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New Cryptographic Algorithms for HIP

Abstract

This document provides new cryptographic algorithms to be used with HIP. The Edwards Elliptic Curve and the Keccak sponge functions are the main focus. The HIP parameters and processing instructions impacted by these algorithms are defined.

Status of This Memo

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Table of Contents

1. Introduction

This document adds new cryptographic algorithms for HIPv2 [RFC7401] and [RFC7402]. This includes:

*New elliptic curves for ECDH.

*The Edwards Elliptic Curve Digital Signature Algorithm (EdDSA) used in Host Identities (HI) and for Base Exchange (BEX) signatures.

*Hashes used in Host Identity Tag (HIT) generation, and wherever else hashes are needed.

- *Keyed hashes used for KEYMAT generation and packet MACing operations.

- *AEAD and stream ciphers to use in HIP and HIP enabled secure communication protocols.

The hashes and encryption are all built on the Keccak [Keccak] sponge function and the Xoodyak [Xoodyak] lightweight scheme.

These additions reflect selection of advances in the field of cryptography that would best benefit HIP, particularly in constrained devices and communications.

Ed Note: The Xoodyak function calls should be considered the 1st best effort. There are a few areas open for discussion, like which of the 3 choices for adding in the nonce to the AEAD mode and when to use counter and Id. Also there may be copy errors from the source specification, nicer function calls, better acronyms.

2. Terms and Definitions

2.1. Requirements Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

2.2. Definitions

cSHAKE (The customizable SHAKE function [NIST SP800-185]):
Extends the SHAKE scheme to allow users to customize their use of the function.

DEC function (Doubly-Extendable Cryptographic function):
An extendable output function (XOF) that accepts sequences of strings as input and that supports incremental queries efficiently.

DECK function (Doubly-Extendable Cryptographic Keyed function):
A keyed function that takes a sequence of input strings and returns a pseudorandom string of arbitrary length and that can be computed incrementally.

Keccak:
The family of all sponge functions with a KECCAK-f permutation as the underlying function and multi-rate padding as the padding rule. In particular all the functions referenced from [NIST FIPS-202] and [NIST SP800-185].

KMAC (KECCAK Message Authentication Code [NIST SP800-185]):
A pseduo random function (PRF) and keyed hash function based on KECCAK.

SHAKE (Secure Hash Algorithm KECCAK [NIST FIPS-202]):
A secure hash that allows for an arbitrary output length. SHAKE128 and SHAKE256 are instances of XOFs. SHAKE is shorthand for SHAKE128.

PRF (Pseudorandom Function):
A function that takes as input a key and that it is hard to distinguish from a random oracle by an adversary that does not know the key.

XHASH (Xoodyak Hash Algorithm):
A secure hash, based on Xoodyak, that allows for an arbitrary output length. XHASH is an instance of XOF.

XMAC (Xoodyak Message Authentication Code):
A keyed hash function similar to KMAC, based on Xoodyak, that allows for an arbitrary output length.

XOF (eXtendable-Output Function [NIST FIPS-202]):
A function on bit strings (also called messages) in which the output can be extended to any desired length.

3. HIP Parameter values for new Cryptographic Functions

HIP parameters carry information that is necessary for establishing and maintaining a HIP association. For example, the device's public keys as well as the signaling for negotiating ciphers and payload handling are encapsulated in HIP parameters. Additional information, meaningful for end hosts or middleboxes, may also be included in HIP parameters. The specification of the HIP parameters and their mapping to HIP packets and packet types is flexible to allow HIP extensions to define new parameters and new protocol behavior.

3.1. Elliptic Curves for Diffie-Hellman

Elliptic curves Curve25519 and Curve448 [RFC7748] are specified here for use in the HIP Diffie-Hellman exchange.

Curve25519 and Curve448 are already defined in Section 5.2.1 of [hip-dex], using the HIP-DEX CKDF. Here they are defined for using the new KMAC [NIST SP800-185] or XMAC [Xoodyak] derived KDF in Section 5.

3.1.1. DIFFIE_HELLMAN

The DIFFIE_HELLMAN parameter may be included in selected HIP packets based on the DH Group ID selected. The DIFFIE_HELLMAN parameter is defined in Section 5.2.7 of [RFC7401].

The following Elliptic Curves are defined here:

Group	KDF	Value
Curve25519 [RFC7748]	KMAC	13
Curve448 [RFC7748]	KMAC	14

A new KDF for KEYMAT, Section 6.5 of [RFC7401] using Keccak or Xoodyak is defined in Section 5.

3.2. Edward Digital Signature Algorithm for HITs

This section is extracted from Appendix D of [drip-rid]. It may later be pulled and only maintained there.

Edwards-Curve Digital Signature Algorithm (EdDSA) [RFC8032] are specified here for use as Host Identities (HIs) per HIPv2 [RFC7401]. Further the HIT_SUITE_LIST is specified as used in [RFC7343].

3.2.1. HOST_ID

The HOST_ID parameter specifies the public key algorithm, and for elliptic curves, a name. The HOST_ID parameter is defined in Section 5.2.19 of [RFC7401].

Algorithm profiles	Values
EdDSA	13 [RFC8032]

For hosts that implement EdDSA as the algorithm, the following ECC curves are available:

Algorithm	Curve	Values
EdDSA	RESERVED	0
EdDSA	EdDSA25519	1 [RFC8032]
EdDSA	EdDSA25519ph	2 [RFC8032]
EdDSA	EdDSA448	3 [RFC8032]
EdDSA	EdDSA448ph	4 [RFC8032]

3.2.2. HIT_SUITE_LIST

The HIT_SUITE_LIST parameter contains a list of the supported HIT suite IDs of the Responder. Based on the HIT_SUITE_LIST, the Initiator can determine which source HIT Suite IDs are supported by the Responder. The HIT_SUITE_LIST parameter is defined in Section 5.2.10 of [RFC7401].

The following HIT Suite ID is defined, and the relationship between the four-bit ID value used in the OGA ID field and the eight-bit encoding within the HIT_SUITE_LIST ID field is clarified:

HIT Suite	Four-bit ID	Eight-bit encoding
RESERVED	0	0x00
EdDSA/cSHAKE128	5	0x50
EdDSA/XHASH	6	0x60

The following table provides more detail on the above HIT Suite combinations. The input for each generation algorithm is the encoding of the HI as defined herein.

The output of cSHAKE128 and XHASH are variable per the needs of a specific ORCHID construction. It is at most 96 bits long and is directly used in the ORCHID (without truncation).

Index	Hash function	HMAC	Signature algorithm family	Description
5	cSHAKE128	KMAC128	EdDSA	EdDSA HI hashed with cSHAKE128, output is variable
6	XHASH	XMAC	EdDSA	EdDSA HI hashed with XMAC, output is variable

Table 1: HIT Suites

3.3. Hashing in HIP

Hashing is used in HIP for HIT generation and keyed hashes of HIP payloads. The hash algorithm used is designated as part of the HIT_SUITE_ID. The keyed hash function is the "common" such function used in conjunction with the HIT hash.

3.3.1. Hashing with the Sponge Functions

The XOF function in SHA-3, Secure Hash Algorithm Keccak (SHAKE) [NIST FIPS-202] and the more recent Xoodyak [Xoodyak] algorithm are called sponge functions. Sponge functions have a special feature in which an arbitrary number of output bits are "squeezed" out of the hashing state. This is a significant use change in that hash truncation or multiple "runs" for enough bits are not used with sponge functions.

3.3.1.1. cSHAKE, the customizable SHAKE function

The customizable SHAKE function (cSHAKE) in [NIST SP800-185] will be used as a HIP hash. As a Keccak XOF, it does not use the truncation operation that other hashes need. The invocation of cSHAKE specifies the desired number of bits in the hash output. Further, cSHAKE has a parameter 'S' as a customization bit string. This parameter will be used for including hash specific customization like the ORCHID Context Identifier in a standard fashion.

Hardware implementation of Keccak in VHDL is available from Keccak [Keccak] team website.

3.3.1.2. The Xoodyak Hash

The Xoodyak [Xoodyak] sponge function is a candidate in the NIST Lightweight Cryptography (LWC) Standardization process (see [NISTIR 8369]). Xoodyak has been selected here for use in HIP from the LWC 2nd round candidates as it was developed by the Keccak team, making it more directly in line with Keccak.

Xoodyak has a hash function mode. More specifically, this hash mode is an extendable output function (XOF).

As the Xoodyak specification [Xoodyak_Spec] does not provide high-level function calls, rather a set of primitives to use to construct the various modes, the appropriate primitive calls will be detailed below. Xoodyak as a hash will be called here "XHASH".

To get a n-byte digest of some input x: XHASH(n, x), use the following set of Xoodyak primitives:

```
Cyclist(ε,ε,ε)
Absorb(x)
Squeeze(n)
```

Xoodyak can also naturally implement a DEC function and process a sequence of strings. Here the output depends on the sequence as such and not just on the concatenation of the different strings. To compute a n-byte digest, XHASH(n, {x1, x2, x3}) the Xoodyak primitives are:

```
Cyclist(ε,ε,ε)
Absorb(x1)
Absorb(x2)
Absorb(x3)
Squeeze(n)
```

The equivalent of the parameter 'S' in cSHAKE above can be implemented as the last Absorb primitive call in the DEC function. That is: XHASH(L, {S, N, X}) is equivalent to cSHAKE(X, L, N, S).

3.3.2. RHASH

RHASH is the general term used throughout [RFC7401] to refer to the hash used for a specific HIT suite. For this addendum cSHAKE128 for Keccak or XHASH for Xoodyak is used, even for HITs of EdDSA448.

Unless otherwise specified, L of cSHAKE128 or n of XHASH is 256, resulting in a similar output to SHA256. Any truncation used for, older, fixed output hashes is still used. This is to simplify code integration. One exception to this is in Section 4.

3.3.3. HIP_MAC and HIP_MAC2

The HIP_MAC and HIP_MAC2 parameters in [RFC7401] use HMAC [RFC2104]. This performs two hashes on a string with a key for a keyed hash the length of the underlying hash.

For both HIP_MAC and HIP_MAC2 use, the parameter S below is NULL. It is included for complete function definition.

3.3.3.1. The Keccak Keyed MAC

Here, KMAC from NIST SP 800-185 [NIST SP800-185] is used. This is a single pass using the underlying cSHAKE function. The function call is:

```
     KMAC128(Key, Input String, 256, S)
```

3.3.3.2. The Xoodyak Keyed MAC

Here, XMAC is defined as the keyed hash function based on Xoodyak. It is built with primitives from [Xoodyak_Spec] as a DEC function.

To get a n-byte keyed MAC of some input x: XMAC(Key, n, {x, S}). Where n=256, use the following set of Xoodyak primitives:

```
     Cyclist(Key,Id,ε)
     Absorb(S)           Only if S is non-null
     Absorb(Input String)
     Squeeze(32)
```

Id is "HIP_MAC" and "HIP_MAC2" respectively. Note since S is null in this XMAC usage, the first Absorb call is not performed.

3.4. HIP Cipher

HIP encrypted parameters use the HIP_CIPHER, Section 5.2.8 of [RFC7401]. The Xoodyak cipher, [Xoodyak], is recommended. Here Xoodyak is used in encrypt only mode.

3.4.1. HIP_CIPHER

The HIP_CIPHER parameter value for Xoodyak is:

```
hip_cipher
     Suite ID           Value

     Xoodyak            6     (Xoodyak)
```

The Xoodyak primitive calls for encrypt only are:

```
     Cyclist(Key,Id,ε)
     Absorb(IV)
     C ← Encrypt(P)

     Where Id is HIP parameter name (e.g. "ENCRYPTED").
     IV is from the encrypted HIP parameter.
     P is the plain-text per the specific HIP encrypted parameter.
     C is the ciphertext.
```

3.5. ESP Transform

The ESP_TRANSFORM parameter is used during ESP SA establishment, Section 5.1.2 of [RFC7402]. The Xoodyak cipher, [Xoodyak], is recommended. Here Xoodyak is used in AEAD mode.

Further, it is recommended to use Implicit IV ESP [RFC8750] to match its lightweight over-the-air format with the lightweight Xoodyak AEAD cipher.

3.5.1. ESP_TRANSFORM

The ESP_TRANSFORM Suite IDs for Xoodyak are:

hip_cipher

Suite ID	Value	
Xoodyak-96	16	(Xoodyak)
Xoodyak	17	(Xoodyak)
Implicit IV	18	[8750]

The Implicit IV Suite ID is unique in that it is an AND condition with ciphers that can use it. That is AES-GCM and Xoodyak can both use 'regular' ESP [RFC4303] or [RFC8750].

The Xoodyak primitive calls for AEAD encrypt are:

```
Cyclist(Key,Id,ε)
Absorb(IV)
Absorb(A)
C ← Encrypt(P)
T ← Squeeze(t)
```

Where Id is "ESP_TRANSFORM". The IV is either a 32 bit ESP IV per [RFC4303] or the ESP Seq Number per[RFC8750]. P is the plain-text and A is the associated data. t is either 12 or 16. T is the ESP ICV of length t.

4. Generating a HIT from an HI

The EdDSA/cSHAKE based HITs require a new ORCHID generation method than that described in section 3.2 of [RFC7401]. The XOF functionality of cSHAKE produces an output of L bits. This replaces the Encode_96 function in the ORCHID generation.

For identities that are EdDSA public keys, ORCHIDs will be generated per the process defined in Appendix C.2.1 of [drip-rid].

5. HIP KEYMAT Generation

For either the Keccak or Xoodyak KEYMAT generation, the inputs are consistent. The only practical difference is that cSHAKE allows for 128 or 256 bits of strength, whereas Xoodyak only provides 128 bits.

L is the derived key bit length. Since 4 HIP keys are "drawn" from this output, the length is 4 * HIP_key_size. Per ASIACRYPT 2017, pp. 606-637 [ASIACRYPT-2017] each of these derived keys will have the same strength as the Diffie-Hellman shared secret.

S is the byte string 01001011 || 01000100 || 01000110, which represents the sequence of characters "K", "D", and "F" in 8-bit ASCII.

Salt and info are derived as defined in sec 6.5 of [RFC7401]. There are special security considerations for IKM per [RFC7748].

5.1. The Keccak KEYMAT

The KMAC function provides a new, more efficient, key derivation function over HKDF [RFC5869]. KMAC as a KDF is defined below.

The two HIs MUST be used in constructing IKM as follows:

```
  IKM = Diffie-Hellman secret | sort(HI-I | HI-R)
```

The two HIs are separately DER encoded per [RFC7401]

The choice of KMAC128 or KMAC256 is based on the strength of the output key material. For 256 bits of strength equivalent to HMAC-SHA256, use KMAC256. Per [NIST SP800-56Cr1], Section 4.1, Option 3:

```
  OKM = KMAC[128|256](salt | info, IKM, L, S)
```

5.2. The Xoodyak KEYMAT

Here, XMAC from Section 3.3.3.2 is used. The DEC function XMAC("", L, {DH, sort(HI-I, HI-R), info, Salt, S}) primitives are:

```
  Cyclist(ε, ε, ε)
  Absorb(S)
  Absorb(salt)
  Absorb(info)
  Absorb(max(HI-I , HI-R))
  Absorb(min(HI-I , HI-R))
  Absorb(Diffie-Hellman secret)
  Squeeze(L)   Where L is bytes
```

Ed Note: Need to check that all above are well defined bytestrings per 7401. I think they are.

6. Pseudorandom Function (PRF)

Appendix B of NIST SP 800-185 [NIST SP800-185] defines how to use SHAKE, cSHAKE, or KMAC as a PRF.

For Xoodyak, XMAC from Section 3.3.3.2 is used in the same manner as KMAC above.

7. IANA Considerations

IANA will need to make the following changes to the "Host Identity Protocol (HIP) Parameters" registries:

Diffie Hellman:
This document defines the new Curve25519 and Curve448 for the Diffie-Hellman exchange (see Section 3.1.1).

Host ID:
This document defines the new EdDSA Host ID (see Section 3.2.1).

HIT Suite ID:
This document defines the new HIT Suite of EdDSA/cSHAKE and EdDSA/XHASH (see Section 3.2.2).

HIP Cipher:
This document defines the new Xoodyak cipher for HIP encrypted parameters (see Section 3.4.1).

ESP Transform:
This document defines the new Xoodyak cipher and use of [RFC8750] for the ESP Transform parameter (see Section 3.5).

8. Security Considerations

8.1. Keymat vulnerabilities

[RFC7748] warns about using Curve25519 and Curve448 in Diffie-Hellman for key derivation:

Designers using these curves should be aware that for each public key, there are several publicly computable public keys that are equivalent to it, i.e., they produce the same shared secrets. Thus using a public key as an identifier and knowledge of a shared secret as proof of ownership (without including the public keys in the key derivation) might lead to subtle vulnerabilities.

Thus the two Host IDs are included with the Diffie-Hellman secret in the KEYMAT generation.

8.2. KMAC Security as a KDF

Section 4.1 of NIST SP 800-185 [NIST SP800-185] states:

"The KECCAK Message Authentication Code (KMAC) algorithm is a PRF and keyed hash function based on KECCAK . It provides variable-length output"

That is, the output of KMAC is indistinguishable from a random string, regardless of the length of the output. As such, the output of KMAC can be divided into multiple substrings, each with the strength of the function (KMAC128 or KMAC256) and provided that a long enough key is used, as discussed in Sec. 8.4.1 of SP 800-185.

For example KMAC128(K, X, 512, S), where K is at least 128 bits, can produce 4 128 bit keys each with a strength of 128 bits. That is a single sponge operation is replacing perhaps 5 HMAC-SHA256 operations (each 2 SHA256 operations) in HKDF.

9. Acknowledgments

Quynh Dang of NIST gave considerable guidance on using Keccak and the NIST supporting documents. Joan Deamen of the Keccak team was especially helpful in many aspects of using Keccak and Xoodyak, particularly with the KEYMAT section and the strength of the derived keys.

NIST is entering round 3 (final) of its Lightweight Crypto Competition with anticipated selection the end of 2021 or early in 2022. Events in this process will impact selections in this document.

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