

Javascript Object Signing and Encryption
Internet-Draft
Intended status: Standards Track
Expires: 31 August 2026

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27 February 2026

PQ/T Hybrid Composite Signatures for JOSE and COSE
draft-ietf-jose-pq-composite-sigs-01

Abstract

This document describes JSON Object Signing and Encryption (JOSE) and CBOR Object Signing and Encryption (COSE) serializations for PQ/T hybrid composite signatures. The composite algorithms described combine ML-DSA as the post-quantum component and either ECDSA or EdDSA as the traditional component.

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://ietf-wg-jose.github.io/draft-ietf-jose-pq-composite-sigs/draft-ietf-jose-pq-composite-sigs.html>. Status information for this document may be found at <https://datatracker.ietf.org/doc/draft-ietf-jose-pq-composite-sigs/>.

Discussion of this document takes place on the Javascript Object Signing and Encryption Working Group mailing list (<mailto:jose@ietf.org>), which is archived at <https://mailarchive.ietf.org/arch/browse/jose/>. Subscribe at <https://www.ietf.org/mailman/listinfo/jose/>.

Source for this draft and an issue tracker can be found at <https://github.com/ietf-wg-jose/draft-ietf-jose-pq-composite-sigs>.

Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

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1. Introduction

The impact of a potential Cryptographically Relevant Quantum Computer (CRQC) on algorithms whose security is based on mathematical problems such as integer factorisation or discrete logarithms over finite fields or elliptic curves raises the need for new algorithms that are perceived to be secure against CRQC as well as classical computers. Such algorithms are called post-quantum, while algorithms based on integer factorisation or discrete logarithms are called traditional.

While switching from a traditional algorithm to a post-quantum one intends to strengthen the security against an adversary possessing a quantum computer, the lack of maturing time of post-quantum algorithms compared to traditional algorithms raises uncertainty about their security.

Thus, the joint use of a traditional algorithm and a post-quantum algorithm in protocols represents a solution to this problem by providing security as long as at least one of the traditional or post-quantum components remains secure.

This document describes JSON Object Signing and Encryption (JOSE) and CBOR Object Signing and Encryption (COSE) serializations for hybrid composite signatures. The composite algorithms described combine ML-DSA as the post-quantum component and either ECDSA or EdDSA as the traditional component.

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 follows the terminology for post-quantum hybrid schemes defined in [I-D.draft-ietf-pquip-pqt-hybrid-terminology].

This section recalls some of this terminology, but also adds other definitions used throughout the whole document:

"Asymmetric Traditional Cryptographic Algorithm": An asymmetric cryptographic algorithm based on integer factorisation, finite field discrete logarithms, elliptic curve discrete logarithms, or related mathematical problems. A related mathematical problem is one that can be solved by solving the integer factorisation, finite field discrete logarithm or elliptic curve discrete logarithm problem. Where there is little risk of confusion asymmetric traditional cryptographic algorithms can also be referred to as traditional algorithms for brevity.

"Post-Quantum Algorithm": An asymmetric cryptographic algorithm that is intended to be secure against attacks using quantum computers as well as classical computers. As with all cryptography, it always remains the case that attacks, either quantum or classical, may be found against post-quantum algorithms. Therefore it should not be assumed that just because an algorithm is designed to provide post-quantum security it will not be compromised.

"Post-Quantum Traditional (PQ/T) Hybrid Scheme": A multi-algorithm scheme where at least one component algorithm is a post-quantum algorithm and at least one is a traditional algorithm.

"PQ/T Hybrid Digital Signature": A multi-algorithm digital signature scheme made up of two or more component digital signature algorithms where at least one is a post-quantum algorithm and at least one is a traditional algorithm.

"Composite Algorithm": An algorithm which is a sequence of two component algorithms, as defined in [I-D.draft-ietf-lamps-pq-composite-sigs].

"Component Algorithm": Each cryptographic algorithm that forms part of a cryptographic scheme.

3. Algorithm Key Pair (AKP) Type

This document makes use of the Algorithm Key Pair (AKP) type which is defined in [I-D.draft-ietf-cose-dilithium].

As a reminder, the AKP type is used to express public and private keys for use with algorithms. The parameters for public and private keys contain byte strings.

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

The process to compute JWK Thumbprint and COSE Key Thumbprint as described in [RFC7638] and [RFC9679] is detailed in [I-D.draft-ietf-cose-dilithium].

4. Composite Signature Algorithm

The structures of the composite keys and composite signatures follow an approach similar to [I-D.draft-ietf-lamps-pq-composite-sigs]. The composite design is chosen so that composite keys and signatures can be used as a drop-in replacement in JOSE / COSE object formats. This section gives some details about their construction.

4.1. 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.

Composite Public Key <- Public Key of the 1st Algorithm || Public Key of the 2nd Algorithm and

Composite Private Key <- Private Key of the 1st Algorithm || Private Key of the 2nd Algorithm

For the composite algorithms described in this document (ML-DSA with ECDSA or EdDSA), the Key Generation process is as follows:


```
Composite-ML-DSA.KeyGen() -> (pk, sk)
```

1. Generate component keys

```
mldsaseed = Random(32)
(mldsapK, mldsasK) = ML-DSA.KeyGen_internal(mldsaseed)

(tradPK, tradSK) = Trad.KeyGen()
```

2. Check for component key generation failure

```
if NOT (mldsapK, mldsasK) or NOT (tradPK, tradSK):
    output "Key generation error"
```

3. Serialize keys into composite form

```
pk <- SerializePublicKey(mldsapK, tradPK)
sk <- SerializePrivateKey(mldsaseed, tradSK)
```

4. Output the composite public and private keys

```
return (pk, sk)
```

As in [I-D.draft-ietf-lamps-pq-composite-sigs], this keygen routine uses the seed-based ML-DSA.KeyGen_internal defined in Algorithm 6 of [FIPS.204].

This document 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. These encodings are then directly used with the AKP Key Type. For more information, see the SerializePublicKey, DeserializePublicKey, SerializePrivateKey and DeserializePrivateKey algorithms from [I-D.draft-ietf-lamps-pq-composite-sigs].

Point compression for the ECDSA or EdDSA component is not performed for the AKP JSON Web Key Type but can be performed for the AKP COSE Key Type.

In this document, as in [I-D.draft-ietf-cose-dilithium], the ML-DSA private key MUST be a 32-bytes seed.

4.2. Composite Sign

When signing a message M with the composite Sign algorithm, the signature combiner prepends a prefix as well as a label value specific to the composite algorithm used to bind the two component signatures to the composite algorithm and achieve weak non-separability, as defined in [I-D.draft-ietf-pquip-hybrid-signature-spectrums].

However, only the pure ML-DSA component algorithm is used internally.

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

A composite signature for the message M is generated by:

- * computing the pre-hash of the message M;
- * concatenating the prefix, the label, a byte 0x00 and the pre-hash;
- * encoding the resulting message;
- * calling the two signature component algorithms on this new message;
- * concatenating the two output signatures.

For the composite algorithms described in this document (ML-DSA with ECDSA or EdDSA), the signature process of a message M is as follows:


```
Composite-ML-DSA.Sign(sk, M) -> s
```

1. Compute the Message representative M'

```
M' <- Prefix || Label || 0x00 || PH(M)
M' <- Encode(M')
```

2. Separate the private key sk into component keys and re-generate the ML-DSA key from seed

```
(mldsaseed, tradSK) = DeserializePrivateKey(sk)
(_, mldsask) = ML-DSA.KeyGen_internal(mldsaseed)
```

3. Generate the two component signatures

```
mldsasig <- ML-DSA.Sign(mldsask, M', ctx=Label)
tradsig <- Trad.Sign(tradSK, M')
```

4. If either ML-DSA.Sign() or Trad.Sign() return an error, then this process MUST return an error.

```
if NOT mldsasig or NOT tradsig:
    output "Signature generation error"
```

5. Output the encoded composite signature value.

```
s <- SerializeSignatureValue(mldsasig, tradsig)
return s
```

The serialization routines from [I-D.draft-ietf-lamps-pq-composite-sigs] are again used to obtain the byte string encoding of the composite signature. The SerializeSignatureValue routine simply concatenates the fixed-length ML-DSA signature value and the signature value from the traditional algorithm. For more information, see the SerializeSignatureValue and DeserializeSignatureValue algorithms from [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.

A signature label "Label" is defined in the same way as [I-D.draft-ietf-lamps-pq-composite-sigs]. It is specific to each composite algorithm. Additionally, the composite label is passed into the underlying ML-DSA primitive as the ctx. Signature Label values can be found in Table 4.

Similarly to [I-D.draft-ietf-cose-dilithium] which indicates that the ctx parameter MUST be the empty string, the application context passed in to the composite signature algorithm MUST be the empty string. To align with the structure of the [I-D.draft-ietf-lamps-pq-composite-sigs] combiner, the byte 0x00 is appended in the message M' after the label to indicate the context has length 0. However, a second non-empty context, defined as the label, is passed down into the underlying pure ML-DSA component algorithm, to bind the Composite-ML-DSA algorithm used.

Table 2 (resp. Table 3) indicates the pre-hash algorithms to use for JOSE (resp. COSE).

For JOSE (resp. COSE), M' is base64url-encoded (resp. binary encoded) before signature computations.

4.3. Composite Verify

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

The verification process of a signature sig is as follows:

- * separate the composite public key into the component public keys;
- * separate the composite signature into its 2 component signatures;
- * compute the message M' from the message M whose signature is to be verified;
- * encode the resulting message M';
- * verify each component signature.

Composite-ML-DSA.Verify(pk, M, s) -> true or false

1. Separate the keys and signatures

```
(mldsapK, tradPK) <- DeserializePublicKey(pk)
(mldsasig, tradSig) <- DeserializeSignatureValue(s)
```

If Error during deserialization, or if any of the component keys or signature values are not of the correct type or length for the given component algorithm then output "Invalid signature" and stop.

2. Compute the message representative M'

```
M' <- Prefix || Label || 0x00 || PH(M)
M' <- Encode(M')
```

3. Check each component signature individually, according to its algorithm specification.

```
if NOT ML-DSA.Verify(mldsapK, M', ctx=Label)
  output "Invalid signature"
if NOT Trad.Verify(tradPK, M')
  output "Invalid signature"
if all succeeded, then
  output "Valid signature"
```

The DeserializePublicKey and DeserializeSignatureValue serialization routines from [I-D.draft-ietf-lamps-pq-composite-sigs] are used to get the component public keys and the component signatures. For more information, see the DeserializePublicKey and DeserializeSignatureValue algorithms from [I-D.draft-ietf-lamps-pq-composite-sigs].

4.4. Encoding Rules

In each combination, the byte streams of the keys and of the signatures are directly concatenated.

Signature of the 1st Algorithm || Signature of the 2nd Algorithm

Since all combinations presented in this document start with the ML-DSA algorithm and the key or signature sizes are fixed as defined in [FIPS.204], it is unambiguous to encode or decode a composite key or signature.

Table 1 lists sizes of the three parameter sets of the ML-DSA algorithm.

	Private Key (seed)	Private Key	Public Key	Signature Size
ML-DSA-44	32	2560	1312	2420
ML-DSA-65	32	4032	1952	3309
ML-DSA-87	32	4896	2592	4627

Table 1: Sizes (in bytes) of keys and signatures of ML-DSA

Note that the seed is always 32 bytes, and that ML-DSA.KeyGen_internal from [FIPS.204] is called to produce the expanded private key from the seed, whose size corresponds to the sizes of the private key in the table above.

5. Composite Signature Instantiations

The ML-DSA signature scheme supports three possible parameter sets, each of which corresponding to a specific security strength. See [FIPS.204] for more considerations on that matter.

The traditional signature algorithm for each combination in Table 2 and Table 3 was chosen to match the security level of the ML-DSA post-quantum component.

The [FIPS.204] specification defines both pure and pre-hash modes for ML-DSA, referred to as "ML-DSA" and "HashML-DSA" respectively. This document only specifies a single mode which is similar in construction to HashML-DSA. However, because the pre-hashing is done at the composite level, only the pure ML-DSA algorithm is used as the underlying ML-DSA primitive.

5.1. JOSE algorithms

The following table defines a list of algorithms associated with specific PQ/T combinations to be registered in [IANA.JOSE].

Name	First Algorithm	Second Algorithm	Pre-Hash	Description
ML-DSA-44-ES256	ML-DSA-44	ecdsa-with-SHA256 with secp256r1	SHA256	Composite Signature with ML-DSA-44 and

				ECDSA using P-256 curve and SHA256
ML-DSA-65-ES256	ML-DSA-65	ecdsa-with-SHA256 with secp256r1	SHA512	Composite Signature with ML- DSA-65 and ECDSA using P-256 curve and SHA256
ML-DSA-87-ES384	ML-DSA-87	ecdsa-with-SHA384 with secp384r1	SHA512	Composite Signature with ML- DSA-87 and ECDSA using P-384 curve and SHA384
ML-DSA-44-Ed25519	ML-DSA-44	Ed25519	SHA512	Composite Signature with ML- DSA-44 and Ed25519
ML-DSA-65-Ed25519	ML-DSA-65	Ed25519	SHA512	Composite Signature with ML- DSA-65 and Ed25519
ML-DSA-87-Ed448	ML-DSA-87	Ed448	SHAKE256	Composite Signature with ML- DSA-87 and Ed448

Table 2: JOSE Composite Signature Algorithms for ML-DSA

Examples can be found in Appendix A.1.

5.2. COSE algorithms

The following table defines a list of algorithms associated with specific PQ/T combinations to be registered in [IANA.COSE].

Name	COSE Value	First Algorithm	Second Algorithm	Pre-Hash	Description
ML-DSA-44-ES256	TBD (request assignment -51)	ML-DSA-44	ecdsa-with-SHA256 with secp256r1	SHA256	Composite Signature with ML-DSA-44 and ECDSA using P-256 curve and SHA256
ML-DSA-65-ES256	TBD (request assignment -52)	ML-DSA-65	ecdsa-with-SHA256 with secp256r1	SHA512	Composite Signature with ML-DSA-65 and ECDSA using P-256 curve and SHA256
ML-DSA-87-ES384	TBD (request assignment -53)	ML-DSA-87	ecdsa-with-SHA384 with secp384r1	SHA512	Composite Signature with ML-DSA-87 and ECDSA using P-384 curve and SHA384
ML-DSA-44-Ed25519	TBD (request assignment -54)	ML-DSA-44	Ed25519	SHA512	Composite Signature with ML-DSA-44 and Ed25519
ML-DSA-65-Ed25519	TBD (request assignment -55)	ML-DSA-65	Ed25519	SHA512	Composite Signature with ML-DSA-65 and Ed25519
ML-DSA-87-Ed448	TBD (request assignment -56)	ML-DSA-87	Ed448	SHAKE256	Composite Signature with ML-DSA-87 and Ed448

Table 3: COSE Composite Signature Algorithms for ML-DSA

Examples can be found in Appendix A.2.

5.3. Composite Labels for JOSE and COSE

The JOSE and COSE composite label values are listed in Table 4.

They are represented here as ASCII strings, but implementers MUST convert them to byte strings using the obvious ASCII conversions prior to concatenating them with other byte values, as in [I-D.draft-ietf-lamps-pq-composite-sigs].

=====		
=====+		
"alg"	Label (in ASCII)	Label (in Hex encoding)
Header		
Parameter		
+		
=====+		
ML-DSA-62D534841323536	COMPSIG-MLDSA44-ECDSA-	434F4D505349472D4D4C44534134342D45434453412D5032353
44-ES256	P256-SHA256	
+		
-----+		
ML-DSA-62D534841353132	COMPSIG-MLDSA65-ECDSA-	434F4D505349472D4D4C44534136352D45434453412D5032353
65-ES256	P256-SHA512	
+		
-----+		
ML-DSA-42D534841353132	COMPSIG-MLDSA87-ECDSA-	434F4D505349472D4D4C44534138372D45434453412D5033383
87-ES384	P384-SHA512	
+		
-----+		
ML-DSA-841353132	COMPSIG-	434F4D505349472D4D4C44534134342D456432353531392D534
44-Ed25519	MLDSA44-Ed25519-SHA512	
+		
-----+		
ML-DSA-841353132	COMPSIG-	434F4D505349472D4D4C44534136352D456432353531392D534
65-Ed25519	MLDSA65-Ed25519-SHA512	
+		
-----+		
ML-DSA-B45323536	COMPSIG-	434F4D505349472D4D4C44534138372D45643434382D5348414
87-Ed448	MLDSA87-Ed448-SHAKE256	
+		
-----+		

Table 4: JOSE/COSE Composite Label Values

6. Security Considerations

The security considerations of the component algorithms (ML-DSA, ECDSA, and EdDSA) as described in [FIPS.204], [RFC6090], and [RFC8032] apply to this document.

Similarly, the security considerations relative to the JWS, JWK, and COSE structures [RFC7515], [RFC7517] and [RFC9053] apply to this document.

In addition, the following considerations specific to the composite design and its use in JOSE/COSE must be taken into account.

6.1. Hybrid Security and Quantum Resistance

An important objective of Composite ML-DSA is to provide protection against CRQCs. Under a CRQC, traditional signature algorithms (RSA, ECDSA, and EdDSA) are vulnerable to private-key recovery, enabling attackers to forge arbitrary JWS objects or COSE_Sign/COSE_Sign1 structures and fully impersonate the signer.

By requiring the successful verification of both the ML-DSA component and the traditional component, this construction ensures:

- * ***Dual-Algorithm Security:*** An adversary that compromises only one of the component algorithms cannot produce cryptographically protected JOSE/COSE objects as long as the other component remains secure.
- * ***Impersonation Prevention:*** In particular, this prevents JOSE/COSE signature spoofing and impersonation attacks even if the traditional signature component is compromised.
- * ***EUF-CMA Security:*** The scheme provides existential unforgeability under chosen-message attack (EUF-CMA) provided that at least one component algorithm is EUF-CMA secure and the pre-hash function PH is collision-resistant. This is the case for all combinations present in this document.

6.2. Component Key Integrity and Reuse

To maintain the security properties of the composite scheme, strict key management is required:

- * ***No Key Reuse:*** To avoid key reuse, when generating a new composite key, the generation functions for both component algorithms MUST be executed. Moreover, compliant parties MUST NOT use, import, or export component keys that are used in other contexts, combinations, or as standalone keys.
- * ***Certificate-Level Protection:*** The integrity of the composite public key is protected through mandatory validation of the certificate header (the x5c header in JOSE per [RFC7515] or the x5chain header in COSE per [RFC9360]). Because the certificate itself is protected by a composite signature, an attacker cannot forge a fake certificate to swap a public key even if the traditional algorithm is broken. These specifications require the validation of the composite signature on the certificate itself.

6.3. Domain Separation and Non-Separability

This document uses a signature combiner that prepends a fixed Prefix and a specific Label to the message representative M' .

- * ***Non-separability:*** By binding the two component signatures to the specific composite algorithm, the composite scheme achieves "weak non-separability" as defined in [I-D.draft-ietf-pquip-hybrid-signature-spectrums].
- * ***Cross-Algorithm Prevention:*** The unique label, specific to each composite algorithm, ensures that signatures cannot be removed from the composite and used in other contexts.

For more information about the security properties relative to the signature combiner, the user can read [I-D.draft-ietf-lamps-pq-composite-sigs].

6.4. Security Objectives and Limitations

In JOSE/COSE, the security objective of digital signatures is to ensure that only an authorized signer can produce a valid signature over a given protected header and payload.

Therefore, users should be aware of specific scenarios where Composite ML-DSA may not be appropriate:

- * ***SUF-CMA Security:*** While the construction is SUF-CMA secure against classical adversaries when paired with Ed25519 or Ed448, it is not SUF-CMA secure against quantum adversaries (who can break the traditional component). Consequently, applications for which SUF-CMA security is a strict requirement MUST NOT use Composite ML-DSA.
- * ***Non-repudiation:*** Composite ML-DSA is not suitable for use cases that require non-repudiation or signature uniqueness guarantees. In the JOSE/COSE threat model described above, existential unforgeability under chosen-message attack (EUF-CMA) is sufficient to meet the intended security goals.
- * ***Replay Protection:*** This is not handled by the signature itself but must be addressed through claims such as exp, nbf, and jti in JOSE (Section 4.1 of [RFC7519]) or the equivalent claims in COSE (Section 3 of [RFC8392]).

7. IANA Considerations

7.1. JOSE Algorithms

The following values of the JWS "alg" (algorithm) are requested to be added to the "JSON Web Signature and Encryption Algorithms" registry. They are represented following the registration template provided in [RFC7518].

7.1.1. ML-DSA-44-ES256

- * Algorithm Name: ML-DSA-44-ES256
- * Algorithm Description: Composite Signature with ML-DSA-44 and ECDSA using P-256 curve and SHA-256
- * Algorithm Usage Location(s): alg
- * JOSE Implementation Requirements: Optional
- * Change Controller: IETF
- * Specification Document(s): n/a
- * Algorithm Analysis Documents(s): TBD

7.1.2. ML-DSA-65-ES256

- * Algorithm Name: ML-DSA-65-ES256
- * Algorithm Description: Composite Signature with ML-DSA-65 and ECDSA using P-256 curve and SHA-256
- * Algorithm Usage Location(s): alg
- * JOSE Implementation Requirements: Optional
- * Change Controller: IETF
- * Specification Document(s): n/a
- * Algorithm Analysis Documents(s): TBD

7.1.3. ML-DSA-87-ES384

- * Algorithm Name: ML-DSA-87-ES384

- * Algorithm Description: Composite Signature with ML-DSA-87 and ECDSA using P-384 curve and SHA-384
- * Algorithm Usage Location(s): alg
- * JOSE Implementation Requirements: Optional
- * Change Controller: IETF
- * Specification Document(s): n/a
- * Algorithm Analysis Documents(s): TBD

7.1.4. ML-DSA-44-Ed25519

- * Algorithm Name: ML-DSA-44-Ed25519
- * Algorithm Description: Composite Signature with ML-DSA-44 and Ed25519 using SHA-512
- * Algorithm Usage Location(s): alg
- * JOSE Implementation Requirements: Optional
- * Change Controller: IETF
- * Specification Document(s): n/a
- * Algorithm Analysis Document(s): TBD

7.1.5. ML-DSA-65-Ed25519

- * Algorithm Name: ML-DSA-65-Ed25519
- * Algorithm Description: Composite Signature with ML-DSA-65 and Ed25519 using SHA-512
- * Algorithm Usage Location(s): alg
- * JOSE Implementation Requirements: Optional
- * Change Controller: IETF
- * Specification Document(s): n/a
- * Algorithm Analysis Document(s): TBD

7.1.6. ML-DSA-87-Ed448

- * Algorithm Name: ML-DSA-87-Ed448
- * Algorithm Description: Composite Signature with ML-DSA-87 and Ed448 using SHAKE-256
- * Algorithm Usage Location(s): alg
- * JOSE Implementation Requirements: Optional
- * Change Controller: IETF
- * Specification Document(s): n/a
- * Algorithm Analysis Document(s): TBD

7.2. COSE Algorithms

The following values are requested to be added to the "COSE Algorithms" registry. They are represented following the registration template provided in [RFC9053], [RFC9054].

7.2.1. ML-DSA-44-ES256

- * Name: ML-DSA-44-ES256
- * Value: TBD (request assignment -51)
- * Description: Composite Signature with ML-DSA-44 and ECDSA using P-256 curve and SHA-256
- * Capabilities: [kty]
- * Change Controller: IETF
- * Reference: n/a
- * Recommended: Yes

7.2.2. ML-DSA-65-ES256

- * Name: ML-DSA-65-ES256
- * Value: TBD (request assignment -52)
- * Description: Composite Signature with ML-DSA-65 and ECDSA using P-256 curve and SHA-256

- * Capabilities: [kty]
- * Change Controller: IETF
- * Reference: n/a
- * Recommended: Yes

7.2.3. ML-DSA-87-ES384

- * Name: ML-DSA-87-ES384
- * Value: TBD (request assignment -53)
- * Description: Composite Signature with ML-DSA-87 and ECDSA using P-384 curve and SHA-384
- * Capabilities: [kty]
- * Change Controller: IETF
- * Reference: n/a
- * Recommended: Yes

7.2.4. ML-DSA-44-Ed25519

- * Name: ML-DSA-44-Ed25519
- * Value: TBD (request assignment -54)
- * Description: Composite Signature with ML-DSA-44 and Ed25519 using SHA-512
- * Capabilities: [kty]
- * Change Controller: IETF
- * Reference: n/a
- * Recommended: Yes

7.2.5. ML-DSA-65-Ed25519

- * Name: ML-DSA-65-Ed25519
- * Value: TBD (request assignment -55)

- * Description: Composite Signature with ML-DSA-65 and Ed25519 using SHA-512
- * Capabilities: [kty]
- * Change Controller: IETF
- * Reference: n/a
- * Recommended: Yes

7.2.6. ML-DSA-87-Ed448

- * Name: ML-DSA-87-Ed448
- * Value: TBD (request assignment -56)
- * Description: Composite Signature with ML-DSA-87 and Ed448 using SHAKE-256
- * Capabilities: [kty]
- * Change Controller: IETF
- * Reference: n/a
- * Recommended: Yes

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Appendix A. Examples

A.1. JOSE


```
{
  "mldsa_seed": "0000000000000000000000000000000000000000000000000000000000000000",
  "ecdsha_d": "0000000000000000000000000000000000000000000000000000000000000001",
  "jwk": {
    "kid": "hV-Q1oYd3jbigYtSV3Uz4iidxUleJ_0A3otBX1v793E",
    "kty": "AKP",
    "alg": "ML-DSA-44-ES256",
    "pub": "unH59k4RuutY-pxvu24U5h8YZD2rSVtHU5qRZsoBmBMcRPgmu9VuNOVdteXilzNIXjnjQJg_GAAxep
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Figure 6: ML-DSA-87-Ed448

A.2. COSE

[illegible]

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[illegible]


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[illegible]


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Figure 9: ML-DSA-65-ES256

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}

Figure 12: ML-DSA-87-Ed448

Appendix B. Acknowledgments

We thank Orie Steele for his valuable comments on this document.

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