R1. When sending multiple I1s, an initiator SHOULD wait for a small amount of time after the first R1 reception to allow possibly multiple R1s to

arrive, and it SHOULD respond to an R1 among the set with the largest R1 generation counter. If an Initiator is processing an R1 or has already sent an I2 (still waiting for R2) and it receives another R1 with a larger R1 generation counter, it MAY elect to restart R1 processing with the fresher R1, as if it were the first R1 to arrive.

Upon conclusion of an active HIP association with another host, the R1 generation counter associated with the peer host SHOULD be flushed. A local policy MAY override the default flushing of R1 counters on a per-HIT basis. The reason for recommending the flushing of this counter is that there may be hosts where the R1 generation counter (occasionally) decreases; e.g., due to hardware failure.

4.1.5. Refusing a HIP Exchange

A HIP aware host may choose not to accept a HIP exchange. If the host's policy is to only be an Initiator, it should begin its own HIP exchange. A host MAY choose to have such a policy since only the Initiator HI is protected in the exchange. There is a risk of a race condition if each host's policy is to only be an Initiator, at which point the HIP exchange will fail.

If the host's policy does not permit it to enter into a HIP exchange with the Initiator, it should send an ICMP 'Destination Unreachable, Administratively Prohibited' message. A more complex HIP packet is not used here as it actually opens up more potential DoS attacks than a simple ICMP message.

4.2. Updating a HIP Association

A HIP association between two hosts may need to be updated over time. Examples include the need to rekey expiring user data security associations, add new security associations, or change IP addresses associated with hosts. The UPDATE packet is used for those and other similar purposes. This document only specifies the UPDATE packet format and basic processing rules, with mandatory parameters. The actual usage is defined in separate specifications.

HIP provides a general purpose UPDATE packet, which can carry multiple HIP parameters, for updating the HIP state between two peers. The UPDATE mechanism has the following properties:

- UPDATE messages carry a monotonically increasing sequence number and are explicitly acknowledged by the peer. Lost UPDATEs or acknowledgments may be recovered via retransmission. Multiple UPDATE messages may be outstanding under certain circumstances.

UPDATE is protected by both HMAC and HIP_SIGNATURE parameters, since processing UPDATE signatures alone is a potential DoS attack against intermediate systems.

UPDATE packets are explicitly acknowledged by the use of an acknowledgment parameter that echoes an individual sequence number received from the peer. A single UPDATE packet may contain both a sequence number and one or more acknowledgment numbers (i.e., piggybacked acknowledgment(s) for the peer's UPDATE).

The UPDATE packet is defined in Section 5.3.5.

4.3. Error Processing

HIP error processing behavior depends on whether there exists an active HIP association or not. In general, if an HIP association exists between the sender and receiver of a packet causing an error condition, the receiver SHOULD respond with a NOTIFY packet. On the other hand, if there are no existing HIP associations between the sender and receiver, or the receiver cannot reasonably determine the identity of the sender, the receiver MAY respond with a suitable ICMP message; see Section 5.4 for more details.

The HIP protocol and state machine is designed to recover from one of the parties crashing and losing its state. The following scenarios describe the main use cases covered by the design.

No prior state between the two systems.

The system with data to send is the Initiator. The process follows the standard four packet base exchange, establishing the HIP association.

The system with data to send has no state with the receiver, but the receiver has a residual HIP association.

The system with data to send is the Initiator. The Initiator acts as in no prior state, sending I1 and getting R1. When the Responder receives a valid I2, the old association is 'discovered' and deleted, and the new association is established.

The system with data to send has an HIP association, but the receiver does not.

The system sends data on the outbound user data security association. The receiver 'detects' the situation when it receives a user data packet that it cannot match to any HIP

association. The receiving host MUST discard this packet. Optionally, the receiving host MAY send an ICMP packet with the Parameter Problem type to inform about non-existing HIP association (see Section 5.4), and it MAY initiate a new HIP negotiation. However, responding with these optional mechanisms is implementation or policy dependent.

4.4. HIP State Machine

The HIP protocol itself has little state. In the HIP base exchange, there is an Initiator and a Responder. Once the SAs are established, this distinction is lost. If the HIP state needs to be re-established, the controlling parameters are which peer still has state and which has a datagram to send to its peer. The following state machine attempts to capture these processes.

The state machine is presented in a single system view, representing either an Initiator or a Responder. There is not a complete overlap of processing logic here and in the packet definitions. Both are needed to completely implement HIP.

Implementors must understand that the state machine, as described here, is informational. Specific implementations are free to implement the actual functions differently. Section 6 describes the packet processing rules in more detail. This state machine focuses on the HIP I1, R1, I2, and R2 packets only. Other states may be introduced by mechanisms in other specifications (such as mobility and multihoming).

4.4.1. HIP States

State	Explanation
UNASSOCIATED	State machine start
I1-SENT	Initiating base exchange
I2-SENT	Waiting to complete base exchange
R2-SENT	Waiting to complete base exchange
ESTABLISHED	HIP association established
CLOSING	HIP association closing, no data can be sent
CLOSED	HIP association closed, no data can be sent
E-FAILED	HIP exchange failed

4.4.2. HIP State Processes

System behaviour in state UNASSOCIATED, Table 2.

Trigger	Action
User data to send, requiring a new HIP association	Send I1 and go to I1-SENT
Receive I1	Send R1 and stay at UNASSOCIATED
Receive I2, process	If successful, send R2 and go to R2-SENT
	If fail, stay at UNASSOCIATED
Receive user data for unknown HIP association	Optionally send ICMP as defined in Section 5.4 and stay at UNASSOCIATED
Receive CLOSE	Optionally send ICMP Parameter Problem and stay at UNASSOCIATED

Receive ANYOTHER	Drop and stay at UNASSOCIATED

Table 2: UNASSOCIATED - Start state

System behaviour in state I1-SENT, Table 3.

Trigger	Action
Receive I1	If the local HIT is smaller than the peer HIT, drop I1 and stay at I1-SENT If the local HIT is greater than the peer HIT, send R1 and stay at I1_SENT
Receive I2, process	If successful, send R2 and go to R2-SENT If fail, stay at I1-SENT
Receive R1, process	If successful, send I2 and go to I2-SENT If fail, go to E-FAILED
Receive ANYOTHER	Drop and stay at I1-SENT
Timeout, increment timeout counter	If counter is less than I1_RETRIES_MAX, send I1 and stay at I1-SENT If counter is greater than I1_RETRIES_MAX, go to E-FAILED

Table 3: I1-SENT - Initiating HIP

System behaviour in state I2-SENT, Table 4.

Trigger	Action
Receive I1	Send R1 and stay at I2-SENT
Receive R1, process	If successful, send I2 and cycle at I2-SENT
	If fail, stay at I2-SENT
Receive I2, process	If successful and local HIT is smaller than the peer HIT, drop I2 and stay at I2-SENT
	If succesful and local HIT is greater than the peer HIT, send R2 and go to R2-SENT
	If fail, stay at I2-SENT
Receive R2, process	If successful, go to ESTABLISHED
	If fail, go to E-FAILED
Receive ANYOTHER	Drop and stay at I2-SENT
Timeout, increment timeout counter	If counter is less than I2_RETRIES_MAX, send I2 and stay at I2-SENT
	If counter is greater than I2_RETRIES_MAX, go to E-FAILED

Table 4: I2-SENT - Waiting to finish HIP

System behaviour in state R2-SENT, Table 5.

Trigger	Action
Receive I1	Send R1 and stay at R2-SENT
Receive I2, process	If successful, send R2 and cycle at R2-SENT
	If fail, stay at R2-SENT
Receive R1	Drop and stay at R2-SENT
Receive R2	Drop and stay at R2-SENT
Receive data or UPDATE	Move to ESTABLISHED
Exchange Complete Timeout	Move to ESTABLISHED

Table 5: R2-SENT - Waiting to finish HIP

System behaviour in state ESTABLISHED, Table 6.

Trigger	Action
Receive I1	Send R1 and stay at ESTABLISHED
Receive I2, process with puzzle and possible Opaque data verification	If successful, send R2, drop old HIP association, establish a new HIP association, go to R2-SENT
	If fail, stay at ESTABLISHED
Receive R1	Drop and stay at ESTABLISHED
Receive R2	Drop and stay at ESTABLISHED
Receive user data for HIP association	Process and stay at ESTABLISHED
No packet sent/received during UAL minutes	Send CLOSE and go to CLOSING
Receive CLOSE, process	If successful, send CLOSE_ACK and go to CLOSED
	If fail, stay at ESTABLISHED

Table 6: ESTABLISHED - HIP association established

System behaviour in state CLOSING, Table 7.

Trigger	Action
User data to send, requires the creation of another incarnation of the HIP association	Send I1 and stay at CLOSING
Receive I1	Send R1 and stay at CLOSING
Receive I2, process	If successful, send R2 and go to R2-SENT
	If fail, stay at CLOSING
Receive R1, process	If successful, send I2 and go to I2-SENT
	If fail, stay at CLOSING
Receive CLOSE, process	If successful, send CLOSE_ACK, discard state and go to CLOSED
	If fail, stay at CLOSING
Receive CLOSE_ACK, process	If successful, discard state and go to UNASSOCIATED
	If fail, stay at CLOSING
Receive ANYOTHER	Drop and stay at CLOSING
Timeout, increment timeout sum, reset timer	If timeout sum is less than UAL+MSL minutes, retransmit CLOSE and stay at CLOSING
	If timeout sum is greater than UAL+MSL minutes, go to UNASSOCIATED

Table 7: CLOSING - HIP association has not been used for UAL minutes

System behaviour in state CLOSED, Table 8.

Trigger	Action
Datagram to send, requires the creation of another incarnation of the HIP association	Send I1, and stay at CLOSED
Receive I1	Send R1 and stay at CLOSED
Receive I2, process	If successful, send R2 and go to R2-SENT
	If fail, stay at CLOSED
Receive R1, process	If successful, send I2 and go to I2-SENT
	If fail, stay at CLOSED
Receive CLOSE, process	If successful, send CLOSE_ACK, stay at CLOSED
	If fail, stay at CLOSED
Receive CLOSE_ACK, process	If successful, discard state and go to UNASSOCIATED
	If fail, stay at CLOSED
Receive ANYOTHER	Drop and stay at CLOSED
Timeout (UAL+2MSL)	Discard state and go to UNASSOCIATED

Table 8: CLOSED - CLOSE_ACK sent, resending CLOSE_ACK if necessary

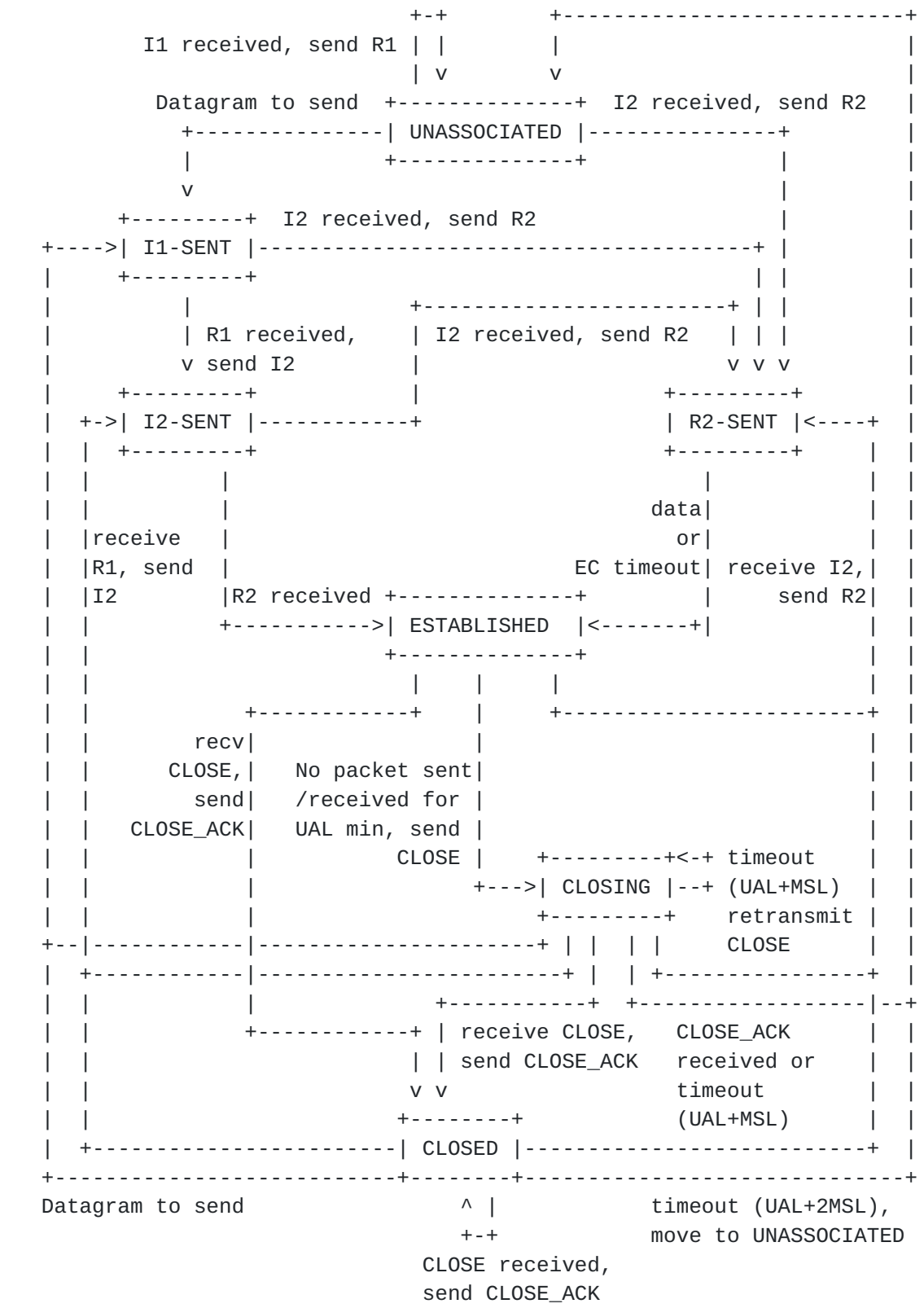
System behaviour in state E-FAILED, Table 9.

Trigger	Action
Wait for implementation specific time	Go to UNASSOCIATED. Re-negotiation is possible after moving to UNASSOCIATED state.

Table 9: E-FAILED - HIP failed to establish association with peer

4.4.3. Simplified HIP State Diagram

The following diagram shows the major state transitions. Transitions based on received packets implicitly assume that the packets are successfully authenticated or processed.


I1 received, send R1
Datagram to send
UNASSOCIATED
I2 received, send R2
I2 received, send R2
I1-SENT
R1 received,
send I2
I2 received, send R2
I2-SENT
R2-SENT
receive
R1, send
I2
R2 received
EC timeout
receive I2,
send R2
ESTABLISHED
data
or
recv
CLOSE,
send
CLOSE_ACK
No packet sent
/received for
UAL min, send
CLOSE
timeout
CLOSING
(UAL+MSL)
retransmit
CLOSE
receive CLOSE,
send CLOSE_ACK
CLOSE_ACK
received or
timeout
(UAL+MSL)
CLOSED
Datagram to send
timeout (UAL+2MSL),
move to UNASSOCIATED
CLOSE received,
send CLOSE_ACK

4.5. User Data Considerations

4.5.1. TCP and UDP Pseudo-header Computation for User Data

When computing TCP and UDP checksums on user data packets that flow through sockets bound to HITs, the IPv6 pseudo-header format [11] MUST be used, even if the actual addresses on the packet are IPv4 addresses. Additionally, the HITs MUST be used in the place of the IPv6 addresses in the IPv6 pseudo-header. Note that the pseudo-header for actual HIP payloads is computed differently; see Section 5.1.1.

4.5.2. Sending Data on HIP Packets

A future version of this document may define how to include user data on various HIP packets. However, currently the HIP header is a terminal header, and not followed by any other headers.

4.5.3. Transport Formats

The actual data transmission format, used for user data after the HIP base exchange, is not defined in this document. Such transport formats and methods are described in separate specifications. All HIP implementations MUST implement, at minimum, the ESP transport format for HIP [24].

When new transport formats are defined, they get the type value from the HIP Transform type value space 2048 - 4095. The order in which the transport formats are presented in the R1 packet, is the preferred order. The last of the transport formats MUST be ESP transport format, represented by the ESP_TRANSFORM parameter.

4.5.4. Reboot and SA Timeout Restart of HIP

Simulating a loss of state is a potential DoS attack. The following process has been crafted to manage state recovery without presenting a DoS opportunity.

If a host reboots or the HIP association times out, it has lost its HIP state. If the host that lost state has a datagram to send to the peer, it simply restarts the HIP base exchange. After the base exchange has completed, the Initiator can create a new SA and start sending data. The peer does not reset its state until it receives a valid I2 HIP packet.

If a system receives a user data packet that cannot be matched to any existing HIP association, it is possible that it has lost the state and its peer has not. It MAY send an ICMP packet with the Parameter

Problem type, the Pointer pointing to the referred HIP-related association information. Reacting to such traffic depends on the implementation and the environment where the implementation is used.

If the host, that apparently has lost its state, decides to restart the HIP base exchange, it sends an I1 packet to the peer. After the base exchange has been completed successfully, the Initiator can create a new HIP association and the peer drops its OLD SA and creates a new one.

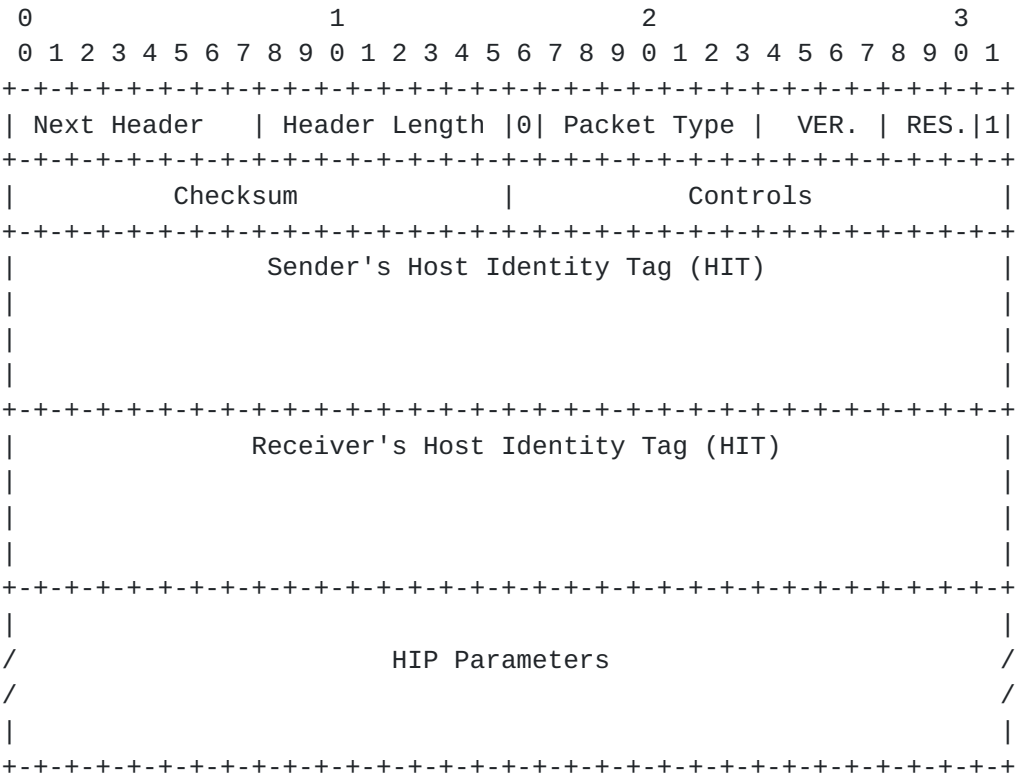
4.6. Certificate Distribution

HIP base specification does not define how to use certificates or how to transfer them between hosts. These functions are defined in a separate specification. A parameter type value, meant to be used for carrying certificates, is reserved, though: CERT, Type 768; see Section 5.2.

5. Packet Formats

5.1. Payload Format

All HIP packets start with a fixed header.



The HIP header is logically an IPv6 extension header. However, this document does not describe processing for Next Header values other than decimal 59, IPPROTO_NONE, the IPv6 no next header value. Future documents MAY do so. However, current implementations MUST ignore trailing data if an unimplemented Next Header value is received.

The Header Length field contains the length of the HIP Header and HIP parameters in 8 bytes units, excluding the first 8 bytes. Since all HIP headers MUST contain the sender's and receiver's HIT fields, the minimum value for this field is 4, and conversely, the maximum length of the HIP Parameters field is (255*8)-32 = 2008 bytes. Note: this sets an additional limit for sizes of parameters included in the Parameters field, independent of the individual parameter maximum lengths.

The Packet Type indicates the HIP packet type. The individual packet types are defined in the relevant sections. If a HIP host receives a

HIP packet that contains an unknown packet type, it MUST drop the packet.

The HIP Version is four bits. The current version is 1. The version number is expected to be incremented only if there are incompatible changes to the protocol. Most extensions can be handled by defining new packet types, new parameter types, or new controls.

The following three bits are reserved for future use. They MUST be zero when sent, and they SHOULD be ignored when handling a received packet.

The two fixed bits in the header are reserved for potential SHIM6 compatibility [27]. For implementations adhering (only) to this specification, they MUST be set as shown when sending and MUST be ignored when receiving. This is to ensure optimal forward compatibility. Note that implementations that implement other compatible specifications in addition to this specification, the corresponding rules may well be different. For example, in the case that the forthcoming SHIM6 protocol happens to be compatible with this specification, an implementation that implements both this specification and the SHIM6 protocol may need to check these bits in order to determine how to handle the packet.

The HIT fields are always 128 bits (16 bytes) long.

5.1.1. Checksum

Since the checksum covers the source and destination addresses in the IP header, it must be recomputed on HIP-aware NAT devies.

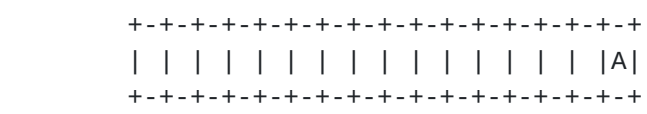
If IPv6 is used to carry the HIP packet, the pseudo-header [11] contains the source and destination IPv6 addresses, HIP packet length in the pseudo-header length field, a zero field, and the HIP protocol number (see Section 4) in the Next Header field. The length field is in bytes and can be calculated from the HIP header length field: (HIP Header Length + 1) * 8.

In case of using IPv4, the IPv4 UDP pseudo header format [1] is used. In the pseudo header, the source and destination addresses are those used in the IP header, the zero field is obviously zero, the protocol is the HIP protocol number (see Section 4), and the length is calculated as in the IPv6 case.

5.1.2. HIP Controls

The HIP Controls section conveys information about the structure of the packet and capabilities of the host.

The following fields have been defined:



A - Anonymous: If this is set, the sender's HI in this packet is anonymous, i.e., one not listed in a directory. Anonymous HIs SHOULD NOT be stored. This control is set in packets R1 and/or I2. The peer receiving an anonymous HI may choose to refuse it.

The rest of the fields are reserved for future use and MUST be set to zero on sent packets and ignored on received packets.

5.1.3. HIP Fragmentation Support

A HIP implementation must support IP fragmentation / reassembly. Fragment reassembly MUST be implemented in both IPv4 and IPv6, but fragment generation is REQUIRED to be implemented in IPv4 (IPv4 stacks and networks will usually do this by default) and RECOMMENDED to be implemented in IPv6. In IPv6 networks, the minimum MTU is larger, 1280 bytes, than in IPv4 networks. The larger MTU size is usually sufficient for most HIP packets, and therefore fragment generation may not be needed. If a host expects to send HIP packets that are larger than the minimum IPv6 MTU, it MUST implement fragment generation even for IPv6.

In IPv4 networks, HIP packets may encounter low MTUs along their routed path. Since HIP does not provide a mechanism to use multiple IP datagrams for a single HIP packet, support for path MTU discovery does not bring any value to HIP in IPv4 networks. HIP-aware NAT devices MUST perform any IPv4 reassembly/fragmentation.

All HIP implementations MUST employ a reassembly algorithm that is sufficiently resistant to DoS attacks.

5.2. HIP Parameters

The HIP Parameters are used to carry the public key associated with the sender's HIT, together with related security and other information. They consist of ordered parameters, encoded in TLV format.

The following parameter types are currently defined.

TLV	Type	Length	Data
R1_COUNTER	128	12	System Boot Counter
PUZZLE	257	12	K and Random #I
SOLUTION	321	20	K, Random #I and puzzle solution J
SEQ	385	4	Update packet ID number
ACK	449	variable	Update packet ID number
DIFFIE_HELLMAN	513	variable	public key
HIP_TRANSFORM	577	variable	HIP Encryption and Integrity Transform
ENCRYPTED	641	variable	Encrypted part of I2 packet
HOST_ID	705	variable	Host Identity with Fully Qualified Domain Name or NAI
CERT	768	variable	HI Certificate; used to transfer certificates. Usage defined in a separate document.
NOTIFY	832	variable	Informational data
ECHO_REQUEST	897	variable	Opaque data to be echoed back; under signature
ECHO_RESPONSE	961	variable	Opaque data echoed back; under signature
HMAC	61505	20	HMAC based message authentication code, with key material from HIP_TRANSFORM
HMAC_2	61569	20	HMAC based message authentication code, with key material from HIP_TRANSFORM

HIP_SIGNATURE_2	61633	variable	Signature of the R1 packet
HIP_SIGNATURE	61697	variable	Signature of the packet
ECHO_REQUEST	63661	variable	Opaque data to be echoed back; after signature
ECHO_RESPONSE	63425	variable	Opaque data echoed back; after signature

Because the ordering (from lowest to highest) of HIP parameters is strictly enforced (see Section 5.2.1), the parameter type values for existing parameters have been spaced to allow for future protocol extensions. Parameters numbered between 0-1023 are used in HIP handshake and update procedures and are covered by signatures. Parameters numbered between 1024-2047 are reserved. Parameters numbered between 2048-4095 are used for parameters related to HIP transform types. Parameters numbered between 4096 and (2^16 - 2^12) 61439 are reserved. Parameters numbered between 61440-62463 are used for signatures and signed MACs. Parameters numbered between 62464-63487 are used for parameters that fall outside of the signed area of the packet. Parameters numbered between 63488-64511 are used for rendezvous and other relaying services. Parameters numbered between 64512-65535 are reserved.

5.2.1. TLV Format

The TLV-encoded parameters are described in the following subsections. The type-field value also describes the order of these fields in the packet, except for type values from 2048 to 4095 which are reserved for new transport forms. The parameters MUST be included in the packet such that their types form an increasing order. If the order does not follow this rule, the packet is considered to be malformed and it MUST be discarded.

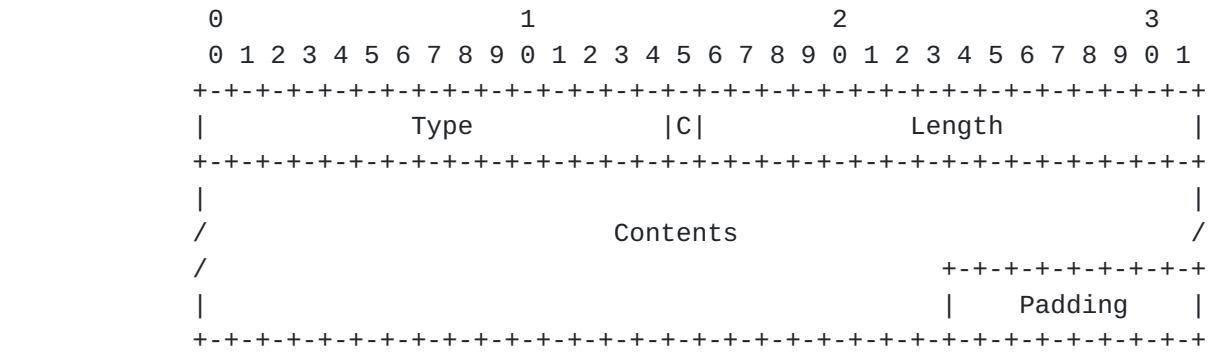
Parameters using type values from 2048 up to 4095 are transport formats. Currently, one transport format is defined: the ESP transport format [24]. The order of these parameters does not follow the order of their type value, but they are put in the packet in order of preference. The first of the transport formats it the most preferred, and so on.

All of the TLV parameters have a length (including Type and Length fields) which is a multiple of 8 bytes. When needed, padding MUST be added to the end of the parameter so that the total length becomes a multiple of 8 bytes. This rule ensures proper alignment of data. If padding is added, the Length field MUST NOT include the padding. Any

added padding bytes MUST be zeroed by the sender, and their values SHOULD NOT be checked by the receiver.

Consequently, the Length field indicates the length of the Contents field (in bytes). The total length of the TLV parameter (including Type, Length, Contents, and Padding) is related to the Length field according to the following formula:

Total Length = 11 + Length - (Length + 3) % 8;



Type	Type code for the parameter. 16 bits long, C-bit being part of the Type code.
C	Critical. One if this parameter is critical, and MUST be recognized by the recipient, zero otherwise. The C bit is considered to be a part of the Type field. Consequently, critical parameters are always odd and non-critical ones have an even value.
Length	Length of the Contents, in bytes.
Contents	Parameter specific, defined by Type
Padding	Padding, 0-7 bytes, added if needed

Critical parameters MUST be recognized by the recipient. If a recipient encounters a critical parameter that it does not recognize, it MUST NOT process the packet any further. It MAY send an ICMP or NOTIFY, as defined in Section 4.3.

Non-critical parameters MAY be safely ignored. If a recipient encounters a non-critical parameter that it does not recognize, it SHOULD proceed as if the parameter was not present in the received packet.

5.2.2. Defining New Parameters

Future specifications may define new parameters as needed. When defining new parameters, care must be taken to ensure that the parameter type values are appropriate and leave suitable space for other future extensions. One must remember that the parameters MUST

always be arranged in the increasing order by type code, thereby limiting the order of parameters (see Section 5.2.1).

The following rules must be followed when defining new parameters.

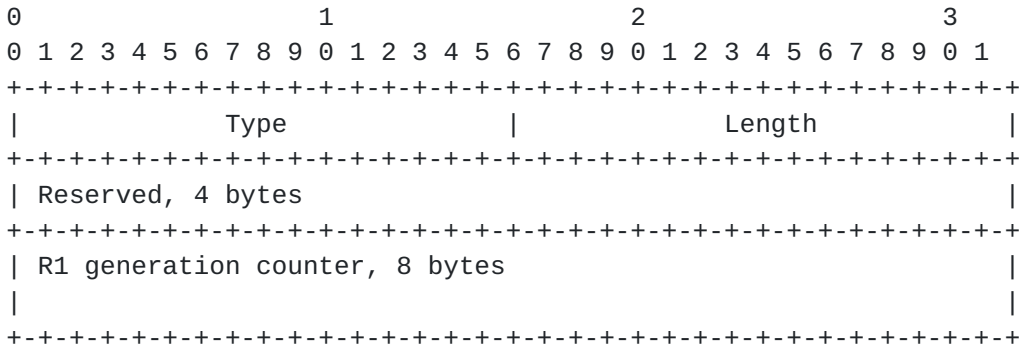
1. The low order bit C of the Type code is used to distinguish between critical and non-critical parameters.

2. A new parameter may be critical only if an old recipient ignoring it would cause security problems. In general, new parameters SHOULD be defined as non-critical, and expect a reply from the recipient.

3. If a system implements a new critical parameter, it MUST provide the ability to configure the associated feature off, such that the critical parameter is not sent at all. The configuration option must be well documented. By default, sending of such a new critical parameter SHOULD be off. In other words, the management interface MUST allow vanilla standards-only mode as a default configuration setting, and MAY allow new critical payloads to be configured on (and off).

4. See section Section 9 for allocation rules regarding type codes.

5.2.3. R1_COUNTER



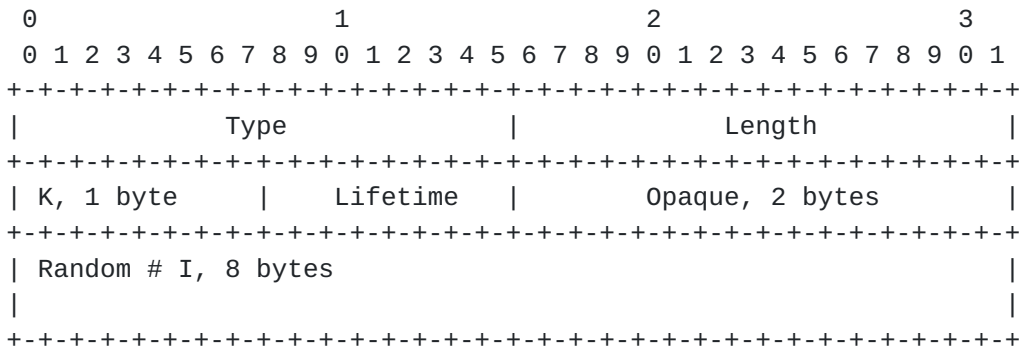
Type	128
Length	12
R1 generation counter	The current generation of valid puzzles

The R1_COUNTER parameter contains an 64-bit unsigned integer in network byte order, indicating the current generation of valid puzzles. The sender is supposed to increment this counter periodically. It is RECOMMENDED that the counter value is incremented at least as often as old PUZZLE values are deprecated so

that SOLUTIONs to them are no longer accepted.

The R1_COUNTER parameter is optional. It SHOULD be included in the R1 (in which case it is covered by the signature), and if present in the R1, it MAY be echoed (including the Reserved field verbatim) by the Initiator in the I2.

5.2.4. PUZZLE



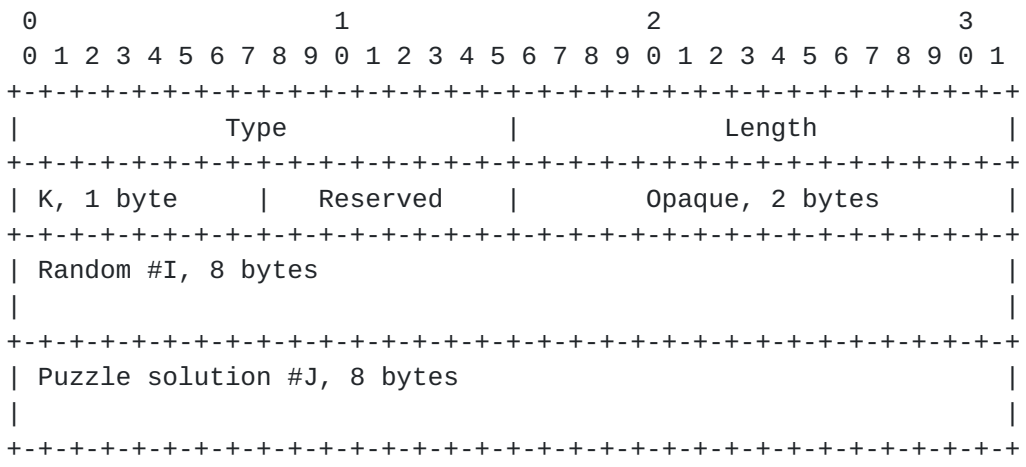
Type	257
Length	12
K	K is the number of verified bits
Lifetime	Puzzle lifetime 2^(value-32) seconds
Opaque	Data set by the Responder, indexing the puzzle
Random #I	random number

Random #I is represented as 64-bit integer, K and Lifetime as 8-bit integer, all in network byte order.

The PUZZLE parameter contains the puzzle difficulty K and a 64-bit puzzle random integer #I. The Puzzle Lifetime indicates the time during which the puzzle solution is valid, and sets a time limit which should not be exceeded by the Initiator while it attempts to solve the puzzle. The lifetime is indicated as a power of 2 using the formula 2^(Lifetime-32) seconds. A puzzle MAY be augmented with an ECHO_REQUEST parameter included in the R1; the contents of the ECHO_REQUEST are then echoed back in the ECHO_RESPONSE, allowing the Responder to use the included information as a part of its puzzle processing.

The Opaque and Random #I field are not covered by the HIP_SIGNATURE_2 parameter.

5.2.5. SOLUTION

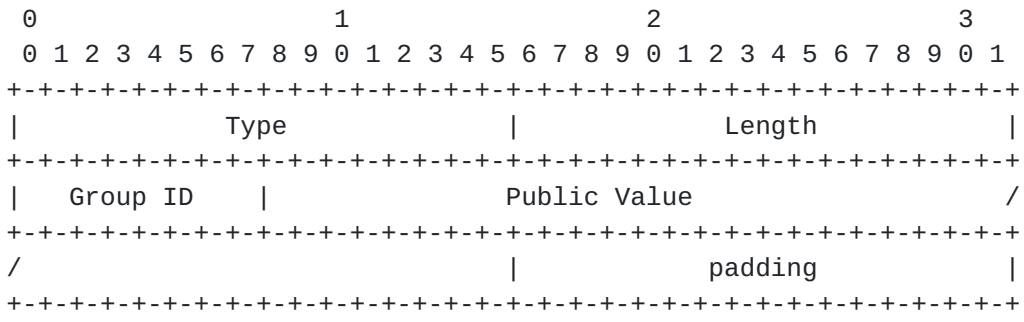


Type	321
Length	20
K	K is the number of verified bits
Reserved	zero when sent, ignored when received
Opaque	copied unmodified from the received PUZZLE parameter
Random #I	random number
Puzzle solution #J	random number

Random #I, and Random #J are represented as 64-bit integers, K as an 8-bit integer, all in network byte order.

The SOLUTION parameter contains a solution to a puzzle. It also echoes back the random difficulty K, the Opaque field, and the puzzle integer #I.

5.2.6. DIFFIE_HELLMAN



Type	513
Length	length in octets, excluding Type, Length, and padding
Group ID	defines values for p and g
Public Value	the sender's public Diffie-Hellman key

The following Group IDs have been defined:

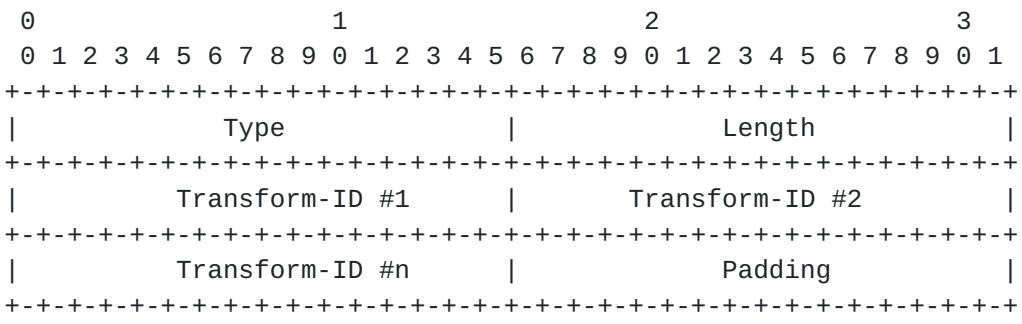
Group	Value
Reserved	0
384-bit group	1
OAKLEY well known group 1	2
1536-bit MODP group	3
3072-bit MODP group	4
6144-bit MODP group	5
8192-bit MODP group	6

The MODP Diffie-Hellman groups are defined in [17]. The OAKLEY group is defined in [8]. The OAKLEY well known group 5 is the same as the 1536-bit MODP group.

A HIP implementation MUST support Group IDs 1 and 3. The 384-bit group can be used when lower security is enough (e.g. web surfing) and when the equipment is not powerful enough (e.g. some PDAs). Equipment powerful enough SHOULD implement also group ID 5. The 384-bit group is defined in Appendix D.

To avoid unnecessary failures during the base exchange, the rest of the groups SHOULD be implemented in hosts where resources are adequate.

5.2.7. HIP_TRANSFORM



Type	577
Length	length in octets, excluding Type, Length, and padding
Transform-ID	Defines the HIP Suite to be used

The following Suite-IDs are defined ([21],[10]):

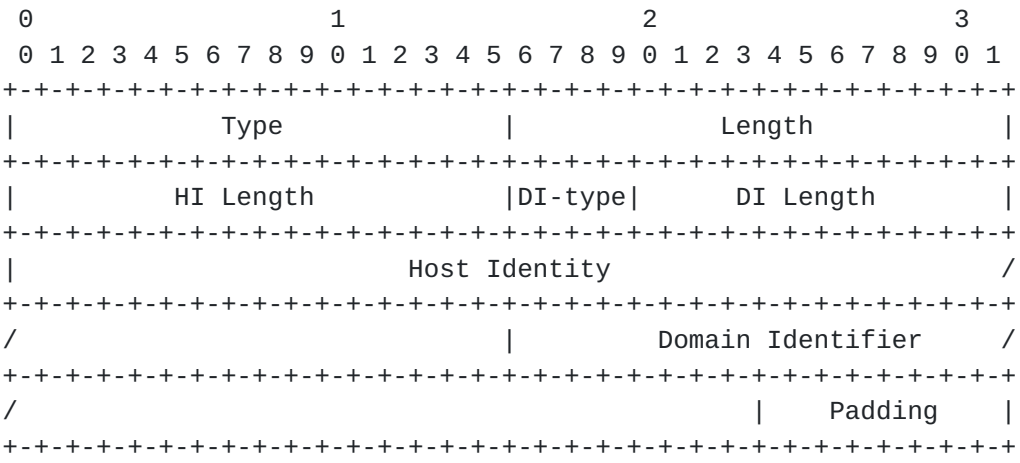
Suite-ID	Value
RESERVED	0
AES-CBC with HMAC-SHA1	1
3DES-CBC with HMAC-SHA1	2
3DES-CBC with HMAC-MD5	3
BLOWFISH-CBC with HMAC-SHA1	4
NULL-ENCRYPT with HMAC-SHA1	5
NULL-ENCRYPT with HMAC-MD5	6

There MUST NOT be more than six (6) HIP Suite-IDs in one HIP transform parameter. The limited number of transforms sets the maximum size of HIP_TRANSFORM parameter. The HIP_TRANSFORM parameter MUST contain at least one of the mandatory Suite-IDs.

The Responder lists supported and desired Suite-IDs in order of preference in the R1, up to the maximum of six Suite-IDs. In the I2, the Initiator MUST choose and insert only one of the corresponding Suite-IDs that will be used for generating the I2.

Mandatory implementations: AES-CBC with HMAC-SHA1 and NULL-ENCRYPTION with HMAC-SHA1.

5.2.8. HOST_ID



Type	705
Length	length in octets, excluding Type, Length, and Padding
HI Length	Length of the Host Identity in octets
DI-type	type of the following Domain Identifier field
DI Length	length of the FQDN or NAI in octets
Host Identity	actual host identity
Domain Identifier	the identifier of the sender

The Host Identity is represented in RFC2535 [12] format. The algorithms used in RDATA format are the following:

Algorithms	Values
RESERVED	0
DSA	3 [RFC2536] (RECOMMENDED)
RSA	5 [RFC3110] (REQUIRED)

The following DI-types have been defined:

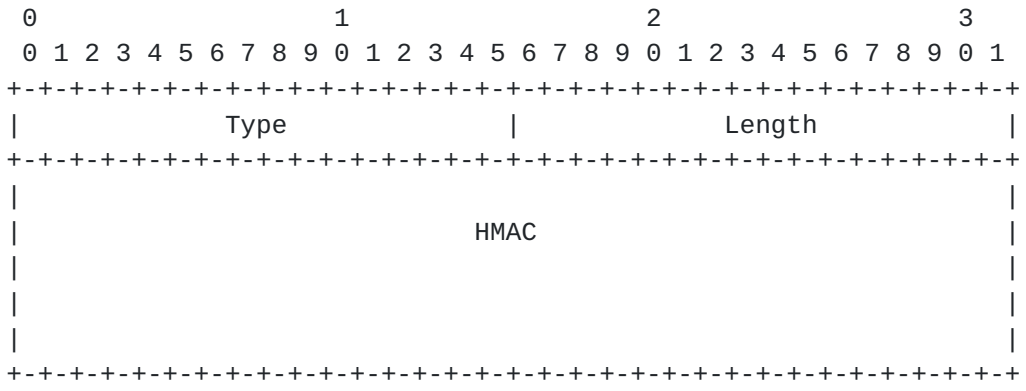
Type	Value
none included	0
FQDN	1
NAI	2

FQDN	Fully Qualified Domain Name, in binary format.
NAI	Network Access Identifier

The format for the FQDN is defined in RFC1035 [3] Section 3.1.

If there is no Domain Identifier, i.e. the DI-type field is zero, also the DI Length field is set to zero.

5.2.9. HMAC



Type	61505
Length	20
HMAC	160 low order bits of the HMAC computed over the HIP packet, excluding the HMAC parameter and any following parameters, such as HIP_SIGNATURE, HIP_SIGNATURE_2, ECHO_REQUEST, or ECHO_RESPONSE. The checksum field MUST be set to zero and the HIP header length in the HIP common header MUST be calculated not to cover any excluded parameters when the HMAC is calculated.

The HMAC calculation and verification process is presented in Section 6.4.1

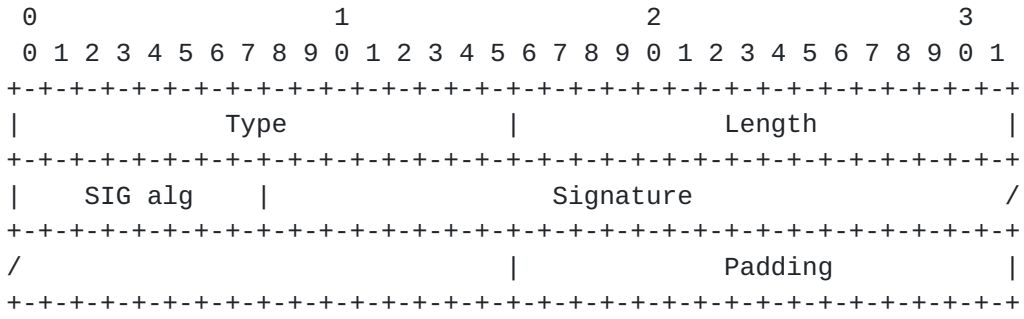
5.2.10. HMAC_2

The parameter structure is the same as in Section 5.2.9. The fields are:

Type	61569
Length	20
HMAC	160 low order bits of the HMAC computed over the HIP packet, excluding the HMAC parameter and any following parameters such as HIP_SIGNATURE, HIP_SIGNATURE_2, ECHO_REQUEST, or ECHO_RESPONSE, and including an additional sender's HOST_ID parameter during the HMAC calculation. The checksum field MUST be set to zero and the HIP header length in the HIP common header MUST be calculated not to cover any excluded parameters when the HMAC is calculated.

The HMAC calculation and verification process is presented in Section 6.4.1

5.2.11. HIP_SIGNATURE



Type	61697
Length	length in octets, excluding Type, Length, and Padding
SIG alg	Signature algorithm
Signature	the signature is calculated over the HIP packet, excluding the HIP_SIGNATURE parameter and any parameters that follow the HIP_SIGNATURE parameter. The checksum field MUST be set to zero, and the HIP header length in the HIP common header MUST be calculated only to the beginning of the HIP_SIGNATURE parameter when the signature is calculated.

The signature algorithms are defined in Section 5.2.8. The signature in the Signature field is encoded using the proper method depending on the signature algorithm (e.g. according to [15] in case of RSA, or according to [13] in case of DSA).

The HIP_SIGNATURE calculation and verification process is presented

in Section 6.4.2

5.2.12. HIP_SIGNATURE_2

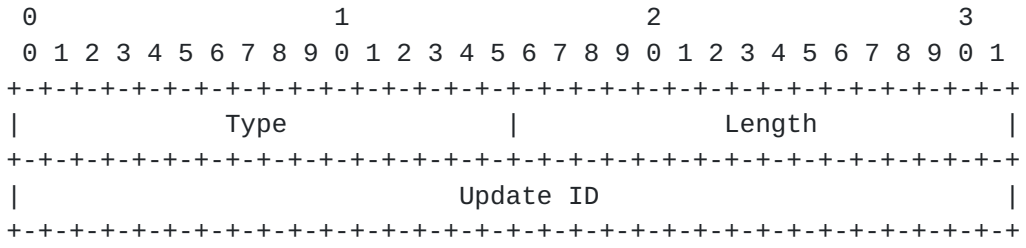
The parameter structure is the same as in Section 5.2.11. The fields are:

Type	61633
Length	length in octets, excluding Type, Length, and Padding
SIG alg	Signature algorithm
Signature	the signature is calculated over the HIP R1 packet, excluding the HIP_SIGNATURE_2 parameter and any parameters that follow. Initiator's HIT, checksum field, and the Opaque and Random #I fields in the PUZZLE parameter MUST be set to zero while computing the HIP_SIGNATURE_2 signature. Further, the HIP packet length in the HIP header MUST be calculated to the beginning of the HIP_SIGNATURE_2 parameter when the signature is calculated.

Zeroing the Initiator's HIT makes it possible to create R1 packets beforehand to minimize the effects of possible DoS attacks. Zeroing the I and Opaque fields allows these fields to be populated dynamically on precomputed R1s.

Signature calculation and verification follows the process in Section 6.4.2.

5.2.13. SEQ

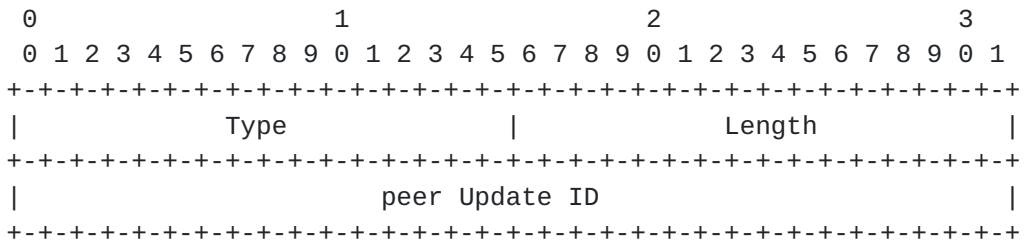


Type	385
Length	4
Update ID	32-bit sequence number

The Update ID is an unsigned quantity, initialized by a host to zero upon moving to ESTABLISHED state. The Update ID has scope within a single HIP association, and not across multiple associations or multiple hosts. The Update ID is incremented by one before each new UPDATE that is sent by the host; the first UPDATE packet originated

by a host has an Update ID of 0.

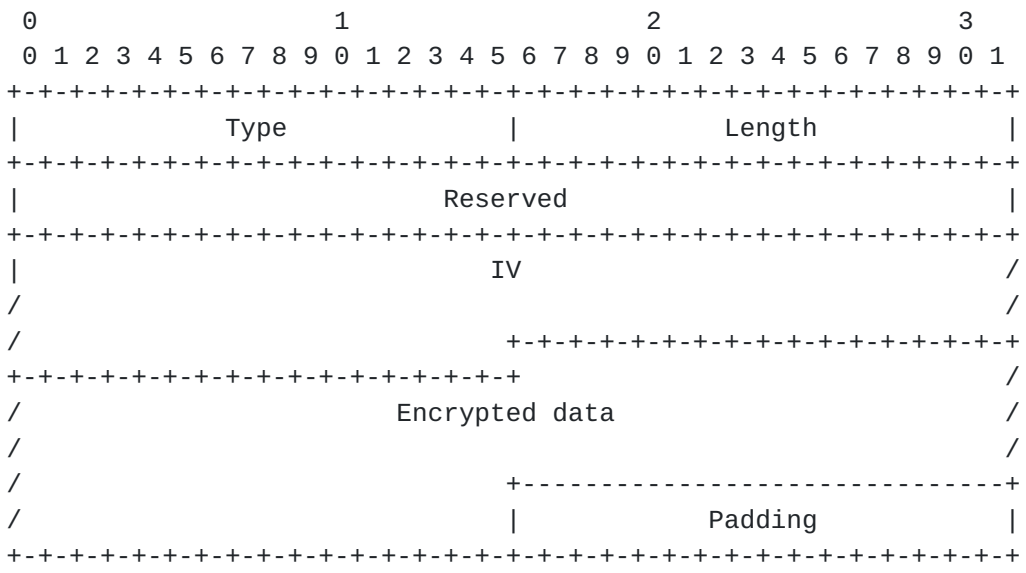
5.2.14. ACK



Type	449
Length	variable (multiple of 4)
peer Update ID	32-bit sequence number corresponding to the Update ID being acked.

The ACK parameter includes one or more Update IDs that have been received from the peer. The Length field identifies the number of peer Update IDs that are present in the parameter.

5.2.15. ENCRYPTED



Type	641
Length	length in octets, excluding Type, Length, and Padding
Reserved	zero when sent, ignored when received
IV	Initialization vector, if needed, otherwise nonexistent. The length of the IV is inferred from the HIP transform.
Encrypted data	The data is encrypted using an encryption algorithm as defined in HIP transform.
Padding	Any Padding, if necessary, to make the parameter a multiple of 8 bytes.

The ENCRYPTED parameter encapsulates another parameter, the encrypted data, which is also in TLV format. Consequently, the first fields in the encapsulated parameter(s) are Type and Length, allowing the contents to be easily parsed after decryption.

Both the ENCRYPTED parameter and the encapsulated parameter(s) MUST be padded. The padding needed for the ENCRYPTED parameter is referred as the "outer" padding. Correspondingly, the padding for the parameter(s) encapsulated within the ENCRYPTED parameter is referred as the "inner" padding.

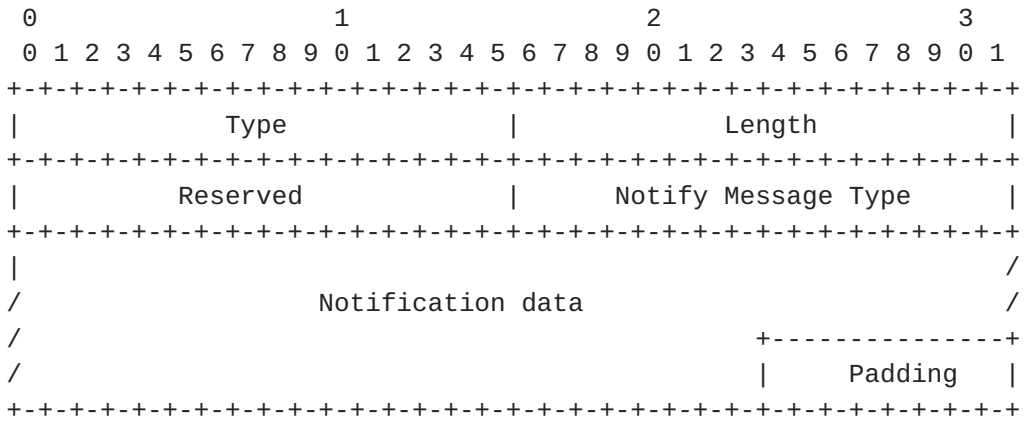
The inner padding follows exactly the rules of Section 5.2.1. The outer padding also follows the same rules but with an exception. Namely, some algorithms require that the data to be encrypted must be a multiple of the cipher algorithm block size. In this case, the outer padding MUST include extra padding, as specified by the encryption algorithm. The size of the extra padding is selected so

that the length of the ENCRYPTED is the minimum value that is both multiple of eight and the cipher block size. The encryption algorithm may specify padding bytes other than zero; for example, AES [32] uses the PKCS5 padding scheme [14] (see section 6.1.1) where the remaining n bytes to fill the block each have the value n.

Note that the length of the cipher suite output may be smaller or larger than the length of the data to be encrypted, since the encryption process may compress the data or add additional padding to the data.

5.2.16. NOTIFY

The NOTIFY parameter is used to transmit informational data, such as error conditions and state transitions, to a HIP peer. A NOTIFY parameter may appear in the NOTIFY packet type. The use of the NOTIFY parameter in other packet types is for further study.



Type	832
Length	length in octets, excluding Type, Length, and Padding
Reserved	zero when sent, ignored when received
Notify Message Type	Specifies the type of notification
Notification Data	Informational or error data transmitted in addition to the Notify Message Type. Values for this field are type specific (see below).
Padding	Any Padding, if necessary, to make the parameter a multiple of 8 bytes.

Notification information can be error messages specifying why an SA could not be established. It can also be status data that a process managing an SA database wishes to communicate with a peer process. The table below lists the Notification messages and their corresponding values.

To avoid certain types of attacks, a Responder SHOULD avoid sending a NOTIFY to any host with which it has not successfully verified a puzzle solution.

Types in the range 0 - 16383 are intended for reporting errors. An implementation that receives a NOTIFY error parameter in response to a request packet (e.g., I1, I2, UPDATE), SHOULD assume that the corresponding request has failed entirely. Unrecognized error types MUST be ignored except that they SHOULD be logged.

Notify payloads with status types MUST be ignored if not recognized.

NOTIFY PARAMETER - ERROR TYPES	Value
UNSUPPORTED_CRITICAL_PARAMETER_TYPE	1

Sent if the parameter type has the "critical" bit set and the parameter type is not recognized. Notification Data contains the two octet parameter type.

INVALID_SYNTAX	7

Indicates that the HIP message received was invalid because some type, length, or value was out of range or because the request was rejected for policy reasons. To avoid a denial of service attack using forged messages, this status may only be returned for packets whose HMAC (if present) and SIGNATURE have been verified. This status MUST be sent in response to any error not covered by one of the other status types, and should not contain details to avoid leaking information to someone probing a node. To aid debugging, more detailed error information SHOULD be written to a console or log.

NO_DH_PROPOSAL_CHOSEN	14

None of the proposed group IDs was acceptable.

INVALID_DH_CHOSEN	15

The D-H Group ID field does not correspond to one offered by the Responder.

NO_HIP_PROPOSAL_CHOSEN	16

None of the proposed HIP Transform crypto suites was acceptable.

INVALID_HIP_TRANSFORM_CHOSEN 17

The HIP Transform crypto suite does not correspond to one offered by the Responder.

AUTHENTICATION_FAILED 24

Sent in response to a HIP signature failure, except when the signature verification fails in a NOTIFY message.

CHECKSUM_FAILED 26

Sent in response to a HIP checksum failure.

HMAC_FAILED 28

Sent in response to a HIP HMAC failure.

ENCRYPTION_FAILED 32

The Responder could not successfully decrypt the ENCRYPTED parameter.

INVALID_HIT 40

Sent in response to a failure to validate the peer's HIT from the corresponding HI.

BLOCKED_BY_POLICY 42

The Responder is unwilling to set up an association for some policy reason (e.g. received HIT is NULL and policy does not allow opportunistic mode).

SERVER_BUSY_PLEASE_RETRY 44

The Responder is unwilling to set up an association as it is suffering under some kind of overload and has chosen to shed load by rejecting your request. You may retry if you wish, however you MUST find another (different) puzzle solution for any such retries. Note that you may need to obtain a new puzzle with a new I1/R1 exchange.

I2_ACKNOWLEDGEMENT 46

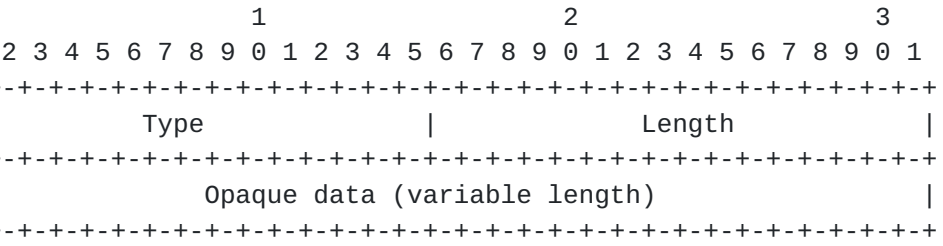
The Responder has received your I2 but had to queue the I2 for processing. The puzzle was correctly solved

and the Responder is willing to set up an association
but has currently a number of I2s in processing queue.
R2 will be sent after the I2 has been processed.

NOTIFY MESSAGES - STATUS TYPES	Value

(None defined at present)

5.2.17. ECHO_REQUEST

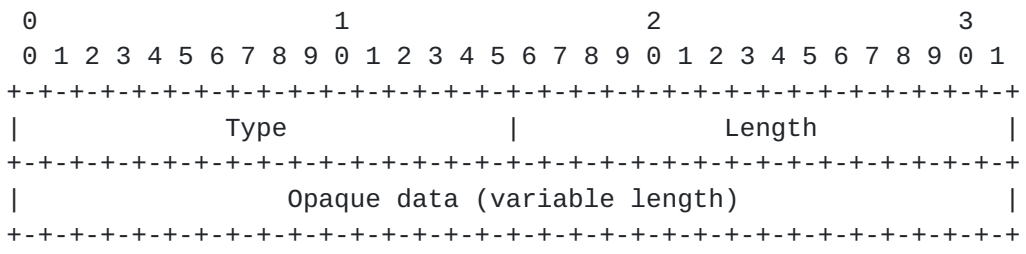


Type	63661 or 897
Length	variable
Opaque data	Opaque data, supposed to be meaningful only to the node that sends ECHO_REQUEST and receives a corresponding ECHO_RESPONSE.

The ECHO_REQUEST parameter contains an opaque blob of data that the sender wants to get echoed back in the corresponding reply packet.

The ECHO_REQUEST and ECHO_RESPONSE parameters MAY be used for any purpose where a node wants to carry some state in a request packet and get it back in a response packet. The ECHO_REQUEST MAY be covered by the HMAC and SIGNATURE. This is dictated by the Type field selected for the parameter; Type 897 ECHO_REQUEST is covered and Type 63661 is not covered. A HIP packet can contain only one ECHO_REQUEST parameter.

5.2.18. ECHO_RESPONSE



Type	63425 or 961
Length	variable
Opaque data	Opaque data, copied unmodified from the ECHO_REQUEST parameter that triggered this response.

The ECHO_RESPONSE parameter contains an opaque blob of data that the sender of the ECHO_REQUEST wants to get echoed back. The opaque data is copied unmodified from the ECHO_REQUEST parameter.

The ECHO_REQUEST and ECHO_RESPONSE parameters MAY be used for any purpose where a node wants to carry some state in a request packet and get it back in a response packet. The ECHO_RESPONSE MAY be covered by the HMAC and SIGNATURE. This is dictated by the Type field selected for the parameter; Type 961 ECHO_RESPONSE is covered and Type 63425 is not.

5.3. HIP Packets

There are eight basic HIP packets (see Table 11). Four are for the HIP base exchange, one is for updating, one is for sending notifications, and two for closing a HIP association.

Packet type	Packet name
1	I1 - the HIP Initiator Packet
2	R1 - the HIP Responder Packet
3	I2 - the Second HIP Initiator Packet
4	R2 - the Second HIP Responder Packet
16	UPDATE - the HIP Update Packet
17	NOTIFY - the HIP Notify Packet
18	CLOSE - the HIP Association Closing Packet
19	CLOSE_ACK - the HIP Closing Acknowledgment Packet

Table 11: HIP packets and packet type numbers

Packets consist of the fixed header as described in Section 5.1, followed by the parameters. The parameter part, in turn, consists of zero or more parameter coded parameters.

In addition to the base packets, other packets types will be defined later in separate specifications. For example, support for mobility and multi-homing is not included in this specification.

See Notation (Section 2.2) for used operations.

In the future, an OPTIONAL upper layer payload MAY follow the HIP header. The Next Header field in the header indicates if there is additional data following the HIP header. The HIP packet, however, MUST NOT be fragmented. This limits the size of the possible additional data in the packet.

5.3.1. I1 - the HIP Initiator Packet

The HIP header values for the I1 packet:

```
Header:
  Packet Type = 1
  SRC HIT = Initiator's HIT
  DST HIT = Responder's HIT, or NULL

IP ( HIP () )
```

The I1 packet contains only the fixed HIP header.

Valid control bits: none

The Initiator gets the Responder's HIT either from a DNS lookup of the Responder's FQDN, from some other repository, or from a local table. If the Initiator does not know the Responder's HIT, it may attempt opportunistic mode by using NULL (all zeros) as the Responder's HIT. If the Initiator sends a NULL as the Responder's HIT, it MUST be able to handle all MUST and SHOULD algorithms from Section 3, which are currently RSA and DSA.

Since this packet is so easy to spoof even if it were signed, no attempt is made to add to its generation or processing cost.

Implementations MUST be able to handle a storm of received I1 packets, discarding those with common content that arrive within a small time delta.

5.3.2. R1 - the HIP Responder Packet

The HIP header values for the R1 packet:

```
Header:
  Packet Type = 2
  SRC HIT = Responder's HIT
  DST HIT = Initiator's HIT

IP ( HIP ( [ R1_COUNTER, ]
           PUZZLE,
           DIFFIE_HELLMAN,
           HIP_TRANSFORM,
           HOST_ID,
           [ ECHO_REQUEST, ]
           HIP_SIGNATURE_2 )
           [, ECHO_REQUEST ])
```

Valid control bits: A

If the Responder HI is an anonymous one, the A control MUST be set.

The Initiator HIT MUST match the one received in I1. If the Responder has multiple HIs, the Responder HIT used MUST match Initiator's request. If the Initiator used opportunistic mode, the Responder may select freely among its HIs.

The R1 generation counter is used to determine the currently valid generation of puzzles. The value is increased periodically, and it

is RECOMMENDED that it is increased at least as often as solutions to old puzzles are no longer accepted.

The Puzzle contains a random #I and the difficulty K. The difficulty K is the number of bits that the Initiator must get zero in the puzzle. The random #I is not covered by the signature and must be zeroed during the signature calculation, allowing the sender to select and set the #I into a pre-computed R1 just prior sending it to the peer.

The Diffie-Hellman value is ephemeral, but can be reused over a number of connections. In fact, as a defense against I1 storms, an implementation MAY use the same Diffie-Hellman value for a period of time, for example, 15 minutes. By using a small number of different puzzles for a given Diffie-Hellman value, the R1 packets can be pre-computed and delivered as quickly as I1 packets arrive. A scavenger process should clean up unused DHs and puzzles.

The HIP_TRANSFORM contains the encryption and integrity algorithms supported by the Responder to protect the HI exchange, in the order of preference. All implementations MUST support the AES [18] with HMAC-SHA-1-96 [6].

The ECHO_REQUEST contains data that the sender wants to receive unmodified in the corresponding response packet in the ECHO_RESPONSE parameter. The ECHO_REQUEST can be either covered by the signature, or it can be left out from it. In the first case, the ECHO_REQUEST gets Type number 897 and in the latter case 63661.

The signature is calculated over the whole HIP envelope, after setting the Initiator HIT, header checksum as well as the Opaque field and the Random #I in the PUZZLE parameter temporarily to zero, and excluding any parameters that follow the signature, as described in Section 5.2.12. This allows the Responder to use precomputed R1s. The Initiator SHOULD validate this signature. It SHOULD check that the Responder HI received matches with the one expected, if any.

5.3.3. I2 - the Second HIP Initiator Packet

The HIP header values for the I2 packet:

```
    Header:
      Type = 3
      SRC HIT = Initiator's HIT
      DST HIT = Responder's HIT

    IP ( HIP ( [R1_COUNTER,]
               SOLUTION,
               DIFFIE_HELLMAN,
               HIP_TRANSFORM,
               ENCRYPTED { HOST_ID } or HOST_ID,
               [ ECHO_RESPONSE ,]
               HMAC,
               HIP_SIGNATURE
               [, ECHO_RESPONSE] ) )
```

Valid control bits: A

The HITs used MUST match the ones used previously.

If the Initiator HI is an anonymous one, the A control MUST be set.

The Initiator MAY include an unmodified copy of the R1_COUNTER parameter received in the corresponding R1 packet into the I2 packet.

The Solution contains the random # I from R1 and the computed # J. The low order K bits of the PHASH(I | ... | J) MUST be zero.

The Diffie-Hellman value is ephemeral. If precomputed, a scavenger process should clean up unused DHs.

The HIP_TRANSFORM contains the single encryption and integrity transform selected by the Initiator, that will be used to protect the HI exchange. The chosen transform MUST correspond to one offered by the Responder in the R1. All implementations MUST support the AES transform [18].

The Initiator's HI MAY be encrypted using the HIP_TRANSFORM encryption algorithm. The keying material is derived from the Diffie-Hellman exchanged as defined in Section 6.5.

The ECHO_RESPONSE contains the unmodified Opaque data copied from the corresponding ECHO_REQUEST parameter. The ECHO_RESPONSE can be either covered by the HMAC and SIGNATURE or not covered. In the former case, the ECHO_RESPONSE gets Type number 961, in the latter it is 63425.

The HMAC is calculated over whole HIP envelope, excluding any parameters after the HMAC, as described in Section 6.4.1. The

Responder MUST validate the HMAC.

The signature is calculated over whole HIP envelope, excluding any parameters after the HIP_SIGNATURE, as described in Section 5.2.11. The Responder MUST validate this signature. It MAY use either the HI in the packet or the HI acquired by some other means.

5.3.4. R2 - the Second HIP Responder Packet

The HIP header values for the R2 packet:

```
Header:
  Packet Type = 4
  SRC HIT = Responder's HIT
  DST HIT = Initiator's HIT

IP ( HIP ( HMAC_2, HIP_SIGNATURE ) )
```

Valid control bits: none

The HMAC_2 is calculated over whole HIP envelope, with Responder's HOST_ID parameter concatenated with the HIP envelope. The HOST_ID parameter is removed after the HMAC calculation. The procedure is described in 8.3.1.

The signature is calculated over whole HIP envelope.

The Initiator MUST validate both the HMAC and the signature.

5.3.5. UPDATE - the HIP Update Packet

Support for the UPDATE packet is MANDATORY.

The HIP header values for the UPDATE packet:

```
Header:
  Packet Type = 16
  SRC HIT = Sender's HIT
  DST HIT = Recipient's HIT

IP ( HIP ( [SEQ, ACK, ] HMAC, HIP_SIGNATURE ) )
```

Valid control bits: None

The UPDATE packet contains mandatory HMAC and HIP_SIGNATURE parameters, and other optional parameters.

The UPDATE packet contains zero or one SEQ parameter. The presence of a SEQ parameter indicates that the receiver MUST ack the UPDATE. An UPDATE that does not contain a SEQ parameter is simply an ACK of a previous UPDATE and itself MUST not be acked.

An UPDATE packet contains zero or one ACK parameters. The ACK parameter echoes the SEQ sequence number of the UPDATE packet being acked. A host MAY choose to ack more than one UPDATE packet at a time; e.g., the ACK may contain the last two SEQ values received, for robustness to ack loss. ACK values are not cumulative; each received unique SEQ value requires at least one corresponding ACK value in reply. Received ACKs that are redundant are ignored.

The UPDATE packet may contain both a SEQ and an ACK parameter. In this case, the ACK is being piggybacked on an outgoing UPDATE. In general, UPDATEs carrying SEQ SHOULD be acked upon completion of the processing of the UPDATE. A host MAY choose to hold the UPDATE carrying ACK for a short period of time to allow for the possibility of piggybacking the ACK parameter, in a manner similar to TCP delayed acknowledgments.

A sender MAY choose to forego reliable transmission of a particular UPDATE (e.g., it becomes overcome by events). The semantics are such that the receiver MUST acknowledge the UPDATE but the sender MAY choose to not care about receiving the ACK.

UPDATEs MAY be retransmitted without incrementing SEQ. If the same subset of parameters is included in multiple UPDATEs with different SEQs, the host MUST ensure that receiver processing of the parameters multiple times will not result in a protocol error.

5.3.6. NOTIFY - the HIP Notify Packet

The NOTIFY packet is OPTIONAL. The NOTIFY packet MAY be used to provide information to a peer. Typically, NOTIFY is used to indicate some type of protocol error or negotiation failure. NOTIFY packets are unacknowledged.

The HIP header values for the NOTIFY packet:

```
   Header:
     Packet Type = 17
     SRC HIT = Sender's HIT
     DST HIT = Recipient's HIT, or zero if unknown

   IP ( HIP (<NOTIFY>i, [HOST_ID, ] HIP_SIGNATURE) )
```

Valid control bits: None

The NOTIFY packet is used to carry one or more NOTIFY parameters.

5.3.7. CLOSE - the HIP Association Closing Packet

The HIP header values for the CLOSE packet:

```
Header:
  Packet Type = 18
  SRC HIT = Sender's HIT
  DST HIT = Recipient's HIT

IP ( HIP ( ECHO_REQUEST, HMAC, HIP_SIGNATURE ) )
```

Valid control bits: none

The sender MUST include an ECHO_REQUEST used to validate CLOSE_ACK received in response, and both an HMAC and a signature (calculated over the whole HIP envelope).

The receiver peer MUST validate both the HMAC and the signature if it has a HIP association state, and MUST reply with a CLOSE_ACK containing an ECHO_REPLY corresponding to the received ECHO_REQUEST.

5.3.8. CLOSE_ACK - the HIP Closing Acknowledgment Packet

The HIP header values for the CLOSE_ACK packet:

```
Header:
  Packet Type = 19
  SRC HIT = Sender's HIT
  DST HIT = Recipient's HIT

IP ( HIP ( ECHO_REPLY, HMAC, HIP_SIGNATURE ) )
```

Valid control bits: none

The sender MUST include both an HMAC and signature (calculated over the whole HIP envelope).

The receiver peer MUST validate both the HMAC and the signature.

5.4. ICMP Messages

When a HIP implementation detects a problem with an incoming packet, and it either cannot determine the identity of the sender of the packet or does not have any existing HIP association with the sender of the packet, it MAY respond with an ICMP packet. Any such replies

MUST be rate limited as described in [4]. In most cases, the ICMP packet will have the Parameter Problem type (12 for ICMPv4, 4 for ICMPv6), with the Pointer field pointing to the field that caused the ICMP message to be generated.

5.4.1. Invalid Version

If a HIP implementation receives a HIP packet that has an unrecognized HIP version number, it SHOULD respond, rate limited, with an ICMP packet with type Parameter Problem, the Pointer pointing to the VER./RES. byte in the HIP header.

5.4.2. Other Problems with the HIP Header and Packet Structure

If a HIP implementation receives a HIP packet that has other unrecoverable problems in the header or packet format, it MAY respond, rate limited, with an ICMP packet with type Parameter Problem, the Pointer pointing to the field that failed to pass the format checks. However, an implementation MUST NOT send an ICMP message if the Checksum fails; instead, it MUST silently drop the packet.

5.4.3. Invalid Puzzle Solution

If a HIP implementation receives an I2 packet that has an invalid puzzle solution, the behavior depends on the underlying version of IP. If IPv6 is used, the implementation SHOULD respond with an ICMP packet with type Parameter Problem, the Pointer pointing to the beginning of the Puzzle solution #J field in the SOLUTION payload in the HIP message.

If IPv4 is used, the implementation MAY respond with an ICMP packet with the type Parameter Problem, copying enough of bytes from the I2 message so that the SOLUTION parameter fits into the ICMP message, the Pointer pointing to the beginning of the Puzzle solution #J field, as in the IPv6 case. Note, however, that the resulting ICMPv4 message exceeds the typical ICMPv4 message size as defined in [2].

5.4.4. Non-existing HIP Association

If a HIP implementation receives a CLOSE, or UPDATE packet, or any other packet whose handling requires an existing association, that has either a Receiver or Sender HIT that does not match with any existing HIP association, the implementation MAY respond, rate limited, with an ICMP packet with the type Parameter Problem, the Pointer pointing to the beginning of the first HIT that does not match.

A host MUST NOT reply with such an ICMP if it receives any of the following messages: I1, R2, I2, R2, and NOTIFY. When introducing new packet types, a specification SHOULD define the appropriate rules for sending or not sending this kind of ICMP replies.

6. Packet Processing

Each host is assumed to have a single HIP protocol implementation that manages the host's HIP associations and handles requests for new ones. Each HIP association is governed by a conceptual state machine, with states defined above in Section 4.4. The HIP implementation can simultaneously maintain HIP associations with more than one host. Furthermore, the HIP implementation may have more than one active HIP association with another host; in this case, HIP associations are distinguished by their respective HITs. It is not possible to have more than one HIP association between any given pair of HITs. Consequently, the only way for two hosts to have more than one parallel association is to use different HITs, at least at one end.

The processing of packets depends on the state of the HIP association(s) with respect to the authenticated or apparent originator of the packet. A HIP implementation determines whether it has an active association with the originator of the packet based on the HITs. In the case of user data carried in a specific transport format, the transport format document specifies how the incoming packets are matched with the active associations.

6.1. Processing Outgoing Application Data

In a HIP host, an application can send application level data using an identifier specified via the underlying API. The API can be a backwards compatible API (see [28]), using identifiers that look similar to IP addresses, or a completely new API, providing enhanced services related to Host Identities. Depending on the HIP implementation, the identifier provided to the application may be different; it can be e.g. a HIT or an IP address.

The exact format and method for transferring the data from the source HIP host to the destination HIP host is defined in the corresponding transport format document. The actual data is transferred in the network using the appropriate source and destination IP addresses.

In this document, conceptual processing rules are defined only for the base case where both hosts have only single usable IP addresses; the multi-address multi-homing case will be specified separately.

The following conceptual algorithm describes the steps that are required for handling outgoing datagrams destined to a HIT.

1. If the datagram has a specified source address, it MUST be a HIT. If it is not, the implementation MAY replace the source address with a HIT. Otherwise it MUST drop the packet.

2. If the datagram has an unspecified source address, the implementation must choose a suitable source HIT for the datagram.

3. If there is no active HIP association with the given < source, destination > HIT pair, one must be created by running the base exchange. While waiting for the base exchange to complete, the implementation SHOULD queue at least one packet per HIP association to be formed, and it MAY queue more than one.

4. Once there is an active HIP association for the given < source, destination > HIT pair, the outgoing datagram is passed to transport handling. The possible transport formats are defined in separate documents, of which the ESP transport format for HIP is mandatory for all HIP implementations.

5. Before sending the packet, the HITs in the datagram are replaced with suitable IP addresses. For IPv6, the rules defined in [16] SHOULD be followed. Note that this HIT-to-IP-address conversion step MAY also be performed at some other point in the stack, e.g., before wrapping the packet into the output format.

6.2. Processing Incoming Application Data

The following conceptual algorithm describes the incoming datagram handling when HITs are used at the receiving host as application level identifiers. More detailed steps for processing packets are defined in corresponding transport format documents.

1. The incoming datagram is mapped to an existing HIP association, typically using some information from the packet. For example, such mapping may be based on ESP Security Parameter Index (SPI).

2. The specific transport format is unwrapped, in a way depending on the transport format, yielding a packet that looks like a standard (unencrypted) IP packet. If possible, this step SHOULD also verify that the packet was indeed (once) sent by the remote HIP host, as identified by the HIP association.

3. The IP addresses in the datagram are replaced with the HITs associated with the HIP association. Note that this IP-address-to-HIT conversion step MAY also be performed at some other point in the stack.

4. The datagram is delivered to the upper layer. Demultiplexing the datagram the right upper layer socket is based on the HITs.

6.3. Solving the Puzzle

This subsection describes the puzzle solving details.

In R1, the values I and K are sent in network byte order. Similarly, in I2 the values I and J are sent in network byte order. The SHA-1 hash is created by concatenating, in network byte order, the following data, in the following order:

64-bit random value I, in network byte order, as appearing in R1 and I2.

128-bit Initiator HIT, in network byte order, as appearing in the HIP Payload in R1 and I2.

128-bit Responder HIT, in network byte order, as appearing in the HIP Payload in R1 and I2.

64-bit random value J, in network byte order, as appearing in I2.

In order to be a valid response puzzle, the K low-order bits of the resulting PHASH digest must be zero.

Notes:

i) The length of the data to be hashed is 48 bytes.

ii) All the data in the hash input MUST be in network byte order.

iii) The order of the Initiator and Responder HITs are different in the R1 and I2 packets, see Section 5.1. Care must be taken to copy the values in right order to the hash input.

The following procedure describes the processing steps involved, assuming that the Responder chooses to precompute the R1 packets:

Precomputation by the Responder:
Sets up the puzzle difficulty K.
Creates a signed R1 and caches it.

Responder:
Selects a suitable cached R1.
Generates a random number I.
Sends I and K in an R1.
Saves I and K for a Delta time.

Initiator:
Generates repeated attempts to solve the puzzle until a matching J is found:
Ltrunc(PHASH(I | HIT-I | HIT-R | J), K) == 0
Sends I and J in an I2.

Responder:
Verifies that the received I is a saved one.
Finds the right K based on I.
Computes V := Ltrunc(PHASH(I | HIT-I | HIT-R | J), K)
Rejects if V != 0
Accept if V == 0

6.4. HMAC and SIGNATURE Calculation and Verification

The following subsections define the actions for processing HMAC, HIP_SIGNATURE and HIP_SIGNATURE_2 parameters.

6.4.1. HMAC Calculation

The following process applies both to the HMAC and HMAC_2 parameters. When processing HMAC_2, the difference is that the HMAC calculation includes a pseudo HOST_ID field containing the Responder's information as sent in the R1 packet earlier.

Both the Initiator and the Responder should take some care when verifying or calculating the HMAC_2. Specifically, the Responder should preserve other parameters than the HOST_ID when sending the R2. Also, the Initiator has to preserve the HOST_ID exactly as it was received in the R1 packet.

The HMAC parameter is defined in Section 5.2.9 and HMAC_2 parameter in Section 5.2.10. HMAC calculation and verification process:

Packet sender:

1. Create the HIP packet, without the HMAC or any possible HIP_SIGNATURE or HIP_SIGNATURE_2 parameters.

2. In case of HMAC_2 calculation, add a HOST_ID (Responder) parameter to the packet.

3. Calculate the Length field in the HIP header.

4. Compute the HMAC.

5. In case of HMAC_2, remove the HOST_ID parameter from the packet.

6. Add the HMAC parameter to the packet and any HIP_SIGNATURE or HIP_SIGNATURE_2 parameters that may follow.

7. Recalculate the Length field in the HIP header.

Packet receiver:

1. Verify the HIP header Length field.

2. Remove the HMAC or HMAC_2 parameter, and if the packet contains any HIP_SIGNATURE or HIP_SIGNATURE_2 fields, remove them too, saving the contents if they will be needed later.

3. In case of HMAC_2, build and add a HOST_ID parameter (with Responder information) to the packet. The HOST_ID parameter should be identical to the one previously received from the Responder.

4. Recalculate the HIP packet length in the HIP header and clear the Checksum field (set it to all zeros).

5. Compute the HMAC and verify it against the received HMAC.

6. In case of HMAC_2, remove the HOST_ID parameter from the packet before further processing.

6.4.2. Signature Calculation

The following process applies both to the HIP_SIGNATURE and HIP_SIGNATURE_2 parameters. When processing HIP_SIGNATURE_2, the only difference is that instead of HIP_SIGNATURE parameter, the HIP_SIGNATURE_2 parameter is used, and the Initiator's HIT and PUZZLE Opaque and Random #I fields are cleared (set to all zeros) before computing the signature. The HIP_SIGNATURE parameter is defined in Section 5.2.11 and the HIP_SIGNATURE_2 parameter in Section 5.2.12.

Signature calculation and verification process:

Packet sender:

1. Create the HIP packet without the HIP_SIGNATURE parameter or any parameters that follow the HIP_SIGNATURE parameter.

2. Calculate the Length field and zero the Checksum field in the HIP header.

3. Compute the signature.

4. Add the HIP_SIGNATURE parameter to the packet.

5. Add any parameters that follow the HIP_SIGNATURE parameter.

6. Recalculate the Length field in the HIP header, and calculate the Checksum field.

Packet receiver:

1. Verify the HIP header Length field.

2. Save the contents of the HIP_SIGNATURE parameter and any parameters following the HIP_SIGNATURE parameter and remove them from the packet.

3. Recalculate the HIP packet Length in the HIP header and clear the Checksum field (set it to all zeros).

4. Compute the signature and verify it against the received signature.

The verification can use either the HI received from a HIP packet, the HI from a DNS query, if the FQDN has been received in the HOST_ID packet, or one received by some other means.

6.5. HIP KEYMAT Generation

HIP keying material is derived from the Diffie-Hellman Kij produced during the HIP base exchange. The Initiator has Kij during the creation of the I2 packet, and the Responder has Kij once it receives the I2 packet. This is why I2 can already contain encrypted information.

The KEYMAT is derived by feeding Kij and the HITs into the following operation; the | operation denotes concatenation.

```
KEYMAT = K1 | K2 | K3 | ...
      where

K1   = SHA-1( Kij | sort(HIT-I | HIT-R) | I | J | 0x01 )
K2   = SHA-1( Kij | K1 | 0x02 )
K3   = SHA-1( Kij | K2 | 0x03 )
...
K255 = SHA-1( Kij | K254 | 0xff )
K256 = SHA-1( Kij | K255 | 0x00 )
etc.
```

Sort(HIT-I | HIT-R) is defined as the network byte order concatenation of the two HITs, with the smaller HIT preceding the larger HIT, resulting from the numeric comparison of the two HITs interpreted as positive (unsigned) 128-bit integers in network byte order.

I and J values are from the puzzle and its solution that were exchanged in R1 and I2 messages when this HIP association was set up. Both hosts have to store I and J values for the HIP association for future use.

The initial keys are drawn sequentially in the order that is determined by the numeric comparison of the two HITs, with comparison method described in the previous paragraph. HOST_g denotes the host with the greater HIT value, and HOST_l the host with the lower HIT value.

The drawing order for initial keys:

HIP-gl encryption key for HOST_g's outgoing HIP packets

HIP-gl integrity (HMAC) key for HOST_g's outgoing HIP packets

HIP-lg encryption key (currently unused) for HOST_l's outgoing HIP packets

HIP-lg integrity (HMAC) key for HOST_l's outgoing HIP packets

The number of bits drawn for a given algorithm is the "natural" size of the keys. For the mandatory algorithms, the following sizes apply:

AES 128 bits

SHA-1 160 bits

NULL 0 bits

6.6. Initiation of a HIP Exchange

An implementation may originate a HIP exchange to another host based on a local policy decision, usually triggered by an application datagram, in much the same way that an IPsec IKE key exchange can dynamically create a Security Association. Alternatively, a system may initiate a HIP exchange if it has rebooted or timed out, or otherwise lost its HIP state, as described in Section 4.5.4.

The implementation prepares an I1 packet and sends it to the IP

address that corresponds to the peer host. The IP address of the peer host may be obtained via conventional mechanisms, such as DNS lookup. The I1 contents are specified in Section 5.3.1. The selection of which host identity to use, if a host has more than one to choose from, is typically a policy decision.

The following steps define the conceptual processing rules for initiating a HIP exchange:

1. The Initiator gets the Responder's HIT and one or more addresses either from a DNS lookup of the Responder's FQDN, from some other repository, or from a local table. If the Initiator does not know the Responder's HIT, it may attempt opportunistic mode by using NULL (all zeros) as the Responder's HIT.

2. The Initiator sends an I1 to one of the Responder's addresses. The selection of which address to use is a local policy decision.

3. Upon sending an I1, the sender shall transition to state I1-SENT, start a timer whose timeout value should be larger than the worst-case anticipated RTT, and shall increment a timeout counter associated with the I1.

4. Upon timeout, the sender SHOULD retransmit the I1 and restart the timer, up to a maximum of I1_RETRIES_MAX tries.

6.6.1. Sending Multiple I1s in Parallel

For the sake of minimizing the session establishment latency, an implementation MAY send the same I1 to more than one of the Responder's addresses. However, it MUST NOT send to more than three (3) addresses in parallel. Furthermore, upon timeout, the implementation MUST refrain from sending the same I1 packet to multiple addresses. These limitations are placed order to avoid congestion of the network, and potential DoS attacks that might happen, e.g., because someone claims to have hundreds or thousands of addresses.

As the Responder is not guaranteed to distinguish the duplicate I1's it receives at several of its addresses (because it avoids to store states when it answers back an R1), the Initiator may receive several duplicate R1's.

The Initiator SHOULD then select the initial preferred destination address using the source address of the selected received R1, and use the preferred address as a source address for the I2. Processing rules for received R1s are discussed in Section 6.8.

6.6.2. Processing Incoming ICMP Protocol Unreachable Messages

A host may receive an ICMP Destination Protocol Unreachable message as a response to sending an HIP I1 packet. Such a packet may be an indication that the peer does not support HIP, or it may be an attempt to launch an attack by making the Initiator believe that the Responder does not support HIP.

When a system receives an ICMP Destination Protocol Unreachable message while it is waiting for an R1, it MUST NOT terminate the wait. It MAY continue as if it had not received the ICMP message, and send a few more I1s. Alternatively, it MAY take the ICMP message as a hint that the peer most probably does not support HIP, and return to state UNASSOCIATED earlier than otherwise. However, at minimum, it MUST continue waiting for an R1 for a reasonable time before returning to UNASSOCIATED.

6.7. Processing Incoming I1 Packets

An implementation SHOULD reply to an I1 with an R1 packet, unless the implementation is unable or unwilling to setup a HIP association. If the implementation is unable to setup a HIP association, the host SHOULD send an ICMP Destination Protocol Unreachable, Administratively Prohibited, message to the I1 source address. If the implementation is unwilling to setup a HIP association, the host MAY ignore the I1. This latter case may occur during a DoS attack such as an I1 flood.

The implementation MUST be able to handle a storm of received I1 packets, discarding those with common content that arrive within a small time delta.

A spoofed I1 can result in an R1 attack on a system. An R1 sender MUST have a mechanism to rate limit R1s to an address.

It is RECOMMENDED that the HIP state machine does not transition upon sending an R1.

The following steps define the conceptual processing rules for responding to an I1 packet:

1. The Responder MUST check that the Responder HIT in the received I1 is either one of its own HITs, or NULL.

2. If the Responder is in ESTABLISHED state, the Responder MAY respond to this with an R1 packet, prepare to drop existing SAs and stay at ESTABLISHED state.

3. If the Responder is in I1-SENT state, it must make a comparison between the sender's HIT and its own HIT. If the sender's HIT is greater than its own HIT, it should drop the I1 and stay at I1-SENT. If the sender's HIT is smaller than its own HIT, it should send R1 and stay at I1-SENT. The HIT comparison goes similarly as in Section 6.5.

4. If the implementation chooses to respond to the I1 with an R1 packet, it creates a new R1 or selects a precomputed R1 according to the format described in Section 5.3.2.

5. The R1 MUST contain the received Responder HIT, unless the received HIT is NULL, in which case the Responder SHOULD select a HIT that is constructed with the MUST algorithm in Section 3, which is currently RSA. Other than that, selecting the HIT is a local policy matter.

6. The Responder sends the R1 to the source IP address of the I1 packet.

6.7.1. R1 Management

All compliant implementations MUST produce R1 packets. An R1 packet MAY be precomputed. An R1 packet MAY be reused for time Delta T, which is implementation dependent. R1 information MUST not be discarded until Delta S after T. Time S is the delay needed for the last I2 to arrive back to the Responder.

An implementation MAY keep state about received I1s and match the received I2s against the state, as discussed in Section 4.1.1.

6.7.2. Handling Malformed Messages

If an implementation receives a malformed I1 message, it SHOULD NOT respond with a NOTIFY message, as such practice could open up a potential denial-of-service danger. Instead, it MAY respond with an ICMP packet, as defined in Section 5.4.

6.8. Processing Incoming R1 Packets

A system receiving an R1 MUST first check to see if it has sent an I1 to the originator of the R1 (i.e., it is in state I1-SENT). If so, it SHOULD process the R1 as described below, send an I2, and go to state I2-SENT, setting a timer to protect the I2. If the system is in state I2-SENT, it MAY respond to an R1 if the R1 has a larger R1 generation counter; if so, it should drop its state due to processing the previous R1 and start over from state I1-SENT. If the system is in any other state with respect to that host, it SHOULD silently drop

the R1.

When sending multiple I1s, an Initiator SHOULD wait for a small amount of time after the first R1 reception to allow possibly multiple R1s to arrive, and it SHOULD respond to an R1 among the set with the largest R1 generation counter.

The following steps define the conceptual processing rules for responding to an R1 packet:

1. A system receiving an R1 MUST first check to see if it has sent an I1 to the originator of the R1 (i.e., it has a HIP association that is in state I1-SENT and that is associated with the HITs in the R1. IP addresses in the received R1 packet SHOULD be ignored and the match SHOULD be based on HITs only). If so, it should process the R1 as described below. Note that when the connection was initialized in opportunistic mode, HITs cannot be used, but the Initiator must rely on the Responder's IP address in the received R1 packet.

2. Otherwise, if the system is in any other state than I1-SENT or I2-SENT with respect to the HITs included in the R1, it SHOULD silently drop the R1 and remain in the current state.

3. If the HIP association state is I1-SENT or I2-SENT, the received Initiator's HIT MUST correspond to the HIT used in the original, I1 and the Responder's HIT MUST correspond to the one used, unless the I1 contained a NULL HIT.

4. The system SHOULD validate the R1 signature before applying further packet processing, according to Section 5.2.12.

5. If the HIP association state is I1-SENT, and multiple valid R1s are present, the system SHOULD select from among the R1s with the largest R1 generation counter.

6. If the HIP association state is I2-SENT, the system MAY reenter state I1-SENT and process the received R1 if it has a larger R1 generation counter than the R1 responded to previously.

7. The R1 packet may have the A bit set -- in this case, the system MAY choose to refuse it by dropping the R1 and returning to state UNASSOCIATED. The system SHOULD consider dropping the R1 only if it used a NULL HIT in I1. If the A bit is set, the Responder's HIT is anonymous and should not be stored.

8. The system SHOULD attempt to validate the HIT against the received Host Identity.

9. The system MUST store the received R1 generation counter for future reference.

10. The system attempts to solve the puzzle in R1. The system MUST terminate the search after exceeding the remaining lifetime of the puzzle. If the puzzle is not successfully solved, the implementation may either resend I1 within the retry bounds or abandon the HIP exchange.

11. The system computes standard Diffie-Hellman keying material according to the public value and Group ID provided in the DIFFIE_HELLMAN parameter. The Diffie-Hellman keying material Kij is used for key extraction as specified in Section 6.5. If the received Diffie-Hellman Group ID is not supported, the implementation may either resend I1 within the retry bounds or abandon the HIP exchange.

12. The system selects the HIP transform from the choices presented in the R1 packet and uses the selected values subsequently when generating and using encryption keys, and when sending the I2. If the proposed alternatives are not acceptable to the system, it may either resend I1 within the retry bounds or abandon the HIP exchange.

13. The system initializes the remaining variables in the associated state, including Update ID counters.

14. The system prepares and sends an I2, as described in Section 5.3.3.

15. The system SHOULD start a timer whose timeout value should be larger than the worst-case anticipated RTT, and MUST increment a timeout counter associated with the I2. The sender SHOULD retransmit the I2 upon a timeout and restart the timer, up to a maximum of I2_RETRIES_MAX tries.

16. If the system is in state I1-SENT, it shall transition to state I2-SENT. If the system is in any other state, it remains in the current state.

6.8.1. Handling Malformed Messages

If an implementation receives a malformed R1 message, it MUST silently drop the packet. Sending a NOTIFY or ICMP would not help, as the sender of the R1 typically doesn't have any state. An implementation SHOULD wait for some more time for a possible good R1, after which it MAY try again by sending a new I1 packet.

6.9. Processing Incoming I2 Packets

Upon receipt of an I2, the system MAY perform initial checks to determine whether the I2 corresponds to a recent R1 that has been sent out, if the Responder keeps such state. For example, the sender could check whether the I2 is from an address or HIT that has recently received an R1 from it. The R1 may have had Opaque data included that was echoed back in the I2. If the I2 is considered to be suspect, it MAY be silently discarded by the system.

Otherwise, the HIP implementation SHOULD process the I2. This includes validation of the puzzle solution, generating the Diffie-Hellman key, decrypting the Initiator's Host Identity, verifying the signature, creating state, and finally sending an R2.

The following steps define the conceptual processing rules for responding to an I2 packet:

1. The system MAY perform checks to verify that the I2 corresponds to a recently sent R1. Such checks are implementation dependent. See Appendix A for a description of an example implementation.

2. The system MUST check that the Responder's HIT corresponds to one of its own HITs.

3. If the system is in the R2-SENT state, it MAY check if the newly received I2 is similar to the one that triggered moving to R2-SENT. If so, it MAY retransmit a previously sent R2, reset the R2-SENT timer, and stay in R2-SENT.

4. If the system is in the I2-SENT state, it makes a comparison between its local and sender's HITs (similarly as in Section 6.5). If the local HIT is smaller than the sender's HIT, it should drop the I2 packet. Otherwise, the system should process the received I2 packet.

5. To avoid the possibility to end up with different session keys due to symmetric operation of the peer nodes, the Diffie-Hellman key, I, and J selection is also based on the HIT comparison. If the local HIT is smaller than the peer HIT, the system uses peer Diffie-Hellman key and nonce I from the R1 packet received earlier. The local Diffie-Hellman key and nonce J are taken from the I2 packet sent to the peer earlier. Otherwise, it uses peer Diffie-Hellman key and nonce J from the just arrived I2. The local Diffie-Hellman key and nonce I are the ones that it sent ealier in the R1 packet.

6. If the system is in any other state than R2-SENT, it SHOULD check that the echoed R1 generation counter in I2 is within the acceptable range. Implementations MUST accept puzzles from the current generation and MAY accept puzzles from earlier generations. If the newly received I2 is outside the accepted range, the I2 is stale (perhaps replayed) and SHOULD be dropped.

7. The system MUST validate the solution to the puzzle by computing the hash described in Section 5.3.3 using the same hash algorithm used to generate the Responder's HIT.

8. The I2 MUST have a single value in the HIP_TRANSFORM parameter, which MUST match one of the values offered to the Initiator in the R1 packet.

9. The system must derive Diffie-Hellman keying material Kij based on the public value and Group ID in the DIFFIE_HELLMAN parameter. This key is used to derive the HIP association keys, as described in Section 6.5. If the Diffie-Hellman Group ID is unsupported, the I2 packet is silently dropped.

10. The encrypted HOST_ID decrypted by the Initiator encryption key defined in Section 6.5. If the decrypted data is not a HOST_ID parameter, the I2 packet is silently dropped.

11. The implementation SHOULD also verify that the Initiator's HIT in the I2 corresponds to the Host Identity sent in the I2.

12. The system MUST verify the HMAC according to the procedures in Section 5.2.9.

13. The system MUST verify the HIP_SIGNATURE according to Section 5.2.11 and Section 5.3.3.

14. If the checks above are valid, then the system proceeds with further I2 processing; otherwise, it discards the I2 and remains in the same state.

15. The I2 packet may have the A bit set -- in this case, the system MAY choose to refuse it by dropping the I2 and returning to state UNASSOCIATED. If the A bit is set, the Initiator's HIT is anonymous and should not be stored.

16. The system initializes the remaining variables in the associated state, including Update ID counters.

17. Upon successful processing of an I2 in states UNASSOCIATED, I1-SENT, I2-SENT, and R2-SENT, an R2 is sent and the state machine

transitions to state R2-SENT.

18. Upon successful processing of an I2 in state ESTABLISHED, the old HIP association is dropped and a new one is installed, an R2 is sent, and the state machine transitions to R2-SENT.

19. Upon transitioning to R2-SENT, start a timer. Move to ESTABLISHED if some data has been received on the incoming HIP association, or an UPDATE packet has been received (or some other packet that indicates that the peer has moved to ESTABLISHED). If the timer expires (allowing for maximal retransmissions of I2s), move to UNASSOCIATED.

6.9.1. Handling Malformed Messages

If an implementation receives a malformed I2 message, the behavior SHOULD depend on how much checks the message has already passed. If the puzzle solution in the message has already been checked, the implementation SHOULD report the error by responding with a NOTIFY packet. Otherwise the implementation MAY respond with an ICMP message as defined in Section 5.4.

6.10. Processing Incoming R2 Packets

An R2 received in states UNASSOCIATED, I1-SENT, or ESTABLISHED results in the R2 being dropped and the state machine staying in the same state. If an R2 is received in state I2-SENT, it SHOULD be processed.

The following steps define the conceptual processing rules for incoming R2 packet:

1. The system MUST verify that the HITs in use correspond to the HITs that were received in R1.

2. The system MUST verify the HMAC_2 according to the procedures in Section 5.2.10.

3. The system MUST verify the HIP signature according to the procedures in Section 5.2.11.

4. If any of the checks above fail, there is a high probability of an ongoing man-in-the-middle or other security attack. The system SHOULD act accordingly, based on its local policy.

5. If the system is in any other state than I2-SENT, the R2 is silently dropped.

6. Upon successful processing of the R2, the state machine moves to state ESTABLISHED.

6.11. Sending UPDATE Packets

A host sends an UPDATE packet when it wants to update some information related to a HIP association. There are a number of likely situations, e.g. mobility management and rekeying of an existing ESP Security Association. The following paragraphs define the conceptual rules for sending an UPDATE packet to the peer. Additional steps can be defined in other documents where the UPDATE packet is used.

The system first determines whether there are any outstanding UPDATE messages that may conflict with the new UPDATE message under consideration. When multiple UPDATEs are outstanding (not yet acknowledged), the sender must assume that such UPDATEs may be processed in an arbitrary order. Therefore, any new UPDATEs that depend on a previous outstanding UPDATE being successfully received and acknowledged MUST be postponed until reception of the necessary ACK(s) occurs. One way to prevent any conflicts is to only allow one outstanding UPDATE at a time, but allowing multiple UPDATEs may improve the performance of mobility and multihoming protocols.

1. The first UPDATE packet is sent with Update ID of zero. Otherwise, the system increments its own Update ID value by one before continuing the below steps.

2. The system creates an UPDATE packet that contains a SEQ parameter with the current value of Update ID. The UPDATE packet may also include an ACK of the peer's Update ID found in a received UPDATE SEQ parameter, if any.

3. The system sends the created UPDATE packet and starts an UPDATE timer. The default value for the timer is 2 * RTT estimate. If multiple UPDATEs are outstanding, multiple timers are in effect.

4. If the UPDATE timer expires, the UPDATE is resent. The UPDATE can be resent UPDATE_RETRY_MAX times. The UPDATE timer SHOULD be exponentially backed off for subsequent retransmissions. If no acknowledgment is received from the peer after UPDATE_RETRY_MAX times, the HIP association is considered to be broken and the state machine should move from state ESTABLISHED to state CLOSING as depicted in Section 4.4.3. The UPDATE timer is cancelled upon receiving an ACK from the peer that acknowledges receipt of the UPDATE.

6.12. Receiving UPDATE Packets

When a system receives an UPDATE packet, its processing depends on the state of the HIP association and the presence of and values of the SEQ and ACK parameters. Typically, an UPDATE message also carries optional parameters whose handling is defined in separate documents.

For each association, the peer's next expected in-sequence Update ID ("peer Update ID") is stored. Initially, this value is zero. Update ID comparisons of "less than" and "greater than" are performed with respect to a circular sequence number space.

The sender may send multiple outstanding UPDATE messages. These messages are processed in the order in which they are received at the receiver (i.e., no resequencing is performed). When processing UPDATEs out-of-order, the receiver MUST keep track of which UPDATEs were previously processed, so that duplicates or retransmissions are ACKed and not reprocessed. A receiver MAY choose to define a receive window of Update IDs that it is willing to process at any given time, and discard received UPDATEs falling outside of that window.

1. If there is no corresponding HIP association, the implementation MAY reply with an ICMP Parameter Problem, as specified in Section 5.4.4.

2. If the association is in the ESTABLISHED state and the SEQ (but not ACK) parameter is present, the UPDATE is processed and replied as described in Section 6.12.1.

3. If the association is in the ESTABLISHED state and the ACK (but not SEQ) parameter is present, the UPDATE is processed as described in Section 6.12.2.

4. If the association is in the ESTABLISHED state and there is both an ACK and SEQ in the UPDATE, the ACK is first processed as described in Section 6.12.2 and then the rest of the UPDATE is processed as described in Section 6.12.1.

6.12.1. Handling a SEQ parameter in a received UPDATE message

1. If the Update ID in the received SEQ is not the next in sequence Update ID and is greater than the receiver's window for new UPDATEs, the packet MUST be dropped.

2. If the Update ID in the received SEQ corresponds to an UPDATE that has recently been processed, the packet is treated as a retransmission. The HMAC verification (next step) MUST NOT be

skipped. (A byte-by-byte comparison of the received and a stored packet would be OK, though.) It is recommended that a host cache UPDATE packets sent with ACKs to avoid the cost of generating a new ACK packet to respond to a replayed UPDATE. The system MUST acknowledge, again, such (apparent) UPDATE message retransmissions but SHOULD also consider rate-limiting such retransmission responses to guard against replay attacks.

3. The system MUST verify the HMAC in the UPDATE packet. If the verification fails, the packet MUST be dropped.

4. The system MAY verify the SIGNATURE in the UPDATE packet. If the verification fails, the packet SHOULD be dropped and an error message logged.

5. If a new SEQ parameter is being processed, the parameters in the UPDATE are then processed. The system MUST record the Update ID in the received SEQ parameter, for replay protection.

6. An UPDATE acknowledgement packet with ACK parameter is prepared and sent to the peer. This ACK parameter may be included in a separate UPDATE or piggybacked in an UPDATE with SEQ parameter, as described in Section Section 5.3.5. The ACK parameter MAY acknowledge more than one of the peer's Update IDs.

6.12.2. Handling an ACK Parameter in a Received UPDATE Packet

1. The sequence number reported in the ACK must match with an earlier sent UPDATE packet that has not already been acknowledged. If no match is found or if the ACK does not acknowledge a new UPDATE, the packet MUST either be dropped if no SEQ parameter is present, or the processing steps in Section 6.12.1 are followed.

2. The system MUST verify the HMAC in the UPDATE packet. If the verification fails, the packet MUST be dropped.

3. The system MAY verify the SIGNATURE in the UPDATE packet. If the verification fails, the packet SHOULD be dropped and an error message logged.

4. The corresponding UPDATE timer is stopped (see Section 6.11) so that the now acknowledged UPDATE is no longer retransmitted. If multiple UPDATEs are newly acknowledged, multiple timers are stopped.

6.13. Processing NOTIFY Packets

Processing NOTIFY packets is OPTIONAL. If processed, any errors noted by the NOTIFY parameter SHOULD be taken into account by the HIP state machine (e.g., by terminating a HIP handshake), and the error SHOULD be logged.

6.14. Processing CLOSE Packets

When the host receives a CLOSE message it responds with a CLOSE_ACK message and moves to CLOSED state. (The authenticity of the CLOSE message is verified using both HMAC and SIGNATURE). This processing applies whether or not the HIP association state is CLOSING in order to handle CLOSE messages from both ends crossing in flight.

The HIP association is not discarded before the host moves from the UNASSOCIATED state.

Once the closing process has started, any need to send data packets will trigger creating and establishing of a new HIP association, starting with sending an I1.

If there is no corresponding HIP association, the CLOSE packet is dropped.

6.15. Processing CLOSE_ACK Packets

When a host receives a CLOSE_ACK message it verifies that it is in CLOSING or CLOSED state and that the CLOSE_ACK was in response to the CLOSE (using the included ECHO_REPLY in response to the sent ECHO_REQUEST).

The CLOSE_ACK uses HMAC and SIGNATURE for verification. The state is discarded when the state changes to UNASSOCIATED and, after that, the host MAY respond with an ICMP Parameter Problem to an incoming CLOSE message (See Section 5.4.4).

6.16. Dropping HIP Associations

A HIP implementation is free to drop a HIP association at any time, based on its own policy. If a HIP host decides to drop a HIP association, it deletes the corresponding HIP state, including the keying material. The implementation MUST also drop the peer's R1 generation counter value, unless a local policy explicitly defines that the value of that particular host is stored. An implementation MUST NOT store R1 generation counters by default, but storing R1 generation counter values, if done, MUST be configured by explicit HITs.

7. HIP Policies

There are a number of variables that will influence the HIP exchanges that each host must support. All HIP implementations MUST support more than one simultaneous HIs, at least one of which SHOULD be reserved for anonymous usage. Although anonymous HIs will be rarely used as Responder HIs, they will be common for Initiators. Support for more than two HIs is RECOMMENDED.

Many Initiators would want to use a different HI for different Responders. The implementations SHOULD provide for an ACL of Initiator HIT to Responder HIT. This ACL SHOULD also include preferred transform and local lifetimes.

The value of K used in the HIP R1 packet can also vary by policy. K should never be greater than 20, but for trusted partners it could be as low as 0.

Responders would need a similar ACL, representing which hosts they accept HIP exchanges, and the preferred transform and local lifetimes. Wildcarding SHOULD be supported for this ACL also.

8. Security Considerations

HIP is designed to provide secure authentication of hosts. HIP also attempts to limit the exposure of the host to various denial-of-service and man-in-the-middle (MitM) attacks. In so doing, HIP itself is subject to its own DoS and MitM attacks that potentially could be more damaging to a host's ability to conduct business as usual.

Denial-of-service attacks take advantage of the cost of start of state for a protocol on the Responder compared to the 'cheapness' on the Initiator. HIP makes no attempt to increase the cost of the start of state on the Initiator, but makes an effort to reduce the cost to the Responder. This is done by having the Responder start the 3-way exchange instead of the Initiator, making the HIP protocol 4 packets long. In doing this, packet 2 becomes a 'stock' packet that the Responder MAY use many times. The duration of use is a paranoia versus throughput concern. Using the same Diffie-Hellman values and random puzzle #I has some risk. This risk needs to be balanced against a potential storm of HIP I1 packets.

This shifting of the start of state cost to the Initiator in creating the I2 HIP packet, presents another DoS attack. The attacker spoofs the I1 HIP packet and the Responder sends out the R1 HIP packet. This could conceivably tie up the 'Initiator' with evaluating the R1 HIP packet, and creating the I2 HIP packet. The defense against this attack is to simply ignore any R1 packet where a corresponding I1 was not sent.

A second form of DoS attack arrives in the I2 HIP packet. Once the attacking Initiator has solved the puzzle, it can send packets with spoofed IP source addresses with either invalid encrypted HIP payload component or a bad HIP signature. This would take resources in the Responder's part to reach the point to discover that the I2 packet cannot be completely processed. The defense against this attack is after N bad I2 packets, the Responder would discard any I2s that contain the given Initiator HIT. Thus will shut down the attack. The attacker would have to request another R1 and use that to launch a new attack. The Responder could up the value of K while under attack. On the downside, valid I2s might get dropped too.

A third form of DoS attack is emulating the restart of state after a reboot of one of the partners. A host restarting would send an I1 to a peer, which would respond with an R1 even if it were in the ESTABLISHED state. If the I1 were spoofed, the resulting R1 would be received unexpectedly by the spoofed host and would be dropped, as in the first case above.

A fourth form of DoS attack is emulating the end of state. HIP relies on timers plus a CLOSE/CLOSE_ACK handshake to explicitly signals the end of a state. Because both CLOSE and CLOSE_ACK messages contain an HMAC, an outsider cannot close a connection. The presence of an additional SIGNATURE allows middle-boxes to inspect these messages and discard the associated state (for e.g., firewalling, SPI-based NATing, etc.). However, the optional behavior of replying to CLOSE with an ICMP Parameter Problem packet (as described in Section 5.4.4) might allow an IP spoofer sending CLOSE messages to launch reflection attacks.

A fifth form of DoS attack is replaying R1s to cause the Initiator to solve stale puzzles and become out of synchronization with the Responder. The R1 generation counter is a monotonically increasing counter designed to protect against this attack, as described in section Section 4.1.4.

Man-in-the-middle attacks are difficult to defend against, without third-party authentication. A skillful MitM could easily handle all parts of HIP; but HIP indirectly provides the following protection from a MitM attack. If the Responder's HI is retrieved from a signed DNS zone, a certificate, or through some other secure means, the Initiator can use this to validate the R1 HIP packet.

Likewise, if the Initiator's HI is in a secure DNS zone, a trusted certificate, or otherwise securely available, the Responder can retrieve it after it gets the I2 HIP packet and validate that. However, since an Initiator may choose to use an anonymous HI, it knowingly risks a MitM attack. The Responder may choose not to accept a HIP exchange with an anonymous Initiator.

If an Initiator wants to use opportunistic mode, it is vulnerable to man-in-the-middle attacks. Furthermore, the available HI types are limited to the MUST implement algorithms, as per Section 3. Hence, if a future specification deprecates the current MUST implement algorithm(s) and replaces it (them) with some new one(s), backward compatibility cannot be preserved.

Since not all hosts will ever support HIP, ICMP 'Destination Protocol Unreachable' are to be expected and present a DoS attack. Against an Initiator, the attack would look like the Responder does not support HIP, but shortly after receiving the ICMP message, the Initiator would receive a valid R1 HIP packet. Thus to protect from this attack, an Initiator should not react to an ICMP message until a reasonable delta time to get the real Responder's R1 HIP packet. A similar attack against the Responder is more involved. First an ICMP message is expected if the I1 was a DoS attack and the real owner of the spoofed IP address does not support HIP. The Responder SHOULD

NOT act on this ICMP message to remove the minimal state from the R1 HIP packet (if it has one), but wait for either a valid I2 HIP packet or the natural timeout of the R1 HIP packet. This is to allow for a sophisticated attacker that is trying to break up the HIP exchange. Likewise, the Initiator should ignore any ICMP message while waiting for an R2 HIP packet, deleting state only after a natural timeout.

9. IANA Considerations

This document specifies the IP protocol number 253 to be used with Host Identity Protocol during the experimental phase. This number has been reserved by IANA for experimental use (see [19].

This document defines a new 128-bit value under the CGA Message Type namespace [20], 0xF0EF F02F BFF4 3D0F E793 0C3C 6E61 74EA.

This document also creates a set of new name spaces. These are described below.

Packet Type

The 7-bit Packet Type field in a HIP protocol packet describes the type of a HIP protocol message. It is defined in Section 5.1. The current values are defined in Section 5.3.1 through Section 5.3.8 and are listed below:

* I1 is 1.
* R1 is 2.
* I2 is 3.
* R2 is 4.
* UPDATE is 16.
* NOTIFY is 17.
* CLOSE is 18.
* CLOSE_ACK is 19.

New values are assigned through IETF Consensus [9].

HIP Version

The four bit Version field in a HIP protocol packet describes the version of the HIP protocol. It is defined in Section 5.1. The only currently defined value is 1. New values are assigned through IETF Consensus.

Parameter Type

The 16 bit Type field in a HIP parameters describes the type of the parameter. It is defined in Section 5.2.1. The current

values are defined in Section 5.2.3 through Section 5.2.18 and are listed below:

* R1_COUNTER is 128.
* PUZZLE is 257.
* SOLUTION is 321.
* SEQ is 385.
* ACK is 449.
* DIFFIE_HELLMAN is 513.
* HIP_TRANSFORM is 577.
* ENCRYPTED is 641.
* HOST_ID is 705.
* CERT is 768.
* NOTIFY is 832.
* ECHO_REQUEST is 897.
* ECHO_RESPONSE is 961.
* HMAC is 61505.
* HMAC_2 is 61569.
* HIP_SIGNATURE_2 is 61633.
* HIP_SIGNATURE is 61697.
* ECHO_REQUEST is 63661.
* ECHO_RESPONSE is 63425.

The type codes 0 through 1023 and 61440 through 65535 are reserved for future base protocol extensions, and are assigned through IETF Consensus.

The type codes 32768 through 49141 are reserved for experimentation and private use. Types SHOULD be selected in a

random fashion from this range, thereby reducing the probability of collisions. A method employing genuine randomness (such as flipping a coin) SHOULD be used.

All other type codes are assigned through First Come First Served, with Specification Required [9].

Group ID

The eight bit Group ID values appear in the DIFFIE_HELLMAN parameter, defined in Section 5.2.6. The currently defined values are listed below:

* 384-bit group is 1.

* OAKLEY well known group 1 is 2.

* 1536-bit MODP group is 3.

* 3072-bit MODP group is 4.

* 6144-bit MODP group is 5.

* 8192-bit MODP group is 6.

* Value 0 is reserved.

New values either from the reserved or unassigned space are assigned through IETF Consensus.

Suite ID

The 16 bit Suite ID values in a HIP_TRANSFORM parameter are defined in Section 5.2.7. The currently defined values are listed below:

* AES-CBC with HMAC-SHA1 is 1.

* 3DES-CBC with HMAC-SHA1 is 2.

* 3DES-CBC with HMAC-MD5 is 3.

* BLOWFISH-CBC with HMAC-SHA1 is 4.

* NULL-ENCRYPT with HMAC-SHA1 is 5.

* NULL-ENCRYPT with HMAC-MD5 is 6.

* Value 0 is reserved.

New values either from the reserved or unassigned space are assigned through IETF Consensus.

DI-Type

The four bit DI-Type values in a HOST_ID parameter are defined in Section 5.2.8. The currently defined values are listed below:

* None included is 0.

* FQDN is 1.

* NAI is 2.

New values are assigned through IETF Consensus.

Notify Message Type

The 16 bit Notify Message Type field in a NOTIFY parameter is defined in Section 5.2.16. The currently defined values are listed below:

* UNSUPPORTED_CRITICAL_PARAMETER_TYPE is 1.

* INVALID_SYNTAX is 7.

* NO_DH_PROPOSAL_CHOSEN is 14.

* INVALID_DH_CHOSEN is 15.

* NO_HIP_PROPOSAL_CHOSEN is 16.

* INVALID_HIP_TRANSFORM_CHOSEN is 17.

* AUTHENTICATION_FAILED is 24.

* CHECKSUM_FAILED is 26.

* HMAC_FAILED is 28.

* ENCRYPTION_FAILED is 32.

* INVALID_HIT is 40.

* BLOCKED_BY_POLICY is 42.

* SERVER_BUSY_PLEASE_RETRY is 44.

New values are assigned through First Come First Served, with Specification Required.

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Many others contributed; extensive security tips were provided by Steve Bellovin. Rob Austein kept the DNS parts on track. Paul Kocher taught Bob Moskowitz how to make the puzzle exchange expensive for the Initiator to respond, but easy for the Responder to validate. Bill Sommerfeld supplied the Birthday concept, which later evolved into the R1 generation counter, to simplify reboot management. Erik Nordmark supplied CLOSE-mechanism for closing connections. Rodney Thayer and Hugh Daniels provide extensive feedback. In the early times of this draft, John Gilmore kept Bob Moskowitz challenged to provide something of value.

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Once the HIP Working Group was founded in early 2004, a number of changes were introduced through the working group process. Most notably, the original draft was split in two, one containing the base exchange and the other one defining how to use ESP. Some modifications to the protocol proposed by Aura et al. [29] were added at a later stage.

11. References

11.1. Normative References

[1] Postel, J., "User Datagram Protocol", STD 6, RFC 768, August 1980.

[2] Postel, J., "Internet Control Message Protocol", STD 5, RFC 792, September 1981.

[3] Mockapetris, P., "Domain names - implementation and specification", STD 13, RFC 1035, November 1987.

[4] Conta, A. and S. Deering, "Internet Control Message Protocol (ICMPv6) for the Internet Protocol Version 6 (IPv6)", RFC 1885, December 1995.

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

[6] Madson, C. and R. Glenn, "The Use of HMAC-SHA-1-96 within ESP and AH", RFC 2404, November 1998.

[7] Harkins, D. and D. Carrel, "The Internet Key Exchange (IKE)", RFC 2409, November 1998.

[8] Orman, H., "The OAKLEY Key Determination Protocol", RFC 2412, November 1998.

[9] Narten, T. and H. Alvestrand, "Guidelines for Writing an IANA Considerations Section in RFCs", BCP 26, RFC 2434, October 1998.

[10] Pereira, R. and R. Adams, "The ESP CBC-Mode Cipher Algorithms", RFC 2451, November 1998.

[11] Deering, S. and R. Hinden, "Internet Protocol, Version 6 (IPv6) Specification", RFC 2460, December 1998.

[12] Eastlake, D., "Domain Name System Security Extensions", RFC 2535, March 1999.

[13] Eastlake, D., "DSA KEYs and SIGs in the Domain Name System (DNS)", RFC 2536, March 1999.

[14] Kaliski, B., "PKCS #5: Password-Based Cryptography Specification Version 2.0", RFC 2898, September 2000.

[15] Eastlake, D., "RSA/SHA-1 SIGs and RSA KEYs in the Domain Name System (DNS)", RFC 3110, May 2001.

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

[17] Kivinen, T. and M. Kojo, "More Modular Exponential (MODP) Diffie-Hellman groups for Internet Key Exchange (IKE)", RFC 3526, May 2003.

[18] Frankel, S., Glenn, R., and S. Kelly, "The AES-CBC Cipher Algorithm and Its Use with IPsec", RFC 3602, September 2003.

[19] Narten, T., "Assigning Experimental and Testing Numbers Considered Useful", BCP 82, RFC 3692, January 2004.

[20] Aura, T., "Cryptographically Generated Addresses (CGA)", RFC 3972, March 2005.

[21] Schiller, J., "Cryptographic Algorithms for use in the Internet Key Exchange Version 2", draft-ietf-ipsec-ikev2-algorithms-05 (work in progress), April 2004.

[22] Nikander, P., "A Non-Routable IPv6 Prefix for Keyed Hash Identifiers (KHI)", draft-laganier-ipv6-khi-00 (work in progress), September 2005.

[23] Aboba, B., "The Network Access Identifier", draft-ietf-radext-rfc2486bis-06 (work in progress), July 2005.

[24] Jokela, P., "Using ESP transport format with HIP", draft-ietf-hip-esp-01 (work in progress), October 2005.

[25] NIST, "FIPS PUB 180-1: Secure Hash Standard", April 1995.

11.2. Informative References

[26] Moskowitz, R. and P. Nikander, "Host Identity Protocol Architecture", draft-ietf-hip-arch-03 (work in progress), August 2005.

[27] Bagnulo, M. and E. Nordmark, "Level 3 multihoming shim protocol", draft-ietf-shim6-proto-03 (work in progress), December 2005.

[28] Henderson, T. and P. Nikander, "Using HIP with Legacy Applications", draft-henderson-hip-applications-01 (work in progress), July 2005.

[29] Aura, T., Nagarajan, A., and A. Gurtov, "Analysis of the HIP Base Exchange Protocol", in Proceedings of 10th Australasian Conference on Information Security and Privacy, July 2003.

[30] Krawczyk, H., "SIGMA: The 'SIGn-and-MAc' Approach to Authenticated Diffie-Hellman and Its Use in the IKE-Protocols", in Proceedings of CRYPTO 2003, pages 400-425, August 2003.

[31] Crosby, SA. and DS. Wallach, "Denial of Service via Algorithmic Complexity Attacks", in Proceedings of Usenix Security Symposium 2003, Washington, DC., August 2003.

[32] NIST, "FIPS PUB 197: Advanced Encryption Standard", Nov 2001.

Appendix A. Using Responder Puzzles

As mentioned in Section 4.1.1, the Responder may delay state creation and still reject most spoofed I2s by using a number of pre-calculated R1s and a local selection function. This appendix defines one possible implementation in detail. The purpose of this appendix is to give the implementors an idea on how to implement the mechanism. If the implementation is based on this appendix, it MAY contain some local modification that makes an attacker's task harder.

The Responder creates a secret value S, that it regenerates periodically. The Responder needs to remember two latest values of S. Each time the S is regenerated, R1 generation counter value is incremented by one.

The Responder generates a pre-signed R1 packet. The signature for pre-generated R1s must be recalculated when the Diffie-Hellman key is recomputed or when the R1_COUNTER value changes due to S value regeneration.

When the Initiator sends the I1 packet for initializing a connection, the Responder gets the HIT and IP address from the packet, and generates an I-value for the puzzle. The I value is set to the pre-signed R1 packet.

```
I value calculation:
I = Ltrunc( PHASH ( S | HIT-I | HIT-R | IP-I | IP-R ), 64)
```

The PHASH algorithm is the same that is used to generate the Responder's HIT value.

From an incoming I2 packet, the Responder gets the required information to validate the puzzle: HITs, IP addresses, and the information of the used S value from the R1_COUNTER. Using these values, the Responder can regenerate the I, and verify it against the I received in the I2 packet. If the I values match, it can verify the solution using I, J, and difficulty K. If the I values do not match, the I2 is dropped.

```
puzzle_check:
V := Ltrunc( PHASH( I2.I | I2.hit_i | I2.hit_r | I2.J ), K )
if V != 0, drop the packet
```

If the puzzle solution is correct, the I and J values are stored for later use. They are used as input material when keying material is generated.

The Responder SHOULD NOT keep state about failed puzzle solutions.

Appendix B. Generating a HIT from a HI

The following pseudo-codes illustrate the process to generate a public key encoding from a HI for both RSA and DSA.

The symbol := denotes assignment; the symbol += denotes appending. The pseudo-function encode_in_network_byte_order takes two parameters, an integer (bignum) and a length in bytes, and returns the integer encoded into a byte string of the given length.

```
switch ( HI.algorithm )
{

case RSA:
 buffer := encode_in_network_byte_order ( HI.RSA.e_len,
           ( HI.RSA.e_len > 255 ) ? 3 : 1 )
 buffer += encode_in_network_byte_order ( HI.RSA.e, HI.RSA.e_len )
 buffer += encode_in_network_byte_order ( HI.RSA.n, HI.RSA.n_len )
 break;

case DSA:
 buffer := encode_in_network_byte_order ( HI.DSA.T , 1 )
 buffer += encode_in_network_byte_order ( HI.DSA.Q , 20 )
 buffer += encode_in_network_byte_order ( HI.DSA.P , 64 +
                                          8 * HI.DSA.T )
 buffer += encode_in_network_byte_order ( HI.DSA.G , 64 +
                                          8 * HI.DSA.T )
 buffer += encode_in_network_byte_order ( HI.DSA.Y , 64 +
                                          8 * HI.DSA.T )
 break;

}
```

Appendix C. Example Checksums for HIP Packets

The HIP checksum for HIP packets is specified in Section 6.1.2. Checksums for TCP and UDP packets running over HIP-enabled security associations are specified in Section 3.5. The examples below use IP addresses of 192.168.0.1 and 192.168.0.2 (and their respective IPv4-compatible IPv6 formats), and HITs with the first two bits "01" followed by 124 zeroes followed by a decimal 1 or 2, respectively.

C.1. IPv6 HIP Example (I1)

Source Address:	::192.168.0.1	
Destination Address:	::192.168.0.2	
Upper-Layer Packet Length:	40	0x28
Next Header:	253	0xfd
Payload Protocol:	59	0x3b
Header Length:	4	0x4
Packet Type:	1	0x1
Version:	1	0x1
Reserved:	1	0x1
Control:	0	0x0
Checksum:	8046	0x1f6e
Sender's HIT :	1100::1	
Receiver's HIT:	1100::2	

C.2. IPv4 HIP Packet (I1)

The IPv4 checksum value for the same example I1 packet is the same as the IPv6 checksum (since the checksums due to the IPv4 and IPv6 pseudo-header components are the same).

C.3. TCP Segment

Regardless of whether IPv6 or IPv4 is used, the TCP and UDP sockets use the IPv6 pseudo-header format [11], with the HITs used in place of the IPv6 addresses.

Sender's HIT:	1100::0001	
Receiver's HIT:	1100::0002	
Upper-Layer Packet Length:	20	0x14
Next Header:	6	0x06
Source port:	65500	0xffdc
Destination port:	22	0x0016
Sequence number:	1	0x00000001
Acknowledgment number:	0	0x00000000
Header length:	20	0x14
Flags:	SYN	0x02
Window size:	65535	0xffff
Checksum:	60301	0xeb8d
Urgent pointer:	0	0x0000

```
  0x0000:  6000 0000 0014 0640 1100 0000 0000 0000
  0x0010:  0000 0000 0000 0002 1100 0000 0000 0000
  0x0020:  0000 0000 0000 0002 ffdc 0016 0000 0001
  0x0030:  0000 0000 5002 ffff 8deb 0000
```

Appendix D. 384-bit Group

This 384-bit group is defined only to be used with HIP. NOTE: The security level of this group is very low! The encryption may be broken in a very short time, even real-time. It should be used only when the host is not powerful enough (e.g. some PDAs) and when security requirements are low (e.g. during normal web surfing).

This prime is: 2^384 - 2^320 - 1 + 2^64 * { [2^254 pi] + 5857 }

Its hexadecimal value is:

FFFFFFFF FFFFFFFF C90FDAA2 2168C234 C4C6628B 80DC1CD1
29024E08 8A67CC74 020BBEA6 3B13B202 FFFFFFFF FFFFFFFF

The generator is: 2.

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