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Use of the HSS/LMS Hash-based Signature Algorithm  
in the Cryptographic Message Syntax (CMS)  
<[draft-ietf-lamps-cms-hash-sig-03](#)>

## Abstract

This document specifies the conventions for using the the HSS/LMS hash-based signature algorithm with the Cryptographic Message Syntax (CMS). The HSS/LMS algorithm is one form of hash-based digital signature; it is described in [[HASHSIG](#)].

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## [1.](#) Introduction

This document specifies the conventions for using the HSS/LMS hash-based signature algorithm with the Cryptographic Message Syntax (CMS) [\[CMS\]](#) signed-data content type. The Leighton-Micali Signature (LMS) system provides a one-time digital signature that is a variant of Merkle Tree Signatures (MTS). The Hierarchical Signature System (HSS) is built on top of the LMS system to efficiently scale for a larger numbers of signatures. The HSS/LMS algorithm is one form of hash-based digital signature, and it is described in [\[HASHSIG\]](#). The HSS/LMS signature algorithm can only be used for a fixed number of signing operations. The HSS/LMS signature algorithm uses small private and public keys, and it has low computational cost; however, the signatures are quite large.

### [1.1.](#) ASN.1

CMS values are generated using ASN.1 [\[ASN1-B\]](#), using the Basic Encoding Rules (BER) and the Distinguished Encoding Rules (DER) [\[ASN1-E\]](#).

### [1.2.](#) 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.](#) HSS/LMS Hash-based Signature Algorithm Overview

Merkle Tree Signatures (MTS) are a method for signing a large but fixed number of messages. An MTS system depends on a one-time signature method and a collision-resistant hash function.

This specification makes use of the hash-based algorithm specified in

[[HASHSIG](#)], which is the Leighton and Micali adaptation [[LM](#)] of the original Lamport-Diffie-Winternitz-Merkle one-time signature system [[M1979](#)] [[M1987](#)] [[M1989a](#)] [[M1989b](#)].

As implied by the name, the hash-based signature algorithm depends on a collision-resistant hash function. The hash-based signature algorithm specified in [[HASHSIG](#)] currently uses only the SHA-256 one-way hash function [[SHS](#)], but it also establishes an IANA registry to permit the registration of additional one-way hash functions in the future.

## [2.1.](#) Hierarchical Signature System (HSS)

The MTS system specified in [[HASHSIG](#)] uses a hierarchy of trees. The Hierarchical N-time Signature System (HSS) allows subordinate trees to be generated when needed by the signer. Otherwise, generation of the entire tree might take weeks or longer.

An HSS signature as specified in [[HASHSIG](#)] carries the number of signed public keys (Nspk), followed by that number of signed public keys, followed by the LMS signature as described in [Section 2.2](#). Each signed public key is represented by the hash value at the root of the tree, and it also contains information about the tree structure. The signature over the public key is an LMS signature as described in [Section 2.2](#).

The elements of the HSS signature value for a stand-alone tree can be summarized as:

```
u32str(0) ||  
lms_signature /* signature of message */
```

The elements of the HSS signature value for a tree with Nspk signed public keys can be summarized as:

```
u32str(Nspk) ||  
signed_public_key[0] ||  
signed_public_key[1] ||  
...  
signed_public_key[Nspk-2] ||
```

```
signed_public_key[Nspk-1] ||  
lms_signature_on_message
```

where, as defined in Section 3.3 of [\[HASHSIG\]](#), a signed\_public\_key is the lms\_signature over the public key followed by the public key itself. Note that Nspk is the number of levels in the hierarchy of trees minus 1.

## [2.2.](#) Leighton-Micali Signature (LMS)

Each tree in the system specified in [\[HASHSIG\]](#) uses the Leighton-Micali Signature (LMS) system. LMS systems have two parameters. The first parameter is the height of the tree,  $h$ , which is the number of levels in the tree minus one. The [\[HASHSIG\]](#) specification supports five values for this parameter:  $h=5$ ;  $h=10$ ;  $h=15$ ;  $h=20$ ; and  $h=25$ . Note that there are  $2^h$  leaves in the tree. The second parameter is the number of bytes output by the hash function,  $m$ , which is the amount of data associated with each node in the tree. The [\[HASHSIG\]](#)

specification supports only the SHA-256 hash function [\[SHS\]](#), with  $m=32$ .

Currently, the [\[HASHSIG\]](#) specification supports five tree sizes:

```
LMS_SHA256_M32_H5;  
LMS_SHA256_M32_H10;  
LMS_SHA256_M32_H15;  
LMS_SHA256_M32_H20; and  
LMS_SHA256_M32_H25.
```

The [\[HASHSIG\]](#) specification establishes an IANA registry to permit the registration of additional tree sizes in the future.

An LMS signature consists of four elements: the number of the leaf associated with the LM-OTS signature, an LM-OTS signature as described in [Section 2.3](#), a typecode indicating the particular LMS algorithm, and an array of values that is associated with the path through the tree from the leaf associated with the LM-OTS signature to the root. The array of values contains the siblings of the nodes on the path from the leaf to the root but does not contain the nodes on the path itself. The array for a tree with height  $h$  will have  $h$

values. The first value is the sibling of the leaf, the next value is the sibling of the parent of the leaf, and so on up the path to the root.

The four elements of the LMS signature value can be summarized as:

```
u32str(q) ||  
ots_signature ||  
u32str(type) ||  
path[0] || path[1] || ... || path[h-1]
```

### [2.3.](#) Leighton-Micali One-time Signature Algorithm (LM-OTS)

Merkle Tree Signatures (MTS) depend on a one-time signature method. [\[HASHSIG\]](#) specifies the use of the LM-OTS. An LM-OTS has five parameters.

- n - The number of bytes associated with the hash function. [\[HASHSIG\]](#) supports only SHA-256 [\[SHS\]](#), with n=32.
- H - A preimage-resistant hash function that accepts byte strings of any length, and returns an n-byte string.
- w - The width in bits of the Winternitz coefficients. [\[HASHSIG\]](#) supports four values for this parameter: w=1; w=2; w=4; and w=8.

- p - The number of n-byte string elements that make up the LM-OTS signature.
- ls - The number of left-shift bits used in the checksum function, which is defined in Section 4.4 of [\[HASHSIG\]](#).

The values of p and ls are dependent on the choices of the parameters n and w, as described in [Appendix B](#) of [\[HASHSIG\]](#).

Currently, the [\[HASHSIG\]](#) specification supports four LM-OTS variants:

```
LMOTS_SHA256_N32_W1;  
LMOTS_SHA256_N32_W2;  
LMOTS_SHA256_N32_W4; and  
LMOTS_SHA256_N32_W8.
```

The [[HASHSIG](#)] specification establishes an IANA registry to permit the registration of additional variants in the future.

Signing involves the generation of C, an n-byte random value.

The LM-OTS signature value can be summarized as:

```
u32str(otstype) || C || y[0] || ... || y[p-1]
```

### [3.](#) Algorithm Identifiers and Parameters

The algorithm identifier for an HSS/LMS hash-based signature when SHA-256 [[SHS](#)] is used to hash the content is the id-alg-hss-lms-hashsig-with-sha256 object identifier:

```
id-alg-hss-lms-hashsig-with-sha256 OBJECT IDENTIFIER ::= { iso(1)
    member-body(2) us(840) rsadsi(113549) pkcs(1) pkcs9(9)
    smime(16) alg(3) TBD }
```

The algorithm identifier for an HSS/LMS hash-based signature when SHA-384 [[SHS](#)] is used to hash the content is the id-alg-hss-lms-hashsig-with-sha384 object identifier:

```
id-alg-hss-lms-hashsig-with-sha384 OBJECT IDENTIFIER ::= { iso(1)
    member-body(2) us(840) rsadsi(113549) pkcs(1) pkcs9(9)
    smime(16) alg(3) TBD }
```

The algorithm identifier for an HSS/LMS hash-based signature when SHA-512 [[SHS](#)] is used to hash the content is the id-alg-hss-lms-hashsig-with-sha512 object identifier:

```
id-alg-hss-lms-hashsig-with-sha512 OBJECT IDENTIFIER ::= { iso(1)
    member-body(2) us(840) rsadsi(113549) pkcs(1) pkcs9(9)
    smime(16) alg(3) TBD }
```

When any of these object identifiers is used for a signature, the AlgorithmIdentifier parameters field MUST be absent (that is, the parameters are not present; the parameters are not set to NULL).

The signature values is a large OCTET STRING. The signature format is designed for easy parsing. Each format includes a counter and type codes that indirectly providing all of the information that is needed to parse the value during signature validation.

#### [4.](#) HSS/LMS Public Key Identifier

The AlgorithmIdentifier for an HSS/LMS public key uses the id-alg-hss-lms-hashsig object identifier, and the parameters field MUST be absent.

The SubjectPublicKeyInfo field of an X.509 certificate [[RFC5280](#)] is one place where this algorithm identifier appears. In this situation, the certificate key usage extension MAY contain digitalSignature, nonRepudiation, keyCertSign, and cRLSign; however, it MUST NOT contain other values.

```
pk-HSS-LMS-HashSig PUBLIC-KEY ::= {  
    IDENTIFIER id-alg-hss-lms-hashsig  
    KEY HSS-LMS-HashSig-PublicKey  
    PARAMS ARE absent  
    CERT-KEY-USAGE  
    { digitalSignature, nonRepudiation, keyCertSign, cRLSign } }
```

```
HSS-LMS-HashSig-PublicKey ::= OCTET STRING
```

Note that the id-alg-hss-lms-hashsig algorithm identifier is also referred to as id-alg-mts-hashsig. This synonym is based on the terminology used in an early draft of the document that became [[HASHSIG](#)].

The public key value is an OCTET STRING. Like the signature format, it is designed for easy parsing. The value is the number of levels in the public key, L, followed by the LMS public key.

The HSS/LMS public key value can be summarized as:



```
u32str(L) ||  
lms_public_key
```

## 5. Signed-data Conventions

As specified in [CMS], the digital signature is produced from the message digest and the signer's private key. If signed attributes are absent, then the message digest is the hash of the content. If signed attributes are present, then the hash of the content is placed in the message-digest attribute, the set of signed attributes is DER encoded, and the message digest is the hash of the encoded attributes. In summary:

```
IF (signed attributes are absent)  
THEN md = Hash(content)  
ELSE message-digest attribute = Hash(content);  
      md = Hash(DER(SignedAttributes))
```

```
Sign(md)
```

When using [HASHSIG], the fields in the SignerInfo are used as follows:

digestAlgorithms SHOULD contain the one-way hash function used to compute the message digest on the eContent value. In [HASHSIG], SHA-256 is used throughout the hash tree, and the hash computation includes a random string. This random data makes it harder for an attacker to find collisions. The signer SHOULD use SHA-256 or a stronger hash function to compute the message digest on the content. For this purpose, Algorithm identifiers for SHA-256, SHA-384, and SHA-512 are provided in this document.

Further, the same one-way hash function SHOULD be used to compute the message digest on both the eContent and the signedAttributes value if signedAttributes are present.

signatureAlgorithm MUST contain id-alg-hss-lms-hashsig-with-sha256, id-alg-hss-lms-hashsig-with-sha384, or id-alg-hss-lms-hashsig-with-sha512. The algorithm parameters field MUST be absent.

signature contains the single HSS signature value resulting from the signing operation as specified in [HASHSIG].

## [6.](#) Security Considerations

### [6.1.](#) Implementation Security Considerations

Implementations must protect the private keys. Compromise of the private keys may result in the ability to forge signatures. Along with the private key, the implementation must keep track of which leaf nodes in the tree have been used. Loss of integrity of this tracking data can cause an one-time key to be used more than once. As a result, when a private key and the tracking data are stored on non-volatile media or stored in a virtual machine environment, care must be taken to preserve confidentiality and integrity.

When a LMS key pair is generating a LMS key pair, an implementation must must generate the key pair and the corresponding identifier independently of all other key pairs in the HSS tree.

An implementation must ensure that a LM-OTS private key is used to generate a signature only one time, and ensure that it cannot be used for any other purpose.

The generation of private keys relies on random numbers. The use of inadequate pseudo-random number generators (PRNGs) to generate these values can result in little or no security. An attacker may find it much easier to reproduce the PRNG environment that produced the keys, searching the resulting small set of possibilities, rather than brute force searching the whole key space. The generation of quality random numbers is difficult. [RFC 4086](#) [[RANDOM](#)] offers important guidance in this area.

The generation of hash-based signatures also depends on random numbers. While the consequences of an inadequate pseudo-random number generator (PRNGs) to generate these values is much less severe than the generation of private keys, the guidance in [[RFC4086](#)] remains important.

When computing signatures, the same hash function SHOULD be used to compute the message digest of the content and the signed attributes, if they are present.

### [6.2.](#) Algorithm Security Considerations

At Black Hat USA 2013, some researchers gave a presentation on the current state of public key cryptography. They said: "Current cryptosystems depend on discrete logarithm and factoring which has seen some major new developments in the past 6 months" [[BH2013](#)].

They encouraged preparation for a day when RSA and DSA cannot be depended upon.

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A post-quantum cryptosystem is a system that is secure against quantum computers that have more than a trivial number of quantum bits. It is open to conjecture when it will be feasible to build such a machine. RSA, DSA, and ECDSA are not post-quantum secure.

The LM-OTP one-time signature, LMS, and HSS do not depend on discrete logarithm or factoring, as a result these algorithms are considered to be post-quantum secure.

Hash-based signatures [[HASHSIG](#)] are currently defined to use exclusively SHA-256. An IANA registry is defined to that other hash functions could be used in the future. LM-OTS signature generation prepends a random string as well as other metadata before computing the hash value. The inclusion of the random value reduces the chances of an attacker being able to find collisions, even if the attacker has a large-scale quantum computer.

Today, RSA is often used to digitally sign software updates. This means that the distribution of software updates could be compromised if a significant advance is made in factoring or a quantum computer is invented. The use of HSS/LMS hash-based signatures to protect software update distribution, perhaps using the format described in [[FWPROT](#)], will allow the deployment of software that implements new cryptosystems.

## [7.](#) IANA Considerations

SMI Security for S/MIME Module Identifier (1.2.840.113549.1.9.16.0) registry, change the reference for value 64 to point to this document.

In the SMI Security for S/MIME Algorithms (1.2.840.113549.1.9.16.3) registry, change the description for value 17 to "id-alg-hss-lms-hashsig" and change the reference to point to this document. Also, add the following note to the registry:

Value 17, "id-alg-hss-lms-hashsig", is also referred to as "id-alg-mts-hashsig".

In the SMI Security for S/MIME Algorithms (1.2.840.113549.1.9.16.3) registry, assign a new value for id-alg-hss-lms-hashsig-with-sha256 with a reference to this document.

In the SMI Security for S/MIME Algorithms (1.2.840.113549.1.9.16.3) registry, assign a new value for id-alg-hss-lms-hashsig-with-sha384 with a reference to this document.

In the SMI Security for S/MIME Algorithms (1.2.840.113549.1.9.16.3) registry, assign a new value for id-alg-hss-lms-hashsig-with-sha512 with a reference to this document.

## [8.](#) Acknowledgements

Many thanks to Panos Kampanakis, Jim Schaad, Sean Turner, and Daniel Van Geest for their careful review and comments.

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<[http://www.pqcrypto.org/www.springer.com/cda/content/document/cda\\_downloadaddocument/9783540887010-c1.pdf](http://www.pqcrypto.org/www.springer.com/cda/content/document/cda_downloadaddocument/9783540887010-c1.pdf)>
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MTS-HashSig-2013

```
{ iso(1) member-body(2) us(840) rsadsi(113549) pkcs(1) pkcs9(9)
  id-smime(16) id-mod(0) id-mod-mts-hashsig-2013(64) }
```

DEFINITIONS IMPLICIT TAGS ::= BEGIN

EXPORTS ALL;

IMPORTS

PUBLIC-KEY, SIGNATURE-ALGORITHM, SMIME-CAPS

FROM AlgorithmInformation-2009 -- [RFC 5911](#) [[CMSASN1](#)]

```
{ iso(1) identified-organization(3) dod(6) internet(1)
  security(5) mechanisms(5) pkix(7) id-mod(0)
  id-mod-algorithmInformation-02(58) }
```

mda-sha256, mda-sha384, mda-sha512

FROM PKIX1-PSS-OAEP-Algorithms-2009 -- [RFC 5912](#) [[PKIXASN1](#)]

```
{ iso(1) identified-organization(3) dod(6)
  internet(1) security(5) mechanisms(5) pkix(7) id-mod(0)
  id-mod-pkix1-rsa-pkalgs-02(54) } ;
```

--

-- Object Identifiers

--

```
id-alg-hss-lms-hashsig OBJECT IDENTIFIER ::= { iso(1)
  member-body(2) us(840) rsadsi(113549) pkcs(1) pkcs9(9)
  smime(16) alg(3) 17 }
```

```
id-alg-hss-lms-hashsig-with-sha256 OBJECT IDENTIFIER ::= { iso(1)
  member-body(2) us(840) rsadsi(113549) pkcs(1) pkcs9(9)
  smime(16) alg(3) TBD }
```

```

id-alg-hss-lms-hashsig-with-sha384 OBJECT IDENTIFIER ::= { iso(1)
    member-body(2) us(840) rsadsi(113549) pkcs(1) pkcs9(9)
    smime(16) alg(3) TBD }

id-alg-hss-lms-hashsig-with-sha512 OBJECT IDENTIFIER ::= { iso(1)
    member-body(2) us(840) rsadsi(113549) pkcs(1) pkcs9(9)
    smime(16) alg(3) TBD }

--
-- Signature Algorithm and Public Key
--

sa-HSS-LMS-HashSig-with-SHA256 SIGNATURE-ALGORITHM ::= {
    IDENTIFIER id-alg-hss-lms-hashsig-with-sha256
    PARAMS ARE absent
    HASHES { mda-sha256 }
    PUBLIC-KEYS { pk-HSS-LMS-HashSig }
    SMIME-CAPS { IDENTIFIED BY id-alg-hss-lms-hashsig-with-sha256 } }

sa-HSS-LMS-HashSig-with-SHA384 SIGNATURE-ALGORITHM ::= {
    IDENTIFIER id-alg-hss-lms-hashsig-with-sha384
    PARAMS ARE absent
    HASHES { mda-sha384 }
    PUBLIC-KEYS { pk-HSS-LMS-HashSig }
    SMIME-CAPS { IDENTIFIED BY id-alg-hss-lms-hashsig-with-sha384 } }

sa-HSS-LMS-HashSig-with-SHA512 SIGNATURE-ALGORITHM ::= {
    IDENTIFIER id-alg-hss-lms-hashsig-with-sha512
    PARAMS ARE absent
    HASHES { mda-sha512 }
    PUBLIC-KEYS { pk-HSS-LMS-HashSig }
    SMIME-CAPS { IDENTIFIED BY id-alg-hss-lms-hashsig-with-sha512 } }

```

```

pk-HSS-LMS-HashSig PUBLIC-KEY ::= {
    IDENTIFIER id-alg-hss-lms-hashsig
    KEY HSS-LMS-HashSig-PublicKey
    PARAMS ARE absent

```



```

CERT-KEY-USAGE
    { digitalSignature, nonRepudiation, keyCertSign, cRLSign } }

HSS-LMS-HashSig-PublicKey ::= OCTET STRING

--
-- Expand the signature algorithm set used by CMS [CMSASN1U]
--

SignatureAlgorithmSet SIGNATURE-ALGORITHM ::=
    { sa-HSS-LMS-HashSig-with-SHA256 |
      sa-HSS-LMS-HashSig-with-SHA384 |
      sa-HSS-LMS-HashSig-with-SHA512, ... }

--
-- Expand the S/MIME capabilities set used by CMS [CMSASN1]
--

SMimeCaps SMIME-CAPS ::=
    { sa-HSS-LMS-HashSig-with-SHA256.&smimeCaps |
      sa-HSS-LMS-HashSig-with-SHA384.&smimeCaps |
      sa-HSS-LMS-HashSig-with-SHA512.&smimeCaps, ... }

END

```

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