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Composite ML-DSA Signatures for SSH
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Abstract

This document describes the use of PQ/T composite signatures for the Secure Shell (SSH) protocol. The composite signatures described combine ML-DSA as the post-quantum part and the elliptic curve signature schemes ECDSA, Ed25519 and Ed448 as the traditional part.

About This Document

This note is to be removed before publishing as an RFC.

The latest revision of this draft can be found at <https://example.com/LATEST>. Status information for this document may be found at <https://datatracker.ietf.org/doc/draft-sun-ssh-composite-sigs/>.

Discussion of this document takes place on the Secure Shell Maintenance (sshm) Working Group mailing list (<mailto:ssh@ietf.org>), which is archived at <https://mailarchive.ietf.org/arch/browse/ssh/>. Subscribe at <https://www.ietf.org/mailman/listinfo/ssh/>.

Source for this draft and an issue tracker can be found at <https://github.com/USER/REPO>.

Status of This Memo

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1. Introduction

The development of quantum computers has raised concern towards traditional asymmetric cryptographic algorithms. A Cryptographically Relevant Quantum Computer (CRQC) will break RSA and elliptic curve signature schemes. There is a need to migrate to quantum-resistant signature schemes.

Recently, NIST published the ML-DSA [FIPS204] algorithm, which is a post-quantum signature scheme. However, when using relatively new cryptographic schemes, the lack of maturing time makes people worry. Many hybrid solutions are thus proposed, which combine a traditional algorithm with a post-quantum algorithm.

[FIPS204] defines both pure ML-DSA and pre-hash ML-DSA. This document only uses pure ML-DSA.

This document describes how to combine ML-DSA with the elliptic curve signature schemes ECDSA, Ed25519 and Ed448 for authentication in the SSH [RFC4251] protocol.

2. Conventions and Definitions

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.

This document is consistent with the terminology for hybrid signatures defined in [I-D.draft-ietf-pquip-pqt-hybrid-terminology].

The key and signature formats follows the notation introduced in [RFC4251], Section 3, and the string data type format follows the notation from [RFC4251], Section 5.

3. Composite Algorithms

A composite algorithm has one post-quantum algorithm, and one traditional algorithm.

3.1. Composite Key Generation

Composite public and private keys are generated by calling the key generation functions of the two component algorithms and concatenating the keys in an order given by the registered composite algorithm.

For the composite algorithms described in this document, the Key Generation process is as follows:

```
(pk_1, sk_1) <- ML-DSA.KeyGen()  
(pk_2, sk_2) <- ECCSigAlg.KeyGen()
```

```
Composite Public Key <- SerializePublicKey(pk_1, pk_2)  
Composite Private Key <- SerializePrivateKey(sk_1, sk_2)
```

It makes use of the serialization routines from [I-D.draft-ietf-lamps-pq-composite-sigs] to obtain the byte string encodings of the composite public and private keys.

ECCSigAlg is an elliptic curve signature scheme, i.e., ECDSA, Ed25519 or Ed448.

3.2. Composite Sign

A composite signature's value MUST include two signature components and MUST be in the same order as the components from the corresponding signing key.

For the composite algorithms described in this document, the signature process of a message M follows Section 4.2.1 of [I-D.draft-ietf-lamps-pq-composite-sigs], with an empty application context string:

```
M' <- Prefix || Domain || 0x00 || r || PH(M)
```

```
sig_1 <- ML-DSA.Sign(sk_1, M', ctx=Domain)
```

```
sig_2 <- ECCSigAlgo.Sign(sk_2, M')
```

```
Composite Signature <- SerializeSignatureValue(r, sig_1, sig_2)
```

It makes use of the serialization routines from [I-D.draft-ietf-lamps-pq-composite-sigs] to obtain the byte string encodings of the composite signature.

A signature randomizer r is used to prevent specific attacks unique to composite signature schemes. More details can be found in [I-D.draft-ietf-lamps-pq-composite-sigs].

The prefix "Prefix" string is defined as in [I-D.draft-ietf-lamps-pq-composite-sigs] as the byte encoding of the string "CompositeAlgorithmSignatures2025", which in hex is 436F6D706F73697465416C676F726974686D5369676E61747572657332303235. It can be used by a traditional verifier to detect if the composite signature has been stripped apart.

The domain separator "Domain" is defined in the same way as [I-D.draft-ietf-lamps-pq-composite-sigs] as the DER encoding of the OID of the specific composite algorithm. The specific values can be found in Table 1.

Key Format identifier	Domain Separator (in Hex encoding)
ssh-mldsa44-es256	060B6086480186FA6B50090103
ssh-mldsa65-es256	060B6086480186FA6B50090108
ssh-mldsa87-es384	060B6086480186FA6B5009010C
ssh-mldsa44-ed25519	060B6086480186FA6B50090102
ssh-mldsa65-ed25519	060B6086480186FA6B5009010B
ssh-mldsa87-ed448	060B6086480186FA6B5009010E

Table 1: Composite Domain Separators

3.3. Composite Verify

The Verify algorithm MUST validate a signature only if all component signatures are successfully validated.

```
(pk_1, pk_2) <- DeserializePublicKey(pk)
(r, sig_1, sig_2) <- DeserializeSignatureValue(sig)
```

```
M' <- Prefix || Domain || 0x00 || r || PH(M)
```

```
if not ML-DSA.Verify(pk_1, M', ctx=Domain)
  output "Invalid signature"
if not ECCSigAlgo.Verify(pk_2, M')
  output "Invalid signature"
if all succeeded, then
  output "Valid signature"
```

It makes use of the serialization routines from [I-D.draft-ietf-lamps-pq-composite-sigs] to obtain the component public keys, the randomizer *r*, and the component signatures.

4. Public Key Algorithm

This section gives the concrete composite signature algorithms and their component algorithms. Their usage within SSH follows Section 6.6 of [RFC4253].

The following table defines a list of algorithms associated with specific PQ/T combinations.

Key Format Identifier	First Algorithm	Second Algorithm	Pre-Hash	Description
ssh-mldsa44-es256	ML-DSA-44	ecdsa-with-SHA256 with secp256r1	id-sha256	Composite Signature with ML-DSA-44 and ECDSA using P-256 curve and SHA-256
ssh-mldsa65-es256	ML-DSA-65	ecdsa-with-SHA256 with secp256r1	id-sha512	Composite Signature with ML-DSA-65 and ECDSA using P-256 curve and SHA-256
ssh-mldsa87-es384	ML-DSA-87	ecdsa-with-SHA384 with secp384r1	id-sha512	Composite Signature with ML-DSA-87 and ECDSA using P-384 curve and SHA-384
ssh-mldsa44-ed25519	ML-DSA-44	Ed25519	id-sha512	Composite Signature with ML-DSA-44 and Ed25519 and SHA-512
ssh-mldsa65-ed25519	ML-DSA-65	Ed25519	id-sha512	Composite Signature with ML-DSA-65 and Ed25519 and SHA-512
ssh-mldsa87-ed448	ML-DSA-87	Ed448	id-sha512	Composite Signature with ML-DSA-87 and Ed448 and SHA-512

+-----+-----+-----+-----+-----+

Table 2: Composite ML-DSA Signature Algorithms for SSH

5. Public Key Format

The key format for all parameter sets defined in this document follows the encoding pattern from [RFC4253], Section 6.6.

string identifier

string key

The 'identifier' is the key format identifier given in Table 2.

The 'key' is the composite public key generated as defined in Section 3.1. It is the concatenation of the public keys of the component schemes.

For ML-DSA, the public keys are defined in [FIPS204].

For ECDSA with curves secp256r1 or secp384r1, the public keys are defined in [RFC5656], Section 3.1. The public key is encoded from an elliptic curve point into an octet string as defined in Section 2.3.3 of [SEC1]; point compression MAY be used.

For Ed25519 and Ed448, the public keys are defined in [RFC8709], Section 6.

The "ssh-mldsa44-es256" key format has the following encoding:

string ssh-mldsa44-es256

string key

Here, 'key' is the concatenation of the 1312-octet ML-DSA-44 public key and the ECDSA public key using the secp256r1 curve.

The "ssh-mldsa65-es256" key format has the following encoding:

string ssh-mldsa65-es256

string key

Here, 'key' is the concatenation of the 1952-octet ML-DSA-65 public key and the ECDSA public key using the secp256r1 curve.

The "ssh-mldsa87-es384" key format has the following encoding:

string ssh-mldsa87-es384

string key

Here, 'key' is the concatenation of the 2592-octet ML-DSA-87 public key and the ECDSA public key using the secp384r1 curve.

The "ssh-mldsa44-ed25519" key format has the following encoding:

string ssh-mldsa44-ed25519

string key

Here, 'key' is the concatenation of the 1312-octet ML-DSA-44 public key and the 32-octet Ed25519 public key.

The "ssh-mldsa65-ed25519" key format has the following encoding:

string ssh-mldsa65-ed25519

string key

Here, 'key' is the concatenation of the 1952-octet ML-DSA-65 public key and the 32-octet Ed25519 public key.

The "ssh-mldsa87-ed448" key format has the following encoding:

string ssh-mldsa87-ed448

string key

Here, 'key' is the concatenation of the 2592-octet ML-DSA-87 public key and the 57-octet Ed448 public key.

6. Signature Format

The signature format for all parameter sets defined in this document follows the encoding pattern defined in Section 6.6 of [RFC4253].

string identifier

string signature

The 'identifier' is the key format identifier given in Section 4.

The 'signature' is the composite signature generated as defined in Section 3.1. It is the concatenation of a randomizer and the signatures of the component schemes.

For ML-DSA, the signatures are defined in [FIPS204].

For ECDSA with curves secp256r1 and secp384r1, the signatures and their encodings are defined in [RFC5656], Section 3.1.2.

For Ed25519 and Ed448, the signature are defined in [RFC8709], Section 6.

The "ssh-mldsa44-es256" signature format has the following encoding:

```
*string* ssh-mldsa44-es256
```

```
*string* signature
```

Here, 'signature' is the concatenation of a 32 bytes randomizer and the 2420-octet ML-DSA-44 signature and the ECDSA signature using the secp256r1 curve.

The "ssh-mldsa65-es256" signature format has the following encoding:

```
*string* ssh-mldsa65-es256
```

```
*string* signature
```

Here, 'signature' is the concatenation of a 32 bytes randomizer and the 3309-octet ML-DSA-65 signature and the ECDSA signature using the secp256r1 curve.

The "ssh-mldsa87-es384" signature format has the following encoding:

```
*string* ssh-mldsa87-es384
```

```
*string* signature
```

Here, 'signature' is the concatenation of a 32 bytes randomizer and the 4627-octet ML-DSA-44 signature and the ECDSA signature using the secp384r1 curve.

The "ssh-mldsa44-ed25519" signature format has the following encoding:

```
*string* ssh-mldsa44-ed25519
```

```
*string* signature
```

Here, 'signature' is the concatenation of a 32 bytes randomizer and the 2420-octet ML-DSA-44 signature and the 64-octet Ed25519 signature.

The "ssh-mldsa65-ed25519" signature format has the following encoding:

```
*string* ssh-mldsa65-ed25519
```

```
*string* signature
```

Here, 'signature' is the concatenation of a 32 bytes randomizer and the 3309-octet ML-DSA-44 signature and the 64-octet Ed25519 signature.

The "ssh-mldsa87-ed448" signature format has the following encoding:

```
*string* ssh-mldsa87-ed448
```

```
*string* signature
```

Here, 'signature' is the concatenation of a 32 bytes randomizer and the 4627-octet ML-DSA-44 signature and the 114-octet Ed448 signature.

7. Security Considerations

The Security Considerations section of [RFC4251] also applies to this document.

The user can refer to [FIPS204] for security issues related to the ML-DSA post-quantum component of the composite algorithm and to the Security Considerations sections of [RFC5656] and [RFC8709] for the traditional component.

For the specific security issues raising from the use of a hybrid composite signature scheme, the user can refer to [I-D.draft-ietf-pquip-hybrid-signature-spectrums].

For more information about hybrid composite signature schemes and the different hybrid combinations that appear in this document, the user can read [I-D.draft-ietf-lamps-pq-composite-sigs].

8. IANA Considerations

IANA is requested to add the following entries to "Public Key Algorithm Names" in the "Secure Shell (SSH) Protocol Parameters" registry [IANA.SSH]:

Public Key Algorithm Name	Key Format	Reference
ssh-mldsa44-es256	ssh-mldsa44-es256	THIS-RFC
ssh-mldsa65-es256	ssh-mldsa65-es256	THIS-RFC
ssh-mldsa87-es384	ssh-mldsa87-es384	THIS-RFC
ssh-mldsa44-ed25519	ssh-mldsa44-ed25519	THIS-RFC
ssh-mldsa65-ed25519	ssh-mldsa65-ed25519	THIS-RFC
ssh-mldsa87-ed448	ssh-mldsa87-ed448	THIS-RFC

Table 3: SSH Public Key Code Points

9. References

9.1. Normative References

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- [RFC8709] Harris, B. and L. Velvindron, "Ed25519 and Ed448 Public Key Algorithms for the Secure Shell (SSH) Protocol", RFC 8709, DOI 10.17487/RFC8709, February 2020, <<https://www.rfc-editor.org/rfc/rfc8709>>.

9.2. Informative References

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