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Composite ML-DSA for use in X.509 Public Key Infrastructure
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Abstract

This document defines combinations of ML-DSA [FIPS.204] in hybrid with traditional algorithms RSASSA-PKCS1-v1.5, RSASSA-PSS, ECDSA, Ed25519, and Ed448. These combinations are tailored to meet regulatory guidelines. Composite ML-DSA is applicable in applications that uses X.509 or PKIX data structures that accept ML-DSA, but where the operator wants extra protection against breaks or catastrophic bugs in ML-DSA, and where EUF-CMA-level security is acceptable.

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

Discussion of this document takes place on the LAMPS Working Group mailing list (mailto:spams@ietf.org), which is archived at https://datatracker.ietf.org/wg/lamps/about/. Subscribe at https://www.ietf.org/mailman/listinfo/spams/.

Source for this draft and an issue tracker can be found at https://github.com/lamps-wg/draft-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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Table of Contents

1. Changes since -07 (WGLC) 3
2. Introduction 5
  2.1. Conventions and Terminology 7
  2.2. Composite Design Philosophy 8
3. Overview of the Composite ML-DSA Signature Scheme 9
  3.1. Pre-hashing 10
  3.2. Prefix, Label and CTX 11
4. Composite ML-DSA Functions 12
  4.1. Key Generation 12
  4.2. Sign 14
  4.3. Verify 16
5. Serialization 19
  5.1. SerializePublicKey and DeserializePublicKey 20
  5.2. SerializePrivateKey and DeserializePrivateKey 23
  5.3. SerializeSignatureValue and DeserializeSignatureValue . . 24
6. Use within X.509 and PKIX 27
  6.1. Encoding to DER 27
  6.2. Key Usage Bits 27
  6.3. ASN.1 Definitions 28
7. Algorithm Identifiers and Parameters 30

7.1. RSASSA-PSS Parameters 37
7.2. Rationale for choices 38
8. ASN.1 Module 39
9. IANA Considerations 46
9.1. Object Identifier Allocations 46
9.1.1. Module Registration 46
9.1.2. Object Identifier Registrations 46
10. Security Considerations 49
10.1. Why Hybrids? 50
10.2. EUF-CMA, SUF-CMA and non-separability 50
10.2.1. EUF-CMA 51
10.2.2. SUF-CMA 52
10.2.3. Non-separability 52
10.3. Key Reuse 53
10.4. Use of Prefix for attack mitigation 54
10.5. Policy for Deprecated and Acceptable Algorithms 55
11. Implementation Considerations 55
11.1. FIPS certification 55
11.2. Backwards Compatibility 56
11.3. Profiling down the number of options 57
11.4. External Pre-hashing 58
12. References 59
12.1. Normative References 59
12.2. Informative References 62
Appendix A. Maximum Key and Signature Sizes 64
Appendix B. Component Algorithm Reference 66
Appendix C. Component AlgorithmIdentifiers for Public Keys and Signatures 68
Appendix D. Message Representative Examples 76
Appendix E. Test Vectors 78
Appendix F. Intellectual Property Considerations 201
Appendix G. Contributors and Acknowledgements 201
Authors' Addresses 202

1. Changes since -07 (WGLC)

Interop-affecting changes:

* Removed the randomizer, reverting the signature combiner construction to be similar to the HashComposite construction from -05.

* Fixed the ASN.1 module for the pk-CompositeSignature and sa-CompositeSignature to indicate no ASN.1 wrapping is used. This simply clarifies the intended encoding but could be an interop-affecting change for implementations that built encoders / decoders from the ASN.1 and ended up with a non-intended encoding.

* Aligned the hash function used for the RSA component to the RSA key size (Thanks Dan!).

* Changed the OID-based Domain Separators into HPKE-style signature label strings to match draft-irtf-cfrg-concrete-hybrid-kems-00.

* Updated to new prototype OIDs since it is not binary compatible with the previous release.

* Dan Van Geest correctly pointed out that in ECPrivateKey (RFC5915), the parameters are not optional. They have been added to the private keys in the test vectors.

* The Ed25519 and Ed448 private keys had been wrapped in OCTET STRING to match CurvePrivateKey (RFC8410). This has been changed to 32/57 byte raw.

Editorial changes:

* Incorporated the feedback from IETF 123, clarifying the pubic, private key and signature encodings.

* Many minor editorial fixes based on comments from the working group.

* Adjusted the Security Considerations about EUF-CMA and Non-Separability to match the removal of the randomizer.

* Clarified that the ECDSA public key is raw X9.62 with no OCTET STRING wrapping. Test vectors were already correct.

A full review was performed of the encoding of each component:

* ML-DSA:

  - pub key, priv key, sig value: Raw, according to FIPS 204. Test vectors appear to match.

* RSA:

  - pub key: ASN.1 RSAPublicKey. Test vectors appear to match (manually inspected "id-MLDSA44-RSA2048-PSS-SHA256").

  - priv key: RSAPrivateKey (CRT). Test vectors appear to match (manually inspected "id-MLDSA44-RSA2048-PSS-SHA256").

- sig value: length of sig for "id-MLDSA44-RSA2048-PSS-SHA256" and "id-MLDSA44-RSA2048-PKCS15-SHA256" verified to be 256 bytes, format hard to manually inspect.

* ECDSA: Inspecting test vectors for "id-MLDSA44-ECDSA-P256-SHA256"

  - pub key: The wording of the pub key format in Section 2.2 of RFC5480 is extremely confusing in how it would apply outside of a SubjectPublicKeyInfo. The Composite author’s interpretation was for it to be raw X9.62, which is what is already in the test vectors: verified to be raw X9.62 with a leading byte of 0x04 (uncompressed). Normative text in Section 5 is incorrect and has been changed.

  - priv key: This is the ASN.1 structure ECPrivateKey [RFC5915] as intended, however, as Dan Van Geest points out, the parameters field, while marked OPTIONAL is actually required by Section 3 of RFC5915. That means the private keys here are invalid. This has been corrected in the test vectors.

  - sig value: This is an ASN.1 Ecdsa-Sig-Value [RFC3279] as intended.

* EdDSA:

  - pub key: 32 byte raw.

  - priv key: Had been wrapped in OCTET STRING to match CurvePrivateKey (RFC8410). This has been changed to 32/57 byte raw.

  - sig value: 64 byte raw.

2. Introduction

The advent of quantum computing poses a significant threat to current cryptographic systems. Traditional cryptographic signature algorithms such as RSA, DSA and its elliptic curve variants are vulnerable to quantum attacks. During the transition to post-quantum cryptography (PQC), there is considerable uncertainty regarding the robustness of both existing and new cryptographic algorithms. While we can no longer fully trust traditional cryptography, we also cannot immediately place complete trust in post-quantum replacements until they have undergone extensive scrutiny and real-world testing to uncover and rectify both algorithmic weaknesses as well as implementation flaws across all the new implementations.

Unlike previous migrations between cryptographic algorithms, this migration gives us the foresight that Traditional cryptographic algorithms will be broken in the future, with the Traditional algorithms remaining strong in the interim, the only uncertainty is around the timing. But there are also some novel challenges. For instance, the aggressive migration timelines may require deploying PQC algorithms before their implementations have been fully hardened or certified, and dual-algorithm data protection may be desirable over a longer time period to hedge against CVEs and other implementation flaws in the new implementations.

Cautious implementers may opt to combine cryptographic algorithms in such a way that an adversary would need to break all of them simultaneously to compromise the protected data. These mechanisms are referred to as Post-Quantum/Traditional (PQ/T) Hybrids [RFC9794].

Certain jurisdictions are already recommending or mandating that PQC lattice schemes be used exclusively within a PQ/T hybrid framework. The use of a composite scheme provides a straightforward implementation of hybrid solutions compatible with (and advocated by) some governments and cybersecurity agencies [BSI2021], [ANSSI2024].

Another motivation for using PQ/T Hybrids is regulatory compliance; for example, in some situations it might be possible to add Post-Quantum, via a PQ/T Hybrid, to an already audited and compliant solution without invalidating the existing certification, whereas a full replacement of the Traditional cryptography would almost certainly incur regulatory and compliance delays. In other words, PQ/T Hybrids can allow for deploying Post-Quantum before the PQ modules and operational procedures are fully audited and certified. This, more than any other requirement, is what motivates the large number of algorithm combinations in this specification: the intention is to provide a stepping-stone off of which ever cryptographic algorithm(s) an organization might have deployed today.

This specification defines a specific instantiation of the PQ/T Hybrid paradigm called "composite" where multiple cryptographic algorithms are combined to form a single signature algorithm presenting a single public key and signature value such that it can be treated as a single atomic algorithm at the protocol level; a property referred to as "protocol backwards compatibility" since it can be applied to protocols that are not explicitly hybrid-aware. Composite algorithms address algorithm strength uncertainty because the composite algorithm remains some security so long as one of its components remains strong. Concrete instantiations of composite ML-DSA algorithms are provided based on ML-DSA, RSASSA-PKCS1-v1.5, RSASSA-PSS, ECDSA, Ed25519, and Ed448. Backwards compatibility in the sense of upgraded systems continuing to inter-operate with legacy

systems is not directly covered in this specification, but is the subject of Section 11.2. The idea of a composite was first presented in [Bindel2017].

Composite ML-DSA is applicable in PKIX-related applications that would otherwise use ML-DSA and where EUF-CMA-level security is acceptable.

2.1. Conventions and 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. These words may also appear in this document in lower case as plain English words, absent their normative meanings.

This specification is consistent with the terminology defined in [RFC9794]. In addition, the following terminology is used throughout this specification:

ALGORITHM: The usage of the term "algorithm" within this specification generally refers to any function which has a registered Object Identifier (OID) for use within an ASN.1 AlgorithmIdentifier. This loosely, but not precisely, aligns with the definitions of "cryptographic algorithm" and "cryptographic scheme" given in [RFC9794].

COMPONENT / PRIMITIVE: The words "component" or "primitive" are used interchangeably to refer to an asymmetric cryptographic algorithm that is used internally within a composite algorithm. For example this could be an asymmetric algorithm such as "ML-DSA-65" or "RSASSA-PSS".

DER: Distinguished Encoding Rules as defined in [X.690].

PKI: Public Key Infrastructure, as defined in [RFC5280].

SIGNATURE: A digital cryptographic signature, making no assumptions about which algorithm.

Notation: The algorithm descriptions use python-like syntax. The following symbols deserve special mention:

* || represents concatenation of two byte arrays.

* [:] represents byte array slicing.

* (a, b) represents a pair of values a and b. Typically this indicates that a function returns multiple values; the exact conveyance mechanism -- tuple, struct, output parameters, etc. -- is left to the implementer.

* (a, _): represents a pair of values where one -- the second one in this case -- is ignored.

* Func<TYPE>(): represents a function that is parameterized by <TYPE> meaning that the function's implementation will have minor differences depending on the underlying TYPE. Typically this means that a function will need to look up different constants or use different underlying cryptographic primitives depending on which composite algorithm it is implementing.

2.2. Composite Design Philosophy

[RFC9794] defines composites as:

> _Composite Cryptographic Element_: A cryptographic element that incorporates multiple component cryptographic elements of the same type in a multi-algorithm scheme.

Composite algorithms, as defined in this specification, follow this definition and should be regarded as a single key that performs a single cryptographic operation typical of a digital signature algorithm, such as key generation, signing, or verifying -- using its internal sequence of component keys as if they form a single key. This generally means that the complexity of combining algorithms can and should be handled by the cryptographic library or cryptographic module, and the single composite public key, private key, and signature value can be carried in existing fields in protocols such as PKCS#10 [RFC2986], CMP [RFC4210], X.509 [RFC5280], the CMS [RFC5652], and the Trust Anchor Format [RFC5914]. In this way, composites achieve "protocol backwards-compatibility" in that they will drop cleanly into any protocol that accepts an analogous single-algorithm cryptographic scheme without requiring any modification of the protocol to handle multiple algorithms.

Discussion of the specific choices of algorithm pairings can be found in Section 7.2.

In terms of security properties, Composite ML-DSA will be EUF-CMA secure if at least one of its component algorithms is EUF-CMA secure and the message hash PH is collision resistant. SUF-CMA security of Composite ML-DSA is more complicated. While some of the algorithm combinations defined in this specification are likely to be SUF-CMA secure against classical adversaries, none are SUF-CMA secure against

a quantum adversary. This means that replacing an ML-DSA signature with a Composite ML-DSA signature is a reduction in security and should not be used in applications sensitive to the difference between SUF-CMA and EUF-CMA security. Composite ML-DSA is NOT RECOMMENDED for use in applications where it is has not been shown that EUF-CMA is acceptable. Further discussion can be found in Section 10.2.

3. Overview of the Composite ML-DSA Signature Scheme

Composite ML-DSA is a Post-Quantum / Traditional hybrid signature scheme which combines ML-DSA as specified in [FIPS.204] and [I-D.ietf-lamps-dilithium-certificates] with one of RSASSA-PKCS1-v1_5 or RSASSA-PSS algorithms defined in [RFC8017], the Elliptic Curve Digital Signature Algorithm ECDSA scheme defined in section 6 of [FIPS.186-5], or Ed25519 / Ed448 defined in [RFC8410]. The two component signatures are combined into a composite algorithm via a "signature combiner" function which performs pre-hashing and prepends several signature label values to the message prior to passing it to the component algorithms. Composite ML-DSA achieves weak non-separability as well as several other security properties which are described in the Security Considerations in Section 10.

Composite signature schemes are defined as cryptographic primitives that match the API of a generic signature scheme, which consists of three algorithms:

* KeyGen() -> (pk, sk): A probabilistic key generation algorithm which generates a public key pk and a secret key sk. Some cryptographic modules may also expose a KeyGen(seed) -> (pk, sk), which generates pk and sk deterministically from a seed. This specification assumes a seed-based keygen for ML-DSA.

* Sign(sk, M) -> s: A signing algorithm which takes as input a secret key sk and a message M, and outputs a signature s. Signing routines may take additional parameters such as a context string or a hash function to use for pre-hashing the message.

* Verify(pk, M, s) -> true or false: A verification algorithm which takes as input a public key pk, a message M and a signature s, and outputs true if the signature verifies correctly and false or an error otherwise. Verification routines may take additional parameters such as a context string or a hash function to use for pre-hashing the message.

The following algorithms are defined for serializing and deserializing component values and are provided as internal functions for use by the public functions KeyGen(), Sign(), and Verify(). These algorithms are inspired by similar algorithms in [RFC9180].

* SerializePublicKey(mlkdsaPK, tradPK) -> bytes: Produce a byte string encoding of the component public keys.

* DeserializePublicKey(bytes) -> (mldsaPK, tradPK): Parse a byte string to recover the component public keys.

* SerializePrivateKey(mldsaSeed, tradSK) -> bytes: Produce a byte string encoding of the component private keys. Note that the keygen seed is used as the interoperable private key format for ML-DSA.

* DeserializePrivateKey(bytes) -> (mldsaSeed, tradSK): Parse a byte string to recover the component private keys.

* SerializeSignatureValue(mldsaSig, tradSig) -> bytes: Produce a byte string encoding of the component signature values.

* DeserializeSignatureValue(bytes) -> (mldsaSig, tradSig): Parse a byte string to recover the component signature values.

Full definitions of serialization and deserialization algorithms can be found in Section 5.

3.1. Pre-hashing

In [FIPS.204] NIST defines separate algorithms for pure and pre-hashed modes of ML-DSA, referred to as "ML-DSA" and "HashML-DSA" respectively. This specification defines a single mode which is similar in construction to HashML-DSA. This design provides a compromised balance between performance and security. Since pre-hashing is done at the composite level, "pure" ML-DSA is used as the underlying ML-DSA primitive.

The primary design motivation behind pre-hashing is to perform only a single pass over the potentially large input message M, compared to passing the full message to both component primitives, and to allow for optimizations in cases such as signing the same message digest with multiple keys. The actual length of the to-be-signed message M’ depends on the application context ctx provided at runtime but since ctx has a maximum length of 255 bytes, M’ has a fixed maximum length which depends on the output size of the hash function chosen as PH, but can be computed per composite algorithm.

This simplification into a single strongly-pre-hashed algorithm avoids the need for duplicate sets of "Composite-ML-DSA" and "Hash-Composite-ML-DSA" algorithms.

See Section 11.4 for a discussion of externalizing the pre-hashing step.

3.2. Prefix, Label and CTX

The to-be-signed message representative M′ is created by concatenating several values, including the pre-hashed message.

M′ := Prefix || Label || len(ctx) || ctx || PH(M)

Prefix: A fixed octet string which is the byte encoding of the ASCII string "CompositeAlgorithmSignatures2025" which in hex is: 436F6D706F73697465416C676F726974686D5369676E617475726573323032 35 See Section 10.4 for more information on the prefix.

Label: A signature label which is specific to each composite algorithm. The signature label binds the signature to the specific composite algorithm. Signature label values for each algorithm are listed in Section 7.

len(ctx): A single unsigned byte encoding the length of the context.

ctx: The context bytes, which allows for applications to bind the signature to an application context.

PH(M): The hash of the message to be signed.

Each Composite ML-DSA algorithm has a unique signature label value which is used in constructing the message representative M′ in the Composite-ML-DSA.Sign() (Section 4.2) and Composite-ML-DSA.Verify() (Section 4.3). This helps protect against component signature values being removed from the composite and used out of context of X.509, or if the prohibition on reusing key material between a composite and a non-composite, or between two composites is not adhered to.

Note that there are two different context strings ctx at play: the first is the application context that is passed in to Composite-ML-DSA.Sign and bound to the to-be-signed message M′. The second is the ctx that is passed down into the underlying ML-DSA.Sign and here Composite ML-DSA itself is the application that we wish to bind and so per-algorithm Label is used as the ctx for the underlying ML-DSA primitive. The EdDSA component primitive can also expose a ctx parameter, but this is not used by Composite ML-DSA.

Within Composite ML-DSA, values of Label are fully specified, and runtime-variable Label values are not allowed. For authors of follow-on specifications that allow Label to be runtime-variable, it should be pre-fixed with the length, len(Label) || Label to prevent using this as an injection site that could enable various cryptographic attacks.

4. Composite ML-DSA Functions

This section describes the composite ML-DSA functions needed to instantiate the public API of a digital signature scheme as defined in Section 3.

4.1. Key Generation

In order to maintain security properties of the composite, applications that use composite keys MUST always perform fresh key generations of both component keys and MUST NOT reuse existing key material. See Section 10.3 for a discussion.

To generate a new key pair for composite schemes, the KeyGen() -> (pk, sk) function is used. The KeyGen() function calls the two key generation functions of the component algorithms independently. Multi-threaded, multi-process, or multi-module applications might choose to execute the key generation functions in parallel for better key generation performance or architectural modularity.

The following describes how to instantiate a KeyGen() function for a given composite algorithm represented by <OID>.

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

Explicit inputs:

  None

Implicit inputs mapped from <OID>:

  ML-DSA     The underlying ML-DSA algorithm and
             parameter set, for example "ML-DSA-65".

  Trad       The underlying traditional algorithm and
             parameter set, for example "RSASSA-PSS"
             or "Ed25519".

Output:

  (pk, sk)   The composite key pair.


Key Generation Process:

  1. Generate component keys

     mldsaSeed = Random(32)
     (mldsaPK, mldsaSK) = ML-DSA.KeyGen_internal(mldsaSeed)
     (tradPK, tradSK) = Trad.KeyGen()

  2. Check for component key gen failure

     if NOT (mldsaPK, mldsaSK) or NOT (tradPK, tradSK):
       output "Key generation error"

  3. Output the composite public and private keys

     pk = SerializePublicKey(mldsaPK, tradPK)
     sk = SerializePrivateKey(mldsaSeed, tradSK)
     return (pk, sk)
```

This keygen routine make use of the seed-based ML-DSA.KeyGen_internal(), which is defined in Algorithm 6 of [FIPS.204]. For FIPS-certification implications, see Section 11.1.

In order to ensure fresh keys, the key generation functions MUST be executed for both component algorithms. Compliant parties MUST NOT use, import or export component keys that are used in other contexts, combinations, or by themselves as keys for standalone algorithm use. For more details on the security considerations around key reuse, see Section 10.3.

Note that this keygen routine outputs a serialized composite key, which contains only the ML-DSA seed. Implementations should feel free to modify this routine to additionally output the expanded mldsaSK or to make free use of ML-DSA.KeyGen_internal(mldsaSeed) as needed to expand the ML-DSA seed into an expanded key prior to performing a signing operation.

The above algorithm MAY be modified to expose an interface of Composite-ML-DSA<OID>.KeyGen(seed) if it is desirable to have a deterministic KeyGen that derives both component keys from a shared seed. Details of implementing this variation are not included in this document.

Variations in the keygen process above and signature processes below to accommodate particular private key storage mechanisms or alternate interfaces to the underlying cryptographic modules are considered to be conformant to this specification so long as they produce the same output and error handling. For example, component private keys stored in separate software or hardware modules where it is not possible to do a joint simultaneous keygen would be considered compliant so long as both keys are freshly generated. It is also possible that the underlying cryptographic module does not expose a ML-DSA.KeyGen_internal(seed) that accepts an externally-generated seed, and instead an alternate keygen interface must be used. Note however that cryptographic modules that do not support seed-based ML-DSA key generation will be incapable of importing or exporting composite keys in the standard format since the private key serialization routines defined in Section 5.2 only support ML-DSA keys as seeds.

4.2. Sign

The Sign() algorithm of Composite ML-DSA mirrors the construction of ML-DSA.Sign(sk, M, ctx) defined in Algorithm 3 of Section 5.2 of [FIPS.204]. Composite ML-DSA exposes an API similar to that of ML-DSA, despite the fact that it includes pre-hashing in a similar way to HashML-DSA. Internally it uses pure ML-DSA as the component algorithm since there is no advantage to pre-hashing twice.

The following describes how to instantiate a Sign() function for a given Composite ML-DSA algorithm represented by <OID>. See Section 3.1 for a discussion of the pre-hash function PH. See Section 3.2 for a discussion on the signature label Label and application context ctx. See Section 11.4 for a discussion of externalizing the pre-hashing step.

Composite-ML-DSA<OID>.Sign(sk, M, ctx) -> s

Explicit inputs:

- sk — Composite private key consisting of signing private keys for each component.
- M — The message to be signed, an octet string.
- ctx — The application context string used in the composite signature combiner, which defaults to the empty string.

Implicit inputs mapped from <OID>:

- ML-DSA — The underlying ML-DSA algorithm and parameter set, for example "ML-DSA-65".
- Trad — The underlying traditional algorithm and parameter set, for example "sha256WithRSAEncryption" or "Ed25519".
- Prefix — The prefix octet string.
- Label — A signature label which is specific to each composite algorithm. Additionally, the composite label is passed into the underlying ML-DSA primitive as the ctx. Signature Label values are defined in the "Signature Label Values" section below.
- PH — The function used to pre-hash M.

Output:

- s — The composite signature value.

Signature Generation Process:

1. If len(ctx) > 255:
   return error

2. Compute the Message representative M’.
   As in FIPS 204, len(ctx) is encoded as a single unsigned byte.

```
   M’ :=  Prefix || Label || len(ctx) || ctx || PH( M )
```

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

```
  (mldsaSeed, tradSK) = DeserializePrivateKey(sk)
  (_, mldsaSK) = ML-DSA.KeyGen_internal(mldsaSeed)
```

4. Generate the two component signatures independently by
   calculating the signature over M’ according to their algorithm
   specifications.

```
  mldsaSig = ML-DSA.Sign( mldsaSK, M’, ctx=Label )
  tradSig = Trad.Sign( tradSK, M’ )
```

5. 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"
```

6. Output the encoded composite signature value.

```
 s = SerializeSignatureValue(mldsaSig, tradSig)
 return s
```

Note that in step 4 above, both component signature processes are invoked, and no indication is given about which one failed. This SHOULD be done in a timing-invariant way to prevent side-channel attackers from learning which component algorithm failed.

It is possible to use component private keys stored in separate software or hardware keystores. Variations in the process to accommodate particular private key storage mechanisms are considered to be conformant to this specification so long as it produces the same output and error handling as the process sketched above.

4.3. Verify

The Verify() algorithm of Composite ML-DSA mirrors the construction of ML-DSA.Verify(pk, M, s, ctx) defined in Algorithm 3 Section 5.3 of [FIPS.204]. Composite ML-DSA exposes an API similar to that of ML-DSA, despite the fact that it includes pre-hashing in a similar way to HashML-DSA. Internally it uses pure ML-DSA as the component algorithm since there is no advantage to pre-hashing twice.

Compliant applications MUST output "Valid signature" (true) if and only if all component signatures were successfully validated, and "Invalid signature" (false) otherwise.

The following describes how to instantiate a Verify() function for a given composite algorithm represented by <OID>. See Section 3.1 for a discussion of the pre-hash function PH. See Section 3.2 for a discussion on the signature label Label and application context ctx. See Section 11.4 for a discussion of externalizing the pre-hashing step.

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

Explicit inputs:

pk	Composite public key consisting of verification public keys for each component.
M	Message whose signature is to be verified, an octet string.
s	A composite signature value to be verified.
ctx	The application context string used in the composite signature combiner, which defaults to the empty string.

Implicit inputs mapped from <OID>:

ML-DSA	The underlying ML-DSA algorithm and parameter set, for example "ML-DSA-65".
Trad	The underlying traditional algorithm and parameter set, for example "sha256WithRSAEncryption" or "Ed25519".
Prefix	The prefix octet string.
Label	A signature label which is specific to each composite algorithm. Additionally, the composite label is passed into the underlying ML-DSA primitive as the ctx. Signature Label values are defined in the "Signature Label Values" section below.
PH	The function used to pre-hash M.

Output:

Validity (bool)	"Valid signature" (true) if the composite

signature is valid, "Invalid signature"
(false) otherwise.

Signature Verification Process:

1. If len(ctx) > 255
   return error

2. 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.

3. Compute a Hash of the Message.
   As in FIPS 204, len(ctx) is encoded as a single unsigned byte.

   M’ = Prefix || Label || len(ctx) || ctx || PH(M)

4. Check each component signature individually, according to its algorithm specification.
   If any fail, then the entire signature validation fails.

   if not ML-DSA.Verify(mldsaPK, M’, mldsaSig, ctx=Label) then
       output "Invalid signature"

   if not Trad.Verify(tradPK, M’, tradSig) then
       output "Invalid signature"

   if all succeeded, then
      output "Valid signature"

   Note that in step 4 above, the function fails early if the first component fails to verify. Since no private keys are involved in a signature verification, there are no timing attacks to consider, so this is ok.

5. Serialization

This section presents routines for serializing and deserializing composite public keys, private keys, and signature values to bytes via simple concatenation of the underlying encodings of the component algorithms. The functions defined in this section are considered internal implementation details and are referenced from within the public API definitions in Section 4.

Deserialization is possible because ML-DSA has fixed-length public keys, private keys (seeds), and signature values as shown in the following table.

Algorithm	Public key	Private key	Signature
ML-DSA-44	1312	32	2420
ML-DSA-65	1952	32	3309
ML-DSA-87	2592	32	4627

Table 1: ML-DSA Sizes

While ML-DSA has a single fixed-size representation for each of public key, private key (seed), and signature, a traditional component algorithm might allow multiple valid encodings. For example, a stand-alone RSA private key can be encoded in Chinese Remainder Theorem form. In order to obtain interoperability, composite algorithms MUST use the following encodings of the underlying components:

* *ML-DSA*: MUST be encoded as specified in section 7.2 of [FIPS.204], using a 32-byte seed as the private key. The signature and public key format are encoded as specified in section 7.2 of [FIPS.204].

* *RSA*: the public key MUST be encoded as RSAPublicKey with the (n,e) public key representation as specified in A.1.1 of [RFC8017] and the private key representation as RSAPrivateKey specified in A.1.2 of [RFC8017] with version 0 and 'otherPrimeInfos' absent. An RSA signature MUST be encoded as specified in section 8.1.1 (for RSASSA-PSS-SIGN) or 8.2.1 (for RSASSA-PCKS1-V1_5-SIGN) of [RFC8017].

* *ECDSA*: public key MUST be encoded as an uncompressed X9.62 [X9.62_2005], including the leading byte 0x04 indicating uncompressed. This is consistent with the encoding of ECPoint as specified in section 2.2 of [RFC5480] when no ASN.1 OCTET STRING wrapping is present. A signature MUST be encoded as an Ecdsa-Sig-Value as specified in section 2.2.3 of [RFC3279]. The private key MUST be encoded as ECPrivateKey specified in [RFC5915] with the 'NamedCurve' parameter and without the 'publicKey' field.

* *EdDSA*: public key and signature MUST be encoded as per section 3 of [RFC8032] and the private key is a 32 or 57 byte raw value for Ed25519 and Ed448 respectively, which can be converted to a CurvePrivateKey specified in [RFC8410] by the addition of an OCTET STRING wrapper.

All ASN.1 objects SHALL be encoded using DER on serialization. For all serialization routines below, when their output values are required to be carried in an ASN.1 structure, they are wrapped as described in Section 6.1.

Even with fixed encodings for the traditional component, there might be slight differences in size of the encoded value due to, for example, encoding rules that drop leading zeroes. See Appendix A for a table of maximum sizes for each composite algorithm and further discussion of the reason for variations in these sizes.

The deserialization routines described below do not check for well-formedness of the cryptographic material they are recovering. It is assumed that underlying cryptographic primitives will catch malformed values and raise an appropriate error.

5.1. SerializePublicKey and DeserializePublicKey

The serialization routine for keys simply concatenates the public keys of the component signature algorithms, as defined below:

Composite-ML-DSA.SerializePublicKey(mldsaPK, tradPK) -> bytes

Explicit inputs:

mldsaPK The ML-DSA public key, which is bytes.

tradPK The traditional public key in the appropriate encoding for the underlying component algorithm.

Implicit inputs:

None

Output:

bytes The encoded composite public key.

Serialization Process:

1. Combine and output the encoded public key

   output mldsaPK || tradPK

Deserialization reverses this process. Each component key is deserialized according to their respective specification as shown in Appendix B.

The following describes how to instantiate a DeserializePublicKey(bytes) function for a given composite algorithm represented by <OID>.

```
Composite-ML-DSA<OID>.DeserializePublicKey(bytes)
                                    -> (mldsaPK, tradPK)

Explicit inputs:

  bytes    An encoded composite public key.

Implicit inputs mapped from <OID>:

  ML-DSA   The underlying ML-DSA algorithm and
           parameter set to use, for example "ML-DSA-65".

Output:

  mldsaPK  The ML-DSA public key, which is bytes.

  tradPK   The traditional public key in the appropriate
           encoding for the underlying component algorithm.

Deserialization Process:

  1. Parse each constituent encoded public key.
     The length of the mldsaKey is known based on the
     size of the ML-DSA component key length specified
     by the Object ID.

     switch ML-DSA do
        case ML-DSA-44:
          mldsaPK = bytes[:1312]
          tradPK  = bytes[1312:]
        case ML-DSA-65:
          mldsaPK = bytes[:1952]
          tradPK  = bytes[1952:]
        case ML-DSA-87:
          mldsaPK = bytes[:2592]
          tradPK  = bytes[2592:]

     Note that while ML-DSA has fixed-length keys, RSA and
     ECDSA may not, depending on encoding, so rigorous
     length-checking of the overall composite key is not
     always possible.

  2. Output the component public keys

     output (mldsaPK, tradPK)
```

5.2. SerializePrivateKey and DeserializePrivateKey

The serialization routine for keys simply concatenates the private keys of the component signature algorithms, as defined below:

Composite-ML-DSA.SerializePrivateKey(mldsaSeed, tradSK) -> bytes

Explicit inputs:

mldsaSeed	The ML-DSA private key, which is the bytes of the seed.
tradSK	The traditional private key in the appropriate encoding for the underlying component algorithm.

Implicit inputs:

None

Output:

bytes	The encoded composite private key.

Serialization Process:

1. Combine and output the encoded private key.

   output mldsaSeed || tradSK

Deserialization reverses this process. Each component key is deserialized according to their respective specification as shown in Appendix B.

The following describes how to instantiate a DeserializePrivateKey(bytes) function. Since ML-DSA private keys are 32 bytes for all parameter sets, this function does not need to be parameterized.

Composite-ML-DSA.DeserializePrivateKey(bytes) -> (mldsaSeed, tradSK)

Explicit inputs:

bytes An encoded composite private key.

Implicit inputs:

None

Output:

mldsaSeed The ML-DSA private key, which is the bytes of the seed.

tradSK The traditional private key in the appropriate encoding for the underlying component algorithm.

Deserialization Process:

1. Parse each constituent encoded key.

```
mldsaSeed = bytes[:32]
tradSK  = bytes[32:]
```

Note that while ML-DSA has fixed-length keys, RSA and ECDSA may not, depending on encoding, so rigorous length-checking of the overall composite key is not always possible.

2. Output the component private keys

output (mldsaSeed, tradSK)

5.3. SerializeSignatureValue and DeserializeSignatureValue

The serialization routine for the composite signature value simply concatenates the fixed-length ML-DSA signature value with the signature value from the traditional algorithm, as defined below:

Composite-ML-DSA.SerializeSignatureValue(mldsaSig, tradSig) -> bytes

Explicit inputs:

mldsaSig The ML-DSA signature value, which is bytes.

tradSig The traditional signature value in the appropriate encoding for the underlying component algorithm.

Implicit inputs:

None

Output:

bytes The encoded composite signature value.

Serialization Process:

1. Combine and output the encoded composite signature

   output mldsaSig || tradSig

Deserialization reverses this process, raising an error in the event that the input is malformed. Each component signature is deserialized according to their respective specification as shown in Appendix B.

The following describes how to instantiate a DeserializeSignatureValue(bytes) function for a given composite algorithm represented by <OID>.

Composite-ML-DSA<OID>.DeserializeSignatureValue(bytes)
-> (mldsaSig, tradSig)

Explicit inputs:

bytes An encoded composite signature value.

Implicit inputs mapped from <OID>:

ML-DSA The underlying ML-DSA algorithm and parameter set, for example "ML-DSA-65".

Output:

mldsaSig The ML-DSA signature value, which is bytes.

tradSig The traditional signature value in the appropriate encoding for the underlying component algorithm.

Deserialization Process:

1. Parse each constituent encoded signature.
   The length of the mldsaSig is known based on the size of the ML-DSA component signature length specified by the Object ID.

   ```
   switch ML-DSA do
      case ML-DSA-44:
        mldsaSig = bytes[:2420]
        tradSig  = bytes[2420:]
      case ML-DSA-65:
        mldsaSig = bytes[:3309]
        tradSig  = bytes[3309:]
      case ML-DSA-87:
        mldsaSig = bytes[:4627]
        tradSig  = bytes[4627:]
   ```

   Note that while ML-DSA has fixed-length signatures, RSA and ECDSA may not, depending on encoding, so rigorous length-checking is not always possible here.

3. Output the component signature values

   ```
   output (mldsaSig, tradSig)
   ```

6. Use within X.509 and PKIX

The following sections provide processing logic and the ASN.1 modules necessary to use composite ML-DSA within X.509 and PKIX protocols. Use within the Cryptographic Message Syntax (CMS) will be covered in a separate specification.

While composite ML-DSA keys and signature values MAY be used raw, the following sections provide conventions for using them within X.509 and other PKIX protocols such that Composite ML-DSA can be used as a drop-in replacement for existing digital signature algorithms in PKCS#10 [RFC2986], CMP [RFC4210], X.509 [RFC5280], and related protocols.

6.1. Encoding to DER

The serialization routines presented in Section 5 produce raw binary values. When these values are required to be carried within a DER-encoded message format such as an X.509's subjectPublicKey and signatureValue BIT STRING [RFC5280] or a OneAsymmetricKey.privateKey OCTET STRING [RFC5958], then the BIT STRING or OCTET STRING contains this raw byte string encoding of the public key.

When a Composite ML-DSA public key appears outside of a SubjectPublicKeyInfo type in an environment that uses ASN.1 encoding, it could be encoded as an OCTET STRING by using the Composite-ML-DSA-PublicKey type defined below.

```
Composite-ML-DSA-PublicKey ::= OCTET STRING
```

Size constraints MAY be enforced, as appropriate as per Appendix A.

6.2. Key Usage Bits

When any Composite ML-DSA Object Identifier appears within the SubjectPublicKeyInfo.AlgorithmIdentifier field of an X.509 certificate [RFC5280], the key usage certificate extension MUST only contain signing-type key usages.

The normal keyUsage rules for signing-type keys from [RFC5280] apply, and are reproduced here for completeness.

For Certification Authority (CA) certificates that carry a Composite ML-DSA public key, any combination of the following values MAY be present and any other values MUST NOT be present:

digitalSignature;
nonRepudiation;
keyCertSign; and
cRLSign.

For End Entity certificates, any combination of the following values MAY be present and any other values MUST NOT be present:

digitalSignature;
nonRepudiation; and
cRLSign.

Composite ML-DSA keys MUST NOT be used in a "dual usage" mode because even if the traditional component key supports both signing and encryption, the post-quantum algorithms do not and therefore the overall composite algorithm does not. Implementations MUST NOT use one component of the composite for the purposes of digital signature and the other component for the purposes of encryption or key establishment.

6.3. ASN.1 Definitions

Composite ML-DSA uses a substantially non-ASN.1 based encoding, as specified in Section 5. However, as composite algorithms will be used within ASN.1-based X.509 and PKIX protocols, some conventions for ASN.1 wrapping are necessary.

The following ASN.1 Information Object Classes are defined to allow for compact definitions of each composite algorithm, leading to a smaller overall ASN.1 module.

```
pk-CompositeSignature {OBJECT IDENTIFIER:id}
    PUBLIC-KEY ::= {
      IDENTIFIER id
      -- KEY no ASN.1 wrapping --
      PARAMS ARE absent
      CERT-KEY-USAGE { digitalSignature, nonRepudiation, keyCertSign,
                                                              cRLSign}
      -- PRIVATE-KEY no ASN.1 wrapping --
    }

sa-CompositeSignature{OBJECT IDENTIFIER:id,
   PUBLIC-KEY:publicKeyType }
      SIGNATURE-ALGORITHM ::=  {
         IDENTIFIER id
         -- VALUE no ASN.1 wrapping --
         PARAMS ARE absent
         PUBLIC-KEYS {publicKeyType}
      }
```

Figure 1: ASN.1 Object Information Classes for Composite ML-DSA

As an example, the public key and signature algorithm types associated with id-MLDSA44-ECDSA-P256-SHA256 are defined as:

```
pk-MLDSA44-ECDSA-P256-SHA256 PUBLIC-KEY ::=
  pk-CompositeSignature{ id-MLDSA44-ECDSA-P256-SHA256 }

sa-MLDSA44-ECDSA-P256-SHA256 SIGNATURE-ALGORITHM ::=
    sa-CompositeSignature{
       id-MLDSA44-ECDSA-P256-SHA256,
       pk-MLDSA44-ECDSA-P256-SHA256 }
```

The full set of key types defined by this specification can be found in the ASN.1 Module in Section 8.

Use cases that require an interoperable encoding for composite private keys will often need to place a composite private key inside a OneAsymmetricKey structure defined in [RFC5958], such as when private keys are carried in PKCS #12 [RFC7292], CMP [RFC4210] or CRMF [RFC4211]. The definition of OneAsymmetricKey is copied here for convenience:

```
    OneAsymmetricKey ::= SEQUENCE {
          version                   Version,
          privateKeyAlgorithm       PrivateKeyAlgorithmIdentifier,
          privateKey                PrivateKey,
          attributes            [0] Attributes OPTIONAL,
          ...,
          [[2: publicKey        [1] PublicKey OPTIONAL ]],
          ...
       }
     ...
     PrivateKey ::= OCTET STRING
                       -- Content varies based on type of key.  The
                       -- algorithm identifier dictates the format of
                       -- the key.
```

Figure 2: OneAsymmetricKey as defined in [RFC5958]

When a composite private key is conveyed inside a OneAsymmetricKey structure (version 1 of which is also known as PrivateKeyInfo) [RFC5958], the privateKeyAlgorithm field SHALL be set to the corresponding composite algorithm identifier defined according to Section 7 and its parameters field MUST be absent. The privateKey field SHALL contain the OCTET STRING representation of the serialized composite private key as per Section 5.2. The publicKey field remains OPTIONAL. If the publicKey field is present, it MUST be a composite public key as per Section 5.1.

Some applications might need to reconstruct the SubjectPublicKeyInfo or OneAsymmetricKey objects corresponding to each component key individually, for example if this is required for invoking the underlying primitive. Section 7 provides the necessary mapping between composite and their component algorithms for doing this reconstruction.

Component keys of a composite MUST NOT be used in any other type of key or as a standalone key. For more details on the security considerations around key reuse, see Section 10.3.

7. Algorithm Identifiers and Parameters

This section lists the algorithm identifiers and parameters for all Composite ML-DSA algorithms.

Full specifications for the referenced algorithms can be found in Appendix B.

As the number of algorithms can be daunting, implementers who wish to implement only a single composite algorithm should see Section 11.3 for a discussion of the best algorithm for the most common use cases.

Labels 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 described in Section 3.2.

EDNOTE: the OIDs listed below are prototyping OIDs defined in Entrust's 2.16.840.1.114027.80.9.1 arc but will be replaced by IANA.

* id-MLDSA44-RSA2048-PSS-SHA256
  - OID: 2.16.840.1.114027.80.9.1.20
  - Label: COMPSIG-MLDSA44-RSA2048-PSS-SHA256
  - Pre-Hash function (PH): SHA256
  - ML-DSA variant: ML-DSA-44
  - Traditional Algorithm: RSA
    - Traditional Signature Algorithm: id-RSASSA-PSS
    - RSA size: 2048
    - RSASSA-PSS parameters: See Table 2
* id-MLDSA44-RSA2048-PKCS15-SHA256
  - OID: 2.16.840.1.114027.80.9.1.21
  - Label: COMPSIG-MLDSA44-RSA2048-PKCS15-SHA256
  - Pre-Hash function (PH): SHA256
  - ML-DSA variant: ML-DSA-44
  - Traditional Algorithm: RSA
    - Traditional Signature Algorithm: sha256WithRSAEncryption
    - RSA size: 2048
* id-MLDSA44-Ed25519-SHA512

- OID: 2.16.840.1.114027.80.9.1.22
- Label: COMPSIG-MLDSA44-Ed25519-SHA512
- Pre-Hash function (PH): SHA512
- ML-DSA variant: ML-DSA-44
- Traditional Algorithm: Ed25519
  - Traditional Signature Algorithm: id-Ed25519

* id-MLDSA44-ECDSA-P256-SHA256
  - OID: 2.16.840.1.114027.80.9.1.23
  - Label: COMPSIG-MLDSA44-ECDSA-P256-SHA256
  - Pre-Hash function (PH): SHA256
  - ML-DSA variant: ML-DSA-44
  - Traditional Algorithm: ECDSA
    - Traditional Signature Algorithm: ecdsa-with-SHA256
    - ECDSA curve: secp256r1
* id-MLDSA65-RSA3072-PSS-SHA512
  - OID: 2.16.840.1.114027.80.9.1.24
  - Label: COMPSIG-MLDSA65-RSA3072-PSS-SHA512
  - Pre-Hash function (PH): SHA512
  - ML-DSA variant: ML-DSA-65
  - Traditional Algorithm: RSA
    - Traditional Signature Algorithm: id-RSASSA-PSS
    - RSA size: 3072
    - RSASSA-PSS parameters: See Table 2
* id-MLDSA65-RSA3072-PKCS15-SHA512

- OID: 2.16.840.1.114027.80.9.1.25
- Label: COMPSIG-MLDSA65-RSA3072-PKCS15-SHA512
- Pre-Hash function (PH): SHA512
- ML-DSA variant: ML-DSA-65
- Traditional Algorithm: RSA
  - Traditional Signature Algorithm: sha256WithRSAEncryption
  - RSA size: 3072

* id-MLDSA65-RSA4096-PSS-SHA512
  - OID: 2.16.840.1.114027.80.9.1.26
  - Label: COMPSIG-MLDSA65-RSA4096-PSS-SHA512
  - Pre-Hash function (PH): SHA512
  - ML-DSA variant: ML-DSA-65
  - Traditional Algorithm: RSA
    - Traditional Signature Algorithm: id-RSASSA-PSS
    - RSA size: 4096
    - RSASSA-PSS parameters: See Table 3

* id-MLDSA65-RSA4096-PKCS15-SHA512
  - OID: 2.16.840.1.114027.80.9.1.27
  - Label: COMPSIG-MLDSA65-RSA4096-PKCS15-SHA512
  - Pre-Hash function (PH): SHA512
  - ML-DSA variant: ML-DSA-65
  - Traditional Algorithm: RSA
    - Traditional Signature Algorithm: sha384WithRSAEncryption
    - RSA size: 4096

* id-MLDSA65-ECDSA-P256-SHA512
  - OID: 2.16.840.1.114027.80.9.1.28
  - Label: COMPSIG-MLDSA65-P256-SHA512
  - Pre-Hash function (PH): SHA512
  - ML-DSA variant: ML-DSA-65
  - Traditional Algorithm: ECDSA
    - Traditional Signature Algorithm: ecdsa-with-SHA256
    - ECDSA curve: secp256r1
* id-MLDSA65-ECDSA-P384-SHA512
  - OID: 2.16.840.1.114027.80.9.1.29
  - Label: COMPSIG-MLDSA65-P384-SHA512
  - Pre-Hash function (PH): SHA512
  - ML-DSA variant: ML-DSA-65
  - Traditional Algorithm: ECDSA
    - Traditional Signature Algorithm: ecdsa-with-SHA384
    - ECDSA curve: secp384r1
* id-MLDSA65-ECDSA-brainpoolP256r1-SHA512
  - OID: 2.16.840.1.114027.80.9.1.30
  - Label: COMPSIG-MLDSA65-BP256-SHA512
  - Pre-Hash function (PH): SHA512
  - ML-DSA variant: ML-DSA-65
  - Traditional Algorithm: ECDSA
    - Traditional Signature Algorithm: ecdsa-with-SHA256
    - ECDSA curve: brainpoolP256r1

* id-MLDSA65-Ed25519-SHA512
  - OID: 2.16.840.1.114027.80.9.1.31
  - Label: COMPSIG-MLDSA65-Ed25519-SHA512
  - Pre-Hash function (PH): SHA512
  - ML-DSA variant: ML-DSA-65
  - Traditional Algorithm: Ed25519
    o Traditional Signature Algorithm: id-Ed25519
* id-MLDSA87-ECDSA-P384-SHA512
  - OID: 2.16.840.1.114027.80.9.1.32
  - Label: COMPSIG-MLDSA87-P384-SHA512
  - Pre-Hash function (PH): SHA512
  - ML-DSA variant: ML-DSA-87
  - Traditional Algorithm: ECDSA
    o Traditional Signature Algorithm: ecdsa-with-SHA384
    o ECDSA curve: secp384r1
* id-MLDSA87-ECDSA-brainpoolP384r1-SHA512
  - OID: 2.16.840.1.114027.80.9.1.33
  - Label: COMPSIG-MLDSA87-BP384-SHA512
  - Pre-Hash function (PH): SHA512
  - ML-DSA variant: ML-DSA-87
  - Traditional Algorithm: ECDSA
    o Traditional Signature Algorithm: ecdsa-with-SHA384
    o ECDSA curve: brainpoolP384r1
* id-MLDSA87-Ed448-SHAKE256

- OID: 2.16.840.1.114027.80.9.1.34
- Label: COMPSIG-MLDSA87-Ed448-SHAKE256
- Pre-Hash function (PH): SHAKE256/64**
- ML-DSA variant: ML-DSA-87
- Traditional Algorithm: Ed448
  - Traditional Signature Algorithm: id-Ed448

* id-MLDSA87-RSA3072-PSS-SHA512
  - OID: 2.16.840.1.114027.80.9.1.35
  - Label: COMPSIG-MLDSA87-RSA3072-PSS-SHA512
  - Pre-Hash function (PH): SHA512
  - ML-DSA variant: ML-DSA-87
  - Traditional Algorithm: RSA
    - Traditional Signature Algorithm: id-RSASSA-PSS
    - RSA size: 3072
    - RSASSA-PSS parameters: See Table 2
* id-MLDSA87-RSA4096-PSS-SHA512
  - OID: 2.16.840.1.114027.80.9.1.36
  - Label: COMPSIG-MLDSA87-RSA4096-PSS-SHA512
  - Pre-Hash function (PH): SHA512
  - ML-DSA variant: ML-DSA-87
  - Traditional Algorithm: RSA
    - Traditional Signature Algorithm: id-RSASSA-PSS
    - RSA size: 4096
    - RSASSA-PSS parameters: See Table 3

* id-MLDSA87-ECDSA-P521-SHA512
  - OID: 2.16.840.1.114027.80.9.1.37
  - Label: COMPSIG-MLDSA87-P521-SHA512
  - Pre-Hash function (PH): SHA512
  - ML-DSA variant: ML-DSA-87
  - Traditional Algorithm: ECDSA
    o Traditional Signature Algorithm: ecdsa-with-SHA512
    o ECDSA curve: secp521r1

For all RSA key types and sizes, the exponent is RECOMMENDED to be 65537. Implementations MAY support only 65537 and reject other exponent values. Legacy RSA implementations that use other values for the exponent MAY be used within a composite, but need to be careful when interoperating with other implementations.

**Note: The pre-hash functions were chosen to roughly match the security level of the stronger component. In the case of Ed25519 and Ed448 they match the hash function defined in [RFC8032]; SHA512 for Ed25519ph and SHAKE256(x, 64), which is SHAKE256 producing 64 bytes (512 bits) of output, for Ed448ph.

7.1. RSASSA-PSS Parameters

Use of RSASSA-PSS [RFC8017] requires extra parameters to be specified.

The RSASSA-PSS-params ASN.1 type defined in [RFC8017] is not used in Composite ML-DSA encodings since the parameter values are fixed by this specification. However, below refer to the named fields of the RSASSA-PSS-params ASN.1 type in order to provide a mapping between the use of RSASSA-PSS in Composite ML-DSA and [RFC8017]

When RSA-PSS is used at the 2048-bit or 3072-bit security level, RSASSA-PSS SHALL be instantiated with the following parameters:

RSASSA-PSS-params field	Value
hashAlgorithm	id-sha256
maskGenAlgorithm.algorithm	id-mgf1
maskGenAlgorithm.parameters	id-sha256
saltLength	32
trailerField	1

Table 2: RSASSA-PSS 2048 and 3072 Parameters

When RSA-PSS is used at the 4096-bit security level, RSASSA-PSS SHALL be instantiated with the following parameters:

RSASSA-PSS-params field	Value
hashAlgorithm	id-sha384
maskGenAlgorithm.algorithm	id-mgf1
maskGenAlgorithm.parameters	id-sha384
saltLength	48
trailerField	1

Table 3: RSASSA-PSS 4096 Parameters

7.2. Rationale for choices

In generating the list of composite algorithms, the idea was to provide composite algorithms at various security levels with varying performance characteristics.

The main design consideration in choosing pairings is to prioritize providing pairings of each ML-DSA security level with commonly-deployed traditional algorithms. This supports the design goal of using composites as a stepping stone to efficiently deploy post-quantum on top of existing hardened and certified traditional algorithm implementations. This was prioritized rather than

attempting to exactly match the security level of the post-quantum and traditional components -- which in general is difficult to do since there is no academic consensus on how to compare the "bits of security" against classical adversaries and "qubits of security" against quantum adversaries.

SHA2 is prioritized over SHA3 in order to facilitate implementations that do not have easy access to SHA3 outside of the ML-DSA module. However SHAKE256 is used with Ed448 since this is already the recommended hash functions chosen for ED448ph in [RFC8032].

In some cases, multiple hash functions are used within the same composite algorithm. Consider for example id-MLDSA65-ECDSA-P256-SHA512 which requires SHA512 as the overall composite pre-hash in order to maintain the security level of ML-DSA-65, but uses SHA256 within the ecdsa-with-SHA256 with secp256r1 traditional component. While this increases the implementation burden of needing to carry multiple hash functions for a single composite algorithm, this aligns with the design goal of choosing commonly-implemented traditional algorithms since ecdsa-with-SHA256 with secp256r1 is far more common than, for example, ecdsa-with-SHA512 with secp256r1.

Full specifications for the referenced algorithms can be found in Appendix B.

8. ASN.1 Module

<CODE STARTS>

```
Composite-MLDSA-2025
  { iso(1) identified-organization(3) dod(6) internet(1)
        security(5) mechanisms(5) pkix(7) id-mod(0)
        id-mod-composite-mldsa-2025(TBDMOD) }


DEFINITIONS IMPLICIT TAGS ::= BEGIN

EXPORTS ALL;

IMPORTS
  PUBLIC-KEY, SIGNATURE-ALGORITHM, SMIME-CAPS, AlgorithmIdentifier{}
    FROM AlgorithmInformation-2009  -- RFC 5912 [X509ASN1]
      { iso(1) identified-organization(3) dod(6) internet(1)
        security(5) mechanisms(5) pkix(7) id-mod(0)
        id-mod-algorithmInformation-02(58) }
;

--
```

```
   -- Object Identifiers
   --

   --
   -- Information Object Classes
   --

   pk-CompositeSignature {OBJECT IDENTIFIER:id}
       PUBLIC-KEY ::= {
         IDENTIFIER id
         -- KEY no ASN.1 wrapping --
         PARAMS ARE absent
         CERT-KEY-USAGE { digitalSignature, nonRepudiation, keyCertSign,
                                                              cRLSign}
         -- PRIVATE-KEY no ASN.1 wrapping --
       }

   sa-CompositeSignature{OBJECT IDENTIFIER:id,
      PUBLIC-KEY:publicKeyType }
         SIGNATURE-ALGORITHM ::=  {
            IDENTIFIER id
            -- VALUE no ASN.1 wrapping --
            PARAMS ARE absent
            PUBLIC-KEYS {publicKeyType}
         }


   -- Composite ML-DSA which uses a PreHash Message

   -- TODO: OID to be replaced by IANA
   id-MLDSA44-RSA2048-PSS-SHA256 OBJECT IDENTIFIER ::= {
      joint-iso-itu-t(2) country(16) us(840) organization(1)
      entrust(114027) algorithm(80) composite-mldsa(9) signature(1) 20 }

   pk-MLDSA44-RSA2048-PSS-SHA256 PUBLIC-KEY ::=
     pk-CompositeSignature{ id-MLDSA44-RSA2048-PSS-SHA256}

   sa-MLDSA44-RSA2048-PSS-SHA256 SIGNATURE-ALGORITHM ::=
       sa-CompositeSignature{
          id-MLDSA44-RSA2048-PSS-SHA256,
          pk-MLDSA44-RSA2048-PSS-SHA256 }

   -- TODO: OID to be replaced by IANA
   id-MLDSA44-RSA2048-PKCS15-SHA256 OBJECT IDENTIFIER ::= {
      joint-iso-itu-t(2) country(16) us(840) organization(1)
      entrust(114027) algorithm(80) composite-mldsa(9) signature(1) 21 }

   pk-MLDSA44-RSA2048-PKCS15-SHA256 PUBLIC-KEY ::=
```

```
     pk-CompositeSignature{ id-MLDSA44-RSA2048-PKCS15-SHA256}

   sa-MLDSA44-RSA2048-PKCS15-SHA256 SIGNATURE-ALGORITHM ::=
       sa-CompositeSignature{
          id-MLDSA44-RSA2048-PKCS15-SHA256,
          pk-MLDSA44-RSA2048-PKCS15-SHA256 }


   -- TODO: OID to be replaced by IANA
   id-MLDSA44-Ed25519-SHA512 OBJECT IDENTIFIER ::= {
      joint-iso-itu-t(2) country(16) us(840) organization(1)
      entrust(114027) algorithm(80) composite-mldsa(9) signature(1) 22 }

   pk-MLDSA44-Ed25519-SHA512 PUBLIC-KEY ::=
     pk-CompositeSignature{ id-MLDSA44-Ed25519-SHA512}

   sa-MLDSA44-Ed25519-SHA512 SIGNATURE-ALGORITHM ::=
       sa-CompositeSignature{
          id-MLDSA44-Ed25519-SHA512,
          pk-MLDSA44-Ed25519-SHA512 }


   -- TODO: OID to be replaced by IANA
   id-MLDSA44-ECDSA-P256-SHA256 OBJECT IDENTIFIER ::= {
      joint-iso-itu-t(2) country(16) us(840) organization(1)
      entrust(114027) algorithm(80) composite-mldsa(9) signature(1) 23 }

   pk-MLDSA44-ECDSA-P256-SHA256 PUBLIC-KEY ::=
     pk-CompositeSignature{ id-MLDSA44-ECDSA-P256-SHA256}

   sa-MLDSA44-ECDSA-P256-SHA256 SIGNATURE-ALGORITHM ::=
       sa-CompositeSignature{
          id-MLDSA44-ECDSA-P256-SHA256,
          pk-MLDSA44-ECDSA-P256-SHA256 }


   -- TODO: OID to be replaced by IANA
   id-MLDSA65-RSA3072-PSS-SHA512 OBJECT IDENTIFIER ::= {
      joint-iso-itu-t(2) country(16) us(840) organization(1)
      entrust(114027) algorithm(80) composite-mldsa(9) signature(1) 24 }

   pk-MLDSA65-RSA3072-PSS-SHA512 PUBLIC-KEY ::=
     pk-CompositeSignature{ id-MLDSA65-RSA3072-PSS-SHA512}

   sa-MLDSA65-RSA3072-PSS-SHA512 SIGNATURE-ALGORITHM ::=
       sa-CompositeSignature{
          id-MLDSA65-RSA3072-PSS-SHA512,
          pk-MLDSA65-RSA3072-PSS-SHA512 }
```

```
   -- TODO: OID to be replaced by IANA
   id-MLDSA65-RSA3072-PKCS15-SHA512 OBJECT IDENTIFIER ::= {
      joint-iso-itu-t(2) country(16) us(840) organization(1)
      entrust(114027) algorithm(80) composite-mldsa(9) signature(1) 25 }

   pk-MLDSA65-RSA3072-PKCS15-SHA512 PUBLIC-KEY ::=
     pk-CompositeSignature{ id-MLDSA65-RSA3072-PKCS15-SHA512}

   sa-MLDSA65-RSA3072-PKCS15-SHA512 SIGNATURE-ALGORITHM ::=
       sa-CompositeSignature{
          id-MLDSA65-RSA3072-PKCS15-SHA512,
          pk-MLDSA65-RSA3072-PKCS15-SHA512 }

   -- TODO: OID to be replaced by IANA
   id-MLDSA65-RSA4096-PSS-SHA512 OBJECT IDENTIFIER ::= {
      joint-iso-itu-t(2) country(16) us(840) organization(1)
      entrust(114027) algorithm(80) composite-mldsa(9) signature(1) 26 }

   pk-MLDSA65-RSA4096-PSS-SHA512 PUBLIC-KEY ::=
     pk-CompositeSignature{ id-MLDSA65-RSA4096-PSS-SHA512}

   sa-MLDSA65-RSA4096-PSS-SHA512 SIGNATURE-ALGORITHM ::=
       sa-CompositeSignature{
          id-MLDSA65-RSA4096-PSS-SHA512,
          pk-MLDSA65-RSA4096-PSS-SHA512 }


   -- TODO: OID to be replaced by IANA
   id-MLDSA65-RSA4096-PKCS15-SHA512 OBJECT IDENTIFIER ::= {
      joint-iso-itu-t(2) country(16) us(840) organization(1)
      entrust(114027) algorithm(80) composite-mldsa(9) signature(1) 27 }

   pk-MLDSA65-RSA4096-PKCS15-SHA512 PUBLIC-KEY ::=
     pk-CompositeSignature{ id-MLDSA65-RSA4096-PKCS15-SHA512}

   sa-MLDSA65-RSA4096-PKCS15-SHA512 SIGNATURE-ALGORITHM ::=
       sa-CompositeSignature{
          id-MLDSA65-RSA4096-PKCS15-SHA512,
          pk-MLDSA65-RSA4096-PKCS15-SHA512 }


   -- TODO: OID to be replaced by IANA
   id-MLDSA65-ECDSA-P256-SHA512 OBJECT IDENTIFIER ::= {
      joint-iso-itu-t(2) country(16) us(840) organization(1)
      entrust(114027) algorithm(80) composite-mldsa(9) signature(1) 28 }

   pk-MLDSA65-ECDSA-P256-SHA512 PUBLIC-KEY ::=
     pk-CompositeSignature{ id-MLDSA65-ECDSA-P256-SHA512}
```

```
   sa-MLDSA65-ECDSA-P256-SHA512 SIGNATURE-ALGORITHM ::=
       sa-CompositeSignature{
          id-MLDSA65-ECDSA-P256-SHA512,
          pk-MLDSA65-ECDSA-P256-SHA512 }


   -- TODO: OID to be replaced by IANA
   id-MLDSA65-ECDSA-P384-SHA512 OBJECT IDENTIFIER ::= {
      joint-iso-itu-t(2) country(16) us(840) organization(1)
      entrust(114027) algorithm(80) composite-mldsa(9) signature(1) 29 }

   pk-MLDSA65-ECDSA-P384-SHA512 PUBLIC-KEY ::=
     pk-CompositeSignature{ id-MLDSA65-ECDSA-P384-SHA512}

   sa-MLDSA65-ECDSA-P384-SHA512 SIGNATURE-ALGORITHM ::=
       sa-CompositeSignature{
          id-MLDSA65-ECDSA-P384-SHA512,
          pk-MLDSA65-ECDSA-P384-SHA512 }


   -- TODO: OID to be replaced by IANA
   id-MLDSA65-ECDSA-brainpoolP256r1-SHA512 OBJECT IDENTIFIER ::= {
      joint-iso-itu-t(2) country(16) us(840) organization(1)
      entrust(114027) algorithm(80) composite-mldsa(9) signature(1) 30 }

   pk-MLDSA65-ECDSA-brainpoolP256r1-SHA512 PUBLIC-KEY ::=
     pk-CompositeSignature{ id-MLDSA65-ECDSA-brainpoolP256r1-SHA512}

   sa-MLDSA65-ECDSA-brainpoolP256r1-SHA512 SIGNATURE-ALGORITHM ::=
       sa-CompositeSignature{
          id-MLDSA65-ECDSA-brainpoolP256r1-SHA512,
          pk-MLDSA65-ECDSA-brainpoolP256r1-SHA512 }


   -- TODO: OID to be replaced by IANA
   id-MLDSA65-Ed25519-SHA512 OBJECT IDENTIFIER ::= {
      joint-iso-itu-t(2) country(16) us(840) organization(1)
      entrust(114027) algorithm(80) composite-mldsa(9) signature(1) 31 }

   pk-MLDSA65-Ed25519-SHA512 PUBLIC-KEY ::=
     pk-CompositeSignature{ id-MLDSA65-Ed25519-SHA512}

   sa-MLDSA65-Ed25519-SHA512 SIGNATURE-ALGORITHM ::=
       sa-CompositeSignature{
          id-MLDSA65-Ed25519-SHA512,
          pk-MLDSA65-Ed25519-SHA512 }
```

```
   -- TODO: OID to be replaced by IANA
   id-MLDSA87-ECDSA-P384-SHA512 OBJECT IDENTIFIER ::= {
      joint-iso-itu-t(2) country(16) us(840) organization(1)
      entrust(114027) algorithm(80) composite-mldsa(9) signature(1) 32 }

   pk-MLDSA87-ECDSA-P384-SHA512 PUBLIC-KEY ::=
     pk-CompositeSignature{ id-MLDSA87-ECDSA-P384-SHA512}

   sa-MLDSA87-ECDSA-P384-SHA512 SIGNATURE-ALGORITHM ::=
       sa-CompositeSignature{
          id-MLDSA87-ECDSA-P384-SHA512,
          pk-MLDSA87-ECDSA-P384-SHA512 }


   -- TODO: OID to be replaced by IANA
   id-MLDSA87-ECDSA-brainpoolP384r1-SHA512 OBJECT IDENTIFIER ::= {
      joint-iso-itu-t(2) country(16) us(840) organization(1)
      entrust(114027) algorithm(80) composite-mldsa(9) signature(1) 33 }

   pk-MLDSA87-ECDSA-brainpoolP384r1-SHA512 PUBLIC-KEY ::=
     pk-CompositeSignature{ id-MLDSA87-ECDSA-brainpoolP384r1-SHA512}

   sa-MLDSA87-ECDSA-brainpoolP384r1-SHA512 SIGNATURE-ALGORITHM ::=
       sa-CompositeSignature{
          id-MLDSA87-ECDSA-brainpoolP384r1-SHA512,
          pk-MLDSA87-ECDSA-brainpoolP384r1-SHA512 }


   -- TODO: OID to be replaced by IANA
   id-MLDSA87-Ed448-SHAKE256 OBJECT IDENTIFIER ::= {
      joint-iso-itu-t(2) country(16) us(840) organization(1)
      entrust(114027) algorithm(80) composite-mldsa(9) signature(1) 34 }

   pk-MLDSA87-Ed448-SHAKE256 PUBLIC-KEY ::=
     pk-CompositeSignature{ id-MLDSA87-Ed448-SHAKE256}

   sa-MLDSA87-Ed448-SHAKE256 SIGNATURE-ALGORITHM ::=
       sa-CompositeSignature{
          id-MLDSA87-Ed448-SHAKE256,
          pk-MLDSA87-Ed448-SHAKE256 }


   -- TODO: OID to be replaced by IANA
   id-MLDSA87-RSA3072-PSS-SHA512 OBJECT IDENTIFIER ::= {
      joint-iso-itu-t(2) country(16) us(840) organization(1)
      entrust(114027) algorithm(80) composite-mldsa(9) signature(1) 35 }

   pk-MLDSA87-RSA3072-PSS-SHA512 PUBLIC-KEY ::=
```

```
     pk-CompositeSignature{ id-MLDSA87-RSA3072-PSS-SHA512}

   sa-MLDSA87-RSA3072-PSS-SHA512 SIGNATURE-ALGORITHM ::=
       sa-CompositeSignature{
          id-MLDSA87-RSA3072-PSS-SHA512,
          pk-MLDSA87-RSA3072-PSS-SHA512 }


   -- TODO: OID to be replaced by IANA
   id-MLDSA87-RSA4096-PSS-SHA512 OBJECT IDENTIFIER ::= {
      joint-iso-itu-t(2) country(16) us(840) organization(1)
      entrust(114027) algorithm(80) composite-mldsa(9) signature(1) 36 }

   pk-MLDSA87-RSA4096-PSS-SHA512 PUBLIC-KEY ::=
     pk-CompositeSignature{ id-MLDSA87-RSA4096-PSS-SHA512}

   sa-MLDSA87-RSA4096-PSS-SHA512 SIGNATURE-ALGORITHM ::=
       sa-CompositeSignature{
          id-MLDSA87-RSA4096-PSS-SHA512,
          pk-MLDSA87-RSA4096-PSS-SHA512 }


   -- TODO: OID to be replaced by IANA
   id-MLDSA87-ECDSA-P521-SHA512 OBJECT IDENTIFIER ::= {
      joint-iso-itu-t(2) country(16) us(840) organization(1)
      entrust(114027) algorithm(80) composite-mldsa(9) signature(1) 37 }

   pk-MLDSA87-ECDSA-P521-SHA512 PUBLIC-KEY ::=
     pk-CompositeSignature{ id-MLDSA87-ECDSA-P521-SHA512}

   sa-MLDSA87-ECDSA-P521-SHA512 SIGNATURE-ALGORITHM ::=
       sa-CompositeSignature{
          id-MLDSA87-ECDSA-P521-SHA512,
          pk-MLDSA87-ECDSA-P521-SHA512 }


   SignatureAlgorithmSet SIGNATURE-ALGORITHM ::= {
     sa-MLDSA44-RSA2048-PSS-SHA256 |
     sa-MLDSA44-RSA2048-PKCS15-SHA256 |
     sa-MLDSA44-Ed25519-SHA512 |
     sa-MLDSA44-ECDSA-P256-SHA256 |
     sa-MLDSA65-RSA3072-PSS-SHA512 |
     sa-MLDSA65-RSA3072-PKCS15-SHA512 |
     sa-MLDSA65-RSA4096-PSS-SHA512 |
     sa-MLDSA65-RSA4096-PKCS15-SHA512 |
     sa-MLDSA65-ECDSA-P256-SHA512 |
     sa-MLDSA65-ECDSA-P384-SHA512 |
     sa-MLDSA65-ECDSA-brainpoolP256r1-SHA512 |
```

```
    sa-MLDSA65-Ed25519-SHA512 |
    sa-MLDSA87-ECDSA-P384-SHA512 |
    sa-MLDSA87-ECDSA-brainpoolP384r1-SHA512 |
    sa-MLDSA87-Ed448-SHAKE256 |
    sa-MLDSA87-RSA3072-PSS-SHA512 |
    sa-MLDSA87-RSA4096-PSS-SHA512 |
    sa-MLDSA87-ECDSA-P521-SHA512,
    ... }

END
```

<CODE ENDS>

9. IANA Considerations

IANA is requested to assign an object identifier (OID) for the module identifier (TBDMOD) with a Description of "id-mod-composite-mldsa-2025". The OID for the module should be allocated in the "SMI Security for PKIX Module Identifier" registry (1.3.6.1.5.5.7.0).

IANA is also requested to allocate values from the "SMI Security for PKIX Algorithms" registry (1.3.6.1.5.5.7.6) to identify the eighteen algorithms defined within.

9.1. Object Identifier Allocations

EDNOTE to IANA: OIDs will need to be replaced in both the ASN.1 module and in Section 7.

9.1.1. Module Registration

The following is to be registered in "SMI Security for PKIX Module Identifier":

* Decimal: IANA Assigned - *Replace TBDMOD*
* Description: Composite-Signatures-2025 - id-mod-composite-signatures
* References: This Document

9.1.2. Object Identifier Registrations

The following are to be registered in "SMI Security for PKIX Algorithms":

* id-MLDSA44-RSA2048-PSS-SHA256

- Decimal: IANA Assigned
- Description: id-MLDSA44-RSA2048-PSS-SHA256
- References: This Document

* id-MLDSA44-RSA2048-PKCS15-SHA256
  - Decimal: IANA Assigned
  - Description: id-MLDSA44-RSA2048-PKCS15-SHA256
  - References: This Document
* id-MLDSA44-Ed25519-SHA512
  - Decimal: IANA Assigned
  - Description: id-MLDSA44-Ed25519-SHA512
  - References: This Document
* id-MLDSA44-ECDSA-P256-SHA256
  - Decimal: IANA Assigned
  - Description: id-MLDSA44-ECDSA-P256-SHA256
  - References: This Document
* id-MLDSA65-RSA3072-PSS-SHA512
  - Decimal: IANA Assigned
  - Description: id-MLDSA65-RSA3072-PSS-SHA512
  - References: This Document
* id-MLDSA65-RSA3072-PKCS15-SHA512
  - Decimal: IANA Assigned
  - Description: id-MLDSA65-RSA3072-PKCS15-SHA512
  - References: This Document
* id-MLDSA65-RSA4096-PSS-SHA512

- Decimal: IANA Assigned
- Description: id-MLDSA65-RSA4096-PSS-SHA512
- References: This Document

* id-MLDSA65-RSA4096-PKCS15-SHA512
  - Decimal: IANA Assigned
  - Description: id-MLDSA65-RSA4096-PKCS15-SHA512
  - References: This Document
* id-MLDSA65-ECDSA-P256-SHA512
  - Decimal: IANA Assigned
  - Description: id-MLDSA65-ECDSA-P256-SHA512
  - References: This Document
* id-MLDSA65-ECDSA-P384-SHA512
  - Decimal: IANA Assigned
  - Description: id-MLDSA65-ECDSA-P384-SHA512
  - References: This Document
* id-MLDSA65-ECDSA-brainpoolP256r1-SHA512
  - Decimal: IANA Assigned
  - Description: id-MLDSA65-ECDSA-brainpoolP256r1-SHA512
  - References: This Document
* id-MLDSA65-Ed25519-SHA512
  - Decimal: IANA Assigned
  - Description: id-MLDSA65-Ed25519-SHA512
  - References: This Document
* id-MLDSA87-ECDSA-P384-SHA512

- Decimal: IANA Assigned
- Description: id-MLDSA87-ECDSA-P384-SHA512
- References: This Document

* id-MLDSA87-ECDSA-brainpoolP384r1-SHA512
  - Decimal: IANA Assigned
  - Description: id-MLDSA87-ECDSA-brainpoolP384r1-SHA512
  - References: This Document
* id-MLDSA87-Ed448-SHAKE256
  - Decimal: IANA Assigned
  - Description: id-MLDSA87-Ed448-SHAKE256
  - References: This Document
* id-MLDSA87-RSA3072-PSS-SHA512
  - Decimal: IANA Assigned
  - Description: id-MLDSA87-RSA3072-PSS-SHA512
  - References: This Document
* id-MLDSA87-RSA4096-PSS-SHA512
  - Decimal: IANA Assigned
  - Description: id-MLDSA87-RSA4096-PSS-SHA512
  - References: This Document
* id-MLDSA87-ECDSA-P521-SHA512
  - Decimal: IANA Assigned
  - Description: id-MLDSA87-ECDSA-P521-SHA512
  - References: This Document

10. Security Considerations

10.1. Why Hybrids?

In broad terms, a PQ/T Hybrid can be used either to provide dual-algorithm security or to provide migration flexibility. Let’s quickly explore both.

Dual-algorithm security. The general idea is that the data is protected by two algorithms such that an adversary would need to break both in order to compromise the data. As with most of cryptography, this property is easy to state in general terms, but becomes more complicated when expressed in formalisms. Section 10.2 goes into more detail here. One common counter-argument against PQ/T hybrid signatures is that if an adversary can forge one of the component algorithms, then why attack the hybrid-signed message at all when they could simply forge a completely new message? The answer to this question must be found outside the cryptographic primitives themselves, and instead in policy; once an algorithm is known to be broken it ought to be disallowed for single-algorithm use by cryptographic policy, while hybrids involving that algorithm may continue to be used and to provide value, and also in the fact that the composite public key could be trusted by the verifier while the component keys in isolation are not, thus requiring the adversary to forge a whole composite signature.

Migration flexibility. Some PQ/T hybrids exist to provide a sort of "OR" mode where the application can choose to use one algorithm or the other or both. The intention is that the PQ/T hybrid mechanism builds in backwards compatibility to allow legacy and upgraded applications to co-exist and communicate. The composites presented in this specification do not provide this since they operate in a strict "AND" mode. They do, however, provide codebase migration flexibility. Consider that an organization has today a mature, validated, certified, hardened implementation of RSA or ECC; composites allow them to add an ML-DSA implementation which immediately starts providing benefits against long-term document integrity attacks even if that ML-DSA implementation is still an experimental, non-validated, non-certified, non-hardened implementation. More details of obtaining FIPS certification of a composite algorithm can be found in Section 11.1.

10.2. EUF-CMA, SUF-CMA and non-separability

First, a note about the security model under which this analysis is performed. This specification strictly forbids re-using component key material between composite and non-composite keys, or between multiple composite keys. This specification also exists within the X.509 PKI architecture where trust in a public verification key is assumed to be established either directly via a trust store or via a

certificate chain. That said, these are both policy mechanisms that are outside the formal definitions of EUF-CMA and SUF-CMA under which a signature primitive must be analysed, therefore this section considers attacks that may be mitigated partially or completely within a strictly-implemented PKI setting, but which need to be considered when considering Composite ML-DSA as a general-purpose signature primitive that could be used outside of the X.509 setting.

The second securtiy model considiration is that composites are designed to provide value even if one algorithm is broken, even if you do not know which. However, the security properties offered by the composite signature can differ based on which algorithm you consider to be broken.

10.2.1. EUF-CMA

A signature algorithm is Existentially Unforgeable under Chosen-Message Attack (EUF-CMA) if an adversary that has access to a signing oracle cannot create a message-signature pair (M, Sig) that would be accepted by the verifier for any message M that was not an input to a signing oracle query.

In general, Composite ML-DSA will be EUF-CMA secure if at least one of the component algorithms is EUF-CMA secure and PH is collision resistant. Any algorithm that creates an existential forgery (M, (mldsaSig, tradSig)) for Composite ML-DSA can be converted into a pair of algorithms that will either create existential forgeries (M', mldsaSig) and (M', tradSig) for the component algorithms or a collision in PH.

However, the nature of the EUF-CMA security guarantee can still change if one of the component algorithms is broken:

* If the traditional component is broken, then Composite ML-DSA will remain EUF-CMA secure against quantum adversaries.

* If ML-DSA is broken, then Composite ML-DSA will only be EUF-CMA secure against classical adversaries.

The same properties will hold for X.509 certificates that use Composite ML-DSA: a classical adversary cannot forge a Composite ML-DSA signed certificate if at least one component algorithm is classically EUF-CMA secure, and a quantum adversary cannot forge a Composite ML-DSA signed certificate if ML-DSA remains quantumly EUF-CMA secure.

10.2.2. SUF-CMA

A signature algorithm is Strongly Unforgeable under Chosen-Message Attack (SUF-CMA) if an adversary that has access to a signing oracle cannot create a message-signature pair (M, Sig) that was not an output of a signing oracle query. This is a stronger property than EUF-CMA since the message M does not need to be different. SUF-CMA security is also more complicated for Composite ML-DSA than EUF-CMA.

A SUF-CMA failure in one component algorithm can lead to a SUF-CMA failure in the composite. For example, an ECDSA signature can be trivially modified to produce a different signature that is still valid for the same message and this property passes directly through to Composite ML-DSA with ECDSA.

Unfortunately, it is not generally sufficient for both component algorithms to be SUF-CMA secure. If repeated calls to the signing oracle produce two valid message-signature pairs (M, (mldsaSig1, tradSig1)) and (M, (mldsaSig2, tradSig2)) for the same message M, but where mldsaSig1 =/= mldsaSig2 and tradSig1 =/= tradSig2, then the adversary can construct a third pair (M, (mldsaSig1, tradSig2)) that will also be valid.

Nevertheless, Composite ML-DSA will not be SUF-CMA secure, and Composite ML-DSA signed X.509 certificates will not be strongly unforgeable, against quantum adversaries since a quantum adversary will be able to break the SUF-CMA security of the traditional component.

Consequently, applications where SUF-CMA security is critical SHOULD NOT use Composite ML-DSA.

10.2.3. Non-separability

Weak Non-Separability (WNS) of a hybrid signature is defined in [I-D.ietf-pquip-hybrid-signature-spectrums] as the guarantee that an adversary cannot simply "remove" one of the component signatures without evidence left behind.

Strong Non-Separability (SNS) is the stronger notion that an adversary cannot take a hybrid signature and produce a component signature, with a potentially different message, that will be accepted by the component verifier.

Composite ML-DSA signs a message M by passing M′ as defined in Section 3.2 to the component signature primitives. Consider an adversary that takes a composite signature (M, (mldsaSig, tradSig)) and splits it into the component signatures (M′, mldsaSig) and (M′,

tradSig). On the traditional side, (M', tradSig) will verify correctly, but the static Prefix defined in Section 3.2 remains as evidence of the original composite. On the ML-DSA side, (M', mldsaSig) is signed with ML-DSA's context value equal to the composite algorithm's Label so will fail to verify under ML-DSA.Verify(M', ctx=""). Consequently, Composite ML-DSA will provide WNS for both components and a limited form of SNS for the ML-DSA component. It can achieve stronger non-separability in practice for both components if the prefix-based mitigation described in Section 10.4 is applied.

When used within X.509, the OID of the signature algorithm is included in the signed object so if one of the component signatures is removed from the Composite ML-DSA signature then the signed-over OID will still indicate the composite algorithm, and this will fail at the X.509 processing layer. Composite ML-DSA therefore provides a version of SNS for X.509. The prohibition on key reuse between composite and single-algorithm contexts discussed in Section 10.3 further strengthens the non-separability in practice.

10.3. Key Reuse

While conformance with this specification requires that both components of a composite key MUST be freshly generated, the designers are aware that some implementers may be forced to break this rule due to operational constraints. This section documents the implications of doing so.

When using single-algorithm cryptography, the best practice is to always generate fresh key material for each purpose, for example when renewing a certificate, or obtaining both a TLS and S/MIME certificate for the same device. However, in practice key reuse in such scenarios is not always catastrophic to security and therefore often tolerated. However this reasoning does not hold in the PQ/T hybrid setting.

Within the broader context of PQ/T hybrids, we need to consider new attack surfaces that arise due to the hybrid constructions that did not exist in single-algorithm contexts. One of these is key reuse where the component keys within a hybrid are also used by themselves within a single-algorithm context. For example, it might be tempting for an operator to take an already-deployed RSA key pair and combine it with an ML-DSA key pair to form a hybrid key pair for use in a hybrid algorithm. Within a hybrid signature context this leads to a class of attacks referred to as "stripping attacks" discussed in Section 10.2 and may also open up risks from further cross-protocol attacks. Despite the weak non-separability property offered by the composite signature combiner, key reuse MUST be avoided to prevent the introduction of EUF-CMA vulnerabilities.

In addition, there is a further implication to key reuse regarding certificate revocation. Upon receiving a new certificate enrolment request, many certification authorities will check if the requested public key has been previously revoked due to key compromise. Often a CA will perform this check by using the public key hash. Therefore, if one, or even both, components of a composite have been previously revoked, the CA may only check the hash of the combined composite key and not find the revocations. Therefore, because the possibility of key reuse exists even though forbidden in this specification, CAs performing revocation checks on a composite key SHOULD also check both component keys independently to verify that the component keys have not been revoked.

Some application might disregard the requirements of this specification to not reuse key material between single-algorithm and composite contexts. While doing so is still a violation of this specification, the weakening of security from doing so can be mitigated by using an appropriate ctx value, such as ctx=Foobar-dual-cert-sig to indicate that this signature belongs to the Foobar protocol where two certificates were used to create a single composite signature. This specification does not endorse such uses, and per-application security analysis is needed.

10.4. Use of Prefix for attack mitigation

The Prefix value specified in Section 3.2 allows for cautious implementers to wrap their existing Traditional Verify() implementations with a guard that looks for messages starting with this string and fail with an error -- i.e. this can act as an extra protection against taking a composite signature and splitting it back into components. However, an implementation that does this will be unable to perform a Traditional signature and verification on a message which happens to start with this string. The designers accepted this trade-off.

10.5. Policy for Deprecated and Acceptable Algorithms

Traditionally, a public key or certificate contains a single cryptographic algorithm. If and when an algorithm becomes deprecated (for example, RSA-512, or SHA1), the path to deprecating it through policy and removing it from operational environments is, at least is principle, straightforward.

In the composite model this is less obvious since a PQ/T hybrid is expected to still be considered valid after the traditional component is deprecated for individual use. As such, a single composite public key or certificate may contain a mixture of deprecated and non-deprecated algorithms. In general this should be manageable through policy by removing OIDs for the standalone component algorithms while still allowing OIDs for composite algorithms. However, complications may arise when the composite implementation needs to invoke the cryptographic module for a deprecated component algorithm. In particular, this could lead to complex Cryptographic Bills of Materials that show implementations of deprecated algorithms still present and being used.

11. Implementation Considerations

11.1. FIPS certification

The following sections give guidance to implementers wishing to FIPS-certify a composite implementation.

This guidance is not authoritative and has not been endorsed by NIST.

One of the primary design goals of this specification is for the overall composite algorithm to be able to be considered FIPS-approved even when one of the component algorithms is not.

Implementers seeking FIPS certification of a composite signature algorithm where only one of the component algorithms has been FIPS-validated or FIPS-approved should credit the FIPS-validated component algorithm with full security strength, the non-FIPS-validated component algorithm with zero security, and the overall composite should be considered at least as strong and thus FIPS-approved.

The composite algorithm has been designed to treat the underlying primitives as "black-box implementations" and not impose any additional requirements on them that could require an existing implementation of an underlying primitive to run in a mode different from the one under which it was certified. For example, the KeyGen defined in Section 4.1 invokes ML-DSA.KeyGen_internal(seed) which might not be available in a cryptographic module running in FIPS-

mode, but Section 4.1 is only a suggested implementation and the composite KeyGen MAY be implemented using a different available interface for ML-DSA.KeyGen. However, using an interface which doesn't support a seed will prevent the implementation from encoding the private key according to Section 5.2. Another example is pre-hashing; a pre-hash is inherent to RSA, ECDSA, and ML-DSA (ホシ), and composite makes no assumptions or requirements about whether component-specific pre-hashing is done locally as part of the composite, or remotely as part of the component primitive.

Note also that also that Section 4.1 depicts the generation of the seed as mldsaSeed = Random(), when implementing this for FIPS certification, this MUST be the direct output of a FIPS-approved DRBG.

The authors wish to note that composite algorithms provide a design pattern to provide utility in future situations that require care to remain FIPS-compliant, such as future cryptographic migrations as well as bridging across jurisdictions with non-intersecting cryptographic requirements.

11.2. Backwards Compatibility

The term "backwards compatibility" is used here to mean that existing systems as they are deployed today can interoperate with the upgraded systems of the future. This document explicitly does not provide backwards compatibility, only upgraded systems will understand the OIDs defined in this specification.

If backwards compatibility is required, then additional mechanisms will be needed. Migration and interoperability concerns need to be thought about in the context of various types of protocols that make use of X.509 and PKIX with relation to digital signature objects, from online negotiated protocols such as TLS 1.3 [RFC8446] and IKEv2 [RFC7296], to non-negotiated asynchronous protocols such as S/MIME signed email [RFC8551], document signing such as in the context of the European eIDAS regulations [eIDAS2014], and publicly trusted code signing [codesigningbrsv3.8], as well as myriad other standardized and proprietary protocols and applications that leverage CMS [RFC5652] signed structures. Composite simplifies the protocol design work because it can be implemented as a signature algorithm that fits into existing systems.

11.3. Profiling down the number of options

One daunting aspect of this specification is the number of composite algorithm combinations. Each option has been specified because there is a community that has a direct application for it; typically because the traditional component is already deployed in a change-managed environment, or because that specific traditional component is required for regulatory reasons.

However, this large number of combinations leads either to fracturing of the ecosystem into non-interoperable sub-groups when different communities choose non-overlapping subsets to support, or on the other hand it leads to spreading development resources too thin when trying to support all options.

This specification does not list any particular composite algorithm as mandatory-to-implement, however organizations that operate within specific application domains are encouraged to define profiles that select a small number of composites appropriate for that application domain.

For applications that do not have any regulatory requirements or legacy implementations to consider, it is RECOMMENDED to focus implementation effort on as it provides the best overall balance of performance and security.

id-MLDSA65-ECDSA-P256-SHA512

Below we list a few other recommendations for specific scenarios.

In applications that require RSA, it is RECOMMENDED to focus implementation effort on:

id-MLDSA65-RSA3072-PSS-SHA512

In applications that are performance and bandwidth-sensitive, it is RECOMMENDED to focus implementation effort on:

id-MLDSA44-ECDSA-P256-SHA256
or
id-MLDSA44-Ed25519-SHA512

In applications that only allow NIST PQC Level 5, it is RECOMMENDED to focus implementation effort on:

id-MLDSA87-ECDSA-P384-SHA512

In applications that require the signature primitive to provide SUF-CMA, it is RECOMMENDED to focus implementation effort on:

id-MLDSA65-Ed25519-SHA512

11.4. External Pre-hashing

Implementers MAY externalize the pre-hash computation outside the module that computes Composite-ML-DSA.Sign() in an analogous way to how pre-hash signing is used for RSA, ECDSA or HashML-DSA. Such a modification to the Composite-ML-DSA.Sign() algorithm is considered compliant to this specification so long as it produces the same output and error conditions.

Below is a suggested implementation for splitting the pre-hashing and signing between two parties.

Composite-ML-DSA<OID>.Prehash(M) -> ph

Explicit inputs:

M The message to be signed, an octet string.

Implicit inputs mapped from <OID>:

PH The hash function to use for pre-hashing.

Output:

ph The pre-hash which equals PH (M)

Process:

1. Compute the Prehash of the message using the Hash function defined by PH

   ph = PH (M)

2. Output ph

Composite-ML-DSA<OID>.Sign_ph(sk, ph, ctx) -> s

Explicit inputs:

sk Composite private key consisting of signing private keys for each component.

ph The pre-hash digest over the message

ctx The Message context string used in the composite signature combiner, which defaults to the empty string.

Implicit inputs mapped from <OID>:

ML-DSA The underlying ML-DSA algorithm and parameter set, for example "ML-DSA-65".

Trad The underlying traditional algorithm and parameter set, for example "sha256WithRSAEncryption" or "Ed25519".

Prefix The prefix octet string.

Label A signature label which is specific to each composite algorithm. Additionally, the composite label is passed into the underlying ML-DSA primitive as the ctx. Signature Label values are defined in the "Signature Label Values" section below.

Process:

1. Identical to Composite-ML-DSA<OID>.Sign (sk, M, ctx) but replace the internally generated PH(M) from step 2 of Composite-ML-DSA<OID>.Sign (sk, M, ctx) with ph which is input into this function.

12. References

12.1. Normative References

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Appendix A. Maximum Key and Signature Sizes

The sizes listed below are maximas. Several factors could cause fluctuations in the size of the traditional component. For example, this could be due to:

* Compressed vs uncompressed EC point.

* The RSA public key (n, e) allows e to vary is size between 3 and n - 1 [RFC8017]. Note that the size table below assumes the recommended value of e = 65537, so for RSA combinations it is in fact not a true maximum.

* When the underlying RSA or EC value is itself DER-encoded, integer values could occasionally be shorter than expected due to leading zeros being dropped from the encoding.

Size values marked with an asterisk (*) in the table are not fixed but maximum possible values for the composite key or ciphertext. Implementations should be careful when performing length checking based on such values.

Non-hybrid ML-DSA is included for reference.

Algorithm	Public key	Private key	Signature
id-ML-DSA-44	1312	32	2420
id-ML-DSA-65	1952	32	3309
id-ML-DSA-87	2592	32	4627
id-MLDSA44-RSA2048-PSS-SHA256	1582*	1226*	2676
id-MLDSA44-RSA2048-PKCS15-SHA256	1582*	1226*	2676
id-MLDSA44-Ed25519-SHA512	1344	64	2484
id-MLDSA44-ECDSA-P256-SHA256	1377	83	2492*
id-MLDSA65-RSA3072-PSS-SHA512	2350*	1802*	3693
id-MLDSA65-RSA3072-PKCS15-SHA512	2350*	1802*	3693
id-MLDSA65-RSA4096-PSS-SHA512	2478*	2383*	3821
id-MLDSA65-RSA4096-PKCS15-SHA512	2478*	2383*	3821
id-MLDSA65-ECDSA-P256-SHA512	2017	83	3381*
id-MLDSA65-ECDSA-P384-SHA512	2049	96	3413*
id-MLDSA65-ECDSA-brainpoolP256r1-SHA512	2017	84	3381*
id-MLDSA65-Ed25519-SHA512	1984	64	3373
id-MLDSA87-ECDSA-P384-SHA512	2689	96	4731*
id-MLDSA87-ECDSA-brainpoolP384r1-SHA512	2689	100	4731*

id-MLDSA87-Ed448-SHAKE256	2649	89	4741
id-MLDSA87-RSA3072-PSS-SHA512	2990*	1802*	5011
id-MLDSA87-RSA4096-PSS-SHA512	3118*	2383*	5139
id-MLDSA87-ECDSA-P521-SHA512	2725	114	4766*

Table 4: Maximum size values of composite ML-DSA

Appendix B. Component Algorithm Reference

This section provides references to the full specification of the algorithms used in the composite constructions.

Component Signature Algorithm ID	OID	Specification
id-ML-DSA-44	2.16.840.1.101.3.4.3.17	[FIPS.204]
id-ML-DSA-65	2.16.840.1.101.3.4.3.18	[FIPS.204]
id-ML-DSA-87	2.16.840.1.101.3.4.3.19	[FIPS.204]
id-Ed25519	1.3.101.112	[RFC8032], [RFC8410]
id-Ed448	1.3.101.113	[RFC8032], [RFC8410]
ecdsa-with-SHA256	1.2.840.10045.4.3.2	[RFC3279], [RFC5915], [RFC5758], [RFC5480], [SEC1], [X9.62_2005]
ecdsa-with-SHA384	1.2.840.10045.4.3.3	[RFC3279], [RFC5915], [RFC5758], [RFC5480], [SEC1], [X9.62_2005]
ecdsa-with-SHA512	1.2.840.10045.4.3.4	[RFC3279], [RFC5915], [RFC5758], [RFC5480], [SEC1], [X9.62_2005]
sha256WithRSAEncryption	1.2.840.113549.1.1.11	[RFC8017]
sha384WithRSAEncryption	1.2.840.113549.1.1.12	[RFC8017]
id-RSASSA-PSS	1.2.840.113549.1.1.10	[RFC8017]

Table 5: Component Signature Algorithms used in Composite Constructions

Elliptic CurveID	OID	Specification
secp256r1	1.2.840.10045.3.1.7	[RFC6090], [SEC2]
secp384r1	1.3.132.0.34	[RFC5480], [RFC6090], [SEC2]
secp521r1	1.3.132.0.35	[RFC5480], [RFC6090], [SEC2]
brainpoolP256r1	1.3.36.3.3.2.8.1.1.7	[RFC5639]
brainpoolP384r1	1.3.36.3.3.2.8.1.1.11	[RFC5639]

Table 6: Elliptic Curves used in Composite Constructions

HashID	OID	Specification
id-sha256	2.16.840.1.101.3.4.2.1	[RFC6234]
id-sha384	2.16.840.1.101.3.4.2.2	[RFC6234]
id-sha512	2.16.840.1.101.3.4.2.3	[RFC6234]
id-shake256	2.16.840.1.101.3.4.2.18	[FIPS.202]
id-mgf1	1.2.840.113549.1.1.8	[RFC8017]

Table 7: Hash algorithms used in pre-hashed Composite Constructions to build PH element

Appendix C. Component AlgorithmIdentifiers for Public Keys and Signatures

Many cryptographic libraries are X.509-focused and do not expose interfaces to instantiate a public key from raw bytes, but only from a SubjectPublicKeyInfo structure as you would find in an X.509 certificate, therefore implementing composite in those libraries requires reconstructing the SPKI for each component algorithm. In order to aid implementers and reduce interoperability issues, this section lists out the full public key and signature AlgorithmIdentifiers for each component algorithm.

For newer Algorithms like Ed25519 or ML-DSA the AlgorithmIdentifiers are the same for Public Key and Signature. Older Algorithms have different AlgorithmIdentifiers for keys and signatures and are specified separately here for each component.

ML-DSA-44

AlgorithmIdentifier of Public Key and Signature

ASN.1:

```
  algorithm AlgorithmIdentifier ::= {
    algorithm id-ML-DSA-44   -- (2 16 840 1 101 3 4 3 17)
   }
```

DER:

```
  30 0B 06 09 60 86 48 01 65 03 04 03 11
```

ML-DSA-65

AlgorithmIdentifier of Public Key and Signature

ASN.1:

```
  algorithm AlgorithmIdentifier ::= {
    algorithm id-ML-DSA-65   -- (2 16 840 1 101 3 4 3 18)
   }
```

DER:

```
  30 0B 06 09 60 86 48 01 65 03 04 03 12
```

ML-DSA-87

AlgorithmIdentifier of Public Key and Signature

ASN.1:

```
  algorithm AlgorithmIdentifier ::= {
    algorithm id-ML-DSA-87   -- (2 16 840 1 101 3 4 3 19)
   }
```

DER:

```
  30 0B 06 09 60 86 48 01 65 03 04 03 13
```

RSASSA-PSS 2048 & 3072

AlgorithmIdentifier of Public Key

Note that we suggest here to use id-RSASSA-PSS (1.2.840.113549.1.1.10) as the public key OID for RSA-PSS, although most implementations also would accept rsaEncryption (1.2.840.113549.1.1.1), and some might in fact prefer or require it.

ASN.1:

```
  algorithm AlgorithmIdentifier ::= {
    algorithm id-RSASSA-PSS   -- (1.2.840.113549.1.1.10)
    }
```

DER:

```
  30 0B 06 09 2A 86 48 86 F7 0D 01 01 0A
```

AlgorithmIdentifier of Signature

ASN.1:

```
  signatureAlgorithm AlgorithmIdentifier ::= {
    algorithm id-RSASSA-PSS,   -- (1.2.840.113549.1.1.10)
    parameters ANY ::= {
      AlgorithmIdentifier ::= {
        algorithm id-sha256,   -- (2.16.840.1.101.3.4.2.1)
        parameters NULL
        },
      AlgorithmIdentifier ::= {
        algorithm id-mgf1,       -- (1.2.840.113549.1.1.8)
        parameters AlgorithmIdentifier ::= {
          algorithm id-sha256,   -- (2.16.840.1.101.3.4.2.1)
          parameters NULL
          }
        },
      saltLength 32
      }
    }
```

DER:

```
  30 41 06 09 2A 86 48 86 F7 0D 01 01 0A 30 34 A0
  0F 30 0D 06 09 60 86 48 01 65 03 04 02 01 05 00
  A1 1C 30 1A 06 09 2A 86 48 86 F7 0D 01 01 08 30
  0D 06 09 60 86 48 01 65 03 04 02 01 05 00 A2 03
  02 01 20
```

RSASSA-PSS 4096

AlgorithmIdentifier of Public Key

```
ASN.1:
  algorithm AlgorithmIdentifier ::= {
    algorithm id-RSASSA-PSS   -- (1.2.840.113549.1.1.10)
    }

DER:
  30 0B 06 09 2A 86 48 86 F7 0D 01 01 0A
```

AlgorithmIdentifier of Signature

```
ASN.1:
  signatureAlgorithm AlgorithmIdentifier ::= {
    algorithm id-RSASSA-PSS,   -- (1.2.840.113549.1.1.10)
    parameters ANY ::= {
      AlgorithmIdentifier ::= {
        algorithm id-sha384,   -- (2.16.840.1.101.3.4.2.2)
        parameters NULL
        },
      AlgorithmIdentifier ::= {
        algorithm id-mgf1,       -- (1.2.840.113549.1.1.8)
        parameters AlgorithmIdentifier ::= {
          algorithm id-sha384,   -- (2.16.840.1.101.3.4.2.2)
          parameters NULL
          }
        },
      saltLength 64
      }
    }

DER:
  30 41 06 09 2A 86 48 86 F7 0D 01 01 0A 30 34 A0
  0F 30 0D 06 09 60 86 48 01 65 03 04 02 02 05 00
  A1 1C 30 1A 06 09 2A 86 48 86 F7 0D 01 01 08 30
  0D 06 09 60 86 48 01 65 03 04 02 02 05 00 A2 03
  02 01 40

*RSASSA-PKCS1-v1_5 2048 & 3072*
```

AlgorithmIdentifier of Public Key

```
ASN.1:
  algorithm AlgorithmIdentifier ::= {
    algorithm rsaEncryption,   -- (1.2.840.113549.1.1.1)
    parameters NULL
    }

DER:
  30 0D 06 09 2A 86 48 86 F7 0D 01 01 01 05 00
```

AlgorithmIdentifier of Signature

ASN.1:

```
signatureAlgorithm AlgorithmIdentifier ::= {
  algorithm sha256WithRSAEncryption,   -- (1.2.840.113549.1.1.11)
  parameters NULL
  }
```

DER:

```
30 0D 06 09 2A 86 48 86 F7 0D 01 01 0D 05 00
```

RSASSA-PKCS1-v1_5 4096

AlgorithmIdentifier of Public Key

ASN.1:

```
algorithm AlgorithmIdentifier ::= {
  algorithm rsaEncryption,   -- (1.2.840.113549.1.1.1)
  parameters NULL
  }
```

DER:

```
30 0D 06 09 2A 86 48 86 F7 0D 01 01 01 05 00
```

AlgorithmIdentifier of Signature

ASN.1:

```
signatureAlgorithm AlgorithmIdentifier ::= {
  algorithm sha384WithRSAEncryption,   -- (1.2.840.113549.1.1.12)
  parameters NULL
  }
```

DER:

```
30 0D 06 09 2A 86 48 86 F7 0D 01 01 0C 05 00
```

ECDSA NIST P256

AlgorithmIdentifier of Public Key

```
ASN.1:
  algorithm AlgorithmIdentifier ::= {
    algorithm id-ecPublicKey   -- (1.2.840.10045.2.1)
    parameters ANY ::= {
      AlgorithmIdentifier ::= {
        algorithm secp256r1   -- (1.2.840.10045.3.1.7)
        }
      }
    }

DER:
  30 13 06 07 2A 86 48 CE 3D 02 01 06 08 2A 86 48 CE 3D 03 01 07

AlgorithmIdentifier of Signature

ASN.1:
  signature AlgorithmIdentifier ::= {
    algorithm ecdsa-with-SHA256   -- (1.2.840.10045.4.3.2)
    }

DER:
  30 0A 06 08 2A 86 48 CE 3D 04 03 02

*ECDSA NIST P384*

AlgorithmIdentifier of Public Key

ASN.1:
  algorithm AlgorithmIdentifier ::= {
    algorithm id-ecPublicKey   -- (1.2.840.10045.2.1)
    parameters ANY ::= {
      AlgorithmIdentifier ::= {
        algorithm secp384r1   -- (1.3.132.0.34)
        }
      }
    }

DER:
  30 10 06 07 2A 86 48 CE 3D 02 01 06 05 2B 81 04 00 22

AlgorithmIdentifier of Signature
```

```
ASN.1:
  signature AlgorithmIdentifier ::= {
    algorithm ecdsa-with-SHA384   -- (1.2.840.10045.4.3.3)
    }

DER:
  30 0A 06 08 2A 86 48 CE 3D 04 03 03
```

ECDSA NIST P521

AlgorithmIdentifier of Public Key

```
ASN.1:
  algorithm AlgorithmIdentifier ::= {
    algorithm id-ecPublicKey   -- (1.2.840.10045.2.1)
    parameters ANY ::= {
      AlgorithmIdentifier ::= {
        algorithm secp521r1   -- (1.3.132.0.35)
        }
      }
    }

DER:
  30 10 06 07 2A 86 48 CE 3D 02 01 06 05 2B 81 04 00 23
```

AlgorithmIdentifier of Signature

```
ASN.1:
  signature AlgorithmIdentifier ::= {
    algorithm ecdsa-with-SHA512   -- (1.2.840.10045.4.3.4)
    }

DER:
  30 0A 06 08 2A 86 48 CE 3D 04 03 04
```

ECDSA Brainpool-P256

AlgorithmIdentifier of Public Key

```
ASN.1:
  algorithm AlgorithmIdentifier ::= {
    algorithm id-ecPublicKey   -- (1.2.840.10045.2.1)
    parameters ANY ::= {
      AlgorithmIdentifier ::= {
        algorithm brainpoolP256r1   -- (1.3.36.3.3.2.8.1.1.7)
        }
      }
    }

DER:
  30 14 06 07 2A 86 48 CE 3D 02 01 06 09 2B 24 03
  03 02 08 01 01 07

AlgorithmIdentifier of Signature

ASN.1:
  signature AlgorithmIdentifier ::= {
    algorithm ecdsa-with-SHA256   -- (1.2.840.10045.4.3.2)
    }

DER:
  30 0A 06 08 2A 86 48 CE 3D 04 03 02

*ECDSA Brainpool-P384*

AlgorithmIdentifier of Public Key

ASN.1:
  algorithm AlgorithmIdentifier ::= {
    algorithm id-ecPublicKey   -- (1.2.840.10045.2.1)
    parameters ANY ::= {
      AlgorithmIdentifier ::= {
        algorithm brainpoolP384r1   -- (1.3.36.3.3.2.8.1.1.11)
        }
      }
    }

DER:
  30 14 06 07 2A 86 48 CE 3D 02 01 06 09 2B 24 03
  03 02 08 01 01 0B

AlgorithmIdentifier of Signature
```

```
ASN.1:
  signature AlgorithmIdentifier ::= {
    algorithm ecdsa-with-SHA384   -- (1.2.840.10045.4.3.3)
    }

DER:
  30 0A 06 08 2A 86 48 CE 3D 04 03 03
```

Ed25519

AlgorithmIdentifier of Public Key and Signature

```
ASN.1:
  algorithm AlgorithmIdentifier ::= {
    algorithm id-Ed25519   -- (1.3.101.112)
    }

DER:
  30 05 06 03 2B 65 70
```

Ed448

AlgorithmIdentifier of Public Key and Signature

```
ASN.1:
  algorithm AlgorithmIdentifier ::= {
    algorithm id-Ed448   -- (1.3.101.113)
    }

DER:
  30 05 06 03 2B 65 71
```

Appendix D. Message Representative Examples

This section provides examples of constructing the message representative M′, showing all intermediate values. This is intended to be useful for debugging purposes.

The input message for this example is the hex string "00 01 02 03 04 05 06 07 08 09".

Each input component is shown. Note that values are shown hex-encoded for display purposes only, they are actually raw binary values.

* Prefix is the fixed constant defined in Section 3.2.

* Label is the specific signature label for this composite algorithm, as defined in Section 7.

* len(ctx) is the length of the Message context String which is 00 when no context is used.

* ctx is the Message context string used in the composite signature combiner. It is empty in this example.

* PH(M) is the output of hashing the message M.

Finally, the fully assembled M’ is given, which is simply the concatenation of the above values.

First is an example of constructing the message representative M’ for MLDSA65-ECDSA-P256-SHA256 without a context string ctx.

Example of id-MLDSA65-ECDSA-P256-SHA512 construction of M’.

```
# Inputs:

M: 00010203040506070809
ctx: <empty>

# Components of M’:

Prefix:
436f6d706f73697465416c676f726974686d5369676e6174757265733230323235

Label: COMPSIG-MLDSA65-P256-SHA512

len(ctx): 00

ctx: <empty>
PH(M): 0f89ee1fcb7b0a4f7809d1267a029719004c5a5e5ec323a7c3523a20974f
9a3f202f56fadba4cd9e8d654ab9f2e96dc5c795ea176fa20ede8d854c342f90353
3


# Outputs:
# M’ = Prefix || Label || len(ctx) || ctx || PH(M)

M’: 436f6d706f73697465416c676f726974686d5369676e6174757265733230323
5434f4d505349472d4d4c44534136352d503235362d534841353132000f89ee1fcb
7b0a4f7809d1267a029719004c5a5e5ec323a7c3523a20974f9a3f202f56fadba4c
d9e8d654ab9f2e96dc5c795ea176fa20ede8d854c342f903533
```

Second is an example of constructing the message representative M’ for MLDSA65-ECDSA-P256-SHA256 with a context string ctx.

The inputs are similar to the first example with the exception that there is an 8 byte context string ’ctx’.

Example of id-MLDSA65-ECDSA-P256-SHA512 construction of M’.

Inputs:

M: 00010203040506070809
ctx: 0813061205162623

Components of M’:

Prefix:
436f6d706f73697465416c676f726974686d5369676e6174757265733230323 5

Label: COMPSIG-MLDSA65-P256-SHA512

len(ctx): 08

ctx: 0813061205162623

PH(M): 0f89ee1fcb7b0a4f7809d1267a029719004c5a5e5ec323a7c3523a20974f 9a3f202f56fadba4cd9e8d654ab9f2e96dc5c795ea176fa20ede8d854c342f90353 3

Outputs:
M’ = Prefix || Label || len(ctx) || ctx || PH(M)

M’: 436f6d706f73697465416c676f726974686d5369676e6174757265733230323 5434f4d505349472d4d4c44534136352d503235362d534841353132080813061205 1626230f89ee1fcb7b0a4f7809d1267a029719004c5a5e5ec323a7c3523a20974f9 a3f202f56fadba4cd9e8d654ab9f2e96dc5c795ea176fa20ede8d854c342f903533

Appendix E. Test Vectors

The following test vectors are provided in a format similar to the NIST ACVP Known-Answer-Tests (KATs).

The structure is that a global message m is signed over in all test cases. m is the ASCII string "The quick brown fox jumps over the lazy dog."

Within each test case there are the following values:

* tcId the name of the algorithm.

* pk the verification public key.

* x5c a self-signed X.509 certificate of the public key.

* sk the raw signature private key.

* sk_pkcs8 the signature private key in a PKCS#8 object.

* s the signature value.

Implementers should be able to perform the following tests using the test vectors below:

1. Load the public key pk or certificate x5c and use it to verify the signature s over the message m.

2. Validate the self-signed certificate x5c.

3. Load the signing private key sk or sk_pkcs8 and use it to produce a new signature which can be verified using the provided pk or x5c.

Test vectors are provided for each underlying ML-DSA algorithm in isolation for the purposes of debugging.

Due to the length of the test vectors, some readers will prefer to retrieve the non-word-wrapped copy from GitHub. The reference implementation written in python that generated them is also available:

https://github.com/lamps-wg/draft-composite-sigs/tree/main/src


```
{
"m":
"VGhlIHF1aWNrIGJyb3duIGZveCBqdW1wcyBvdmVyIHRoZSBsYXp5IGRvZy4=",

"tests": [
{
"tcId": "id-ML-DSA-44",
"pk": "G3anHRfMi5t8ZaM+2bv8lvdD
JaCnSayGHVU4ZE3553Xd04JleJlixI+nh/mtzHleg3DEfbA4pMUMr/04StF+aLVREqI+
6P+j4P6kPCGRfaAVHQG5gsoKo5qGySOlxLKHtgEeae1YyB8P/AZbEtQtB6qr9Lld2gX7
wd4w+WO1Cd0gA+pYaG02B8KxKB2o9WXVJtfi7uv9/XeF0ldD+I+uGxgTB9un1aomnlcR
DmbVieL/WoxSQP2nCxB2XhJ68BFqPTy0pc2zPW9l9Q9czXyM5iviPghNc3oySnuRBhS7
GMGd3eQZVQVhEWlB6CYgNK2z5tQadmPGxre4emKAIubJ4CKi7ZLVTvLMq0FjnQVl2dN/
G8xb9cyaxj0Y5BuiqGj/fuFN2Xxj34MmTIYPQl4zUSVZsKlC/kjhvP5Qmw3Sk4I7ovJw
```

DFNgKzOAkpJl+OgpfoITEBBWSQY3c3hqFxAfWr9/RnoGbBu/yDvnT7Mn+alChkCl0qu/
MeR9qaxlskOFUs95lx1YPO1KUhaCftCZIC7jQeDSgNMG+Y28hSQaBSCqz73wopjAP7jW
54hjiJ0vJcjbBwWWeNIlQtsc1Er924+1NtSYI8HvoKl6JJNMmslvikgklMnI+EbHOLWj
7xoSZzJ3tkY6+KVHdRu3WKkttuXIDhsxexU8zTLQ+6Tbe/LY6fgaTeDMJOsBIUPSHs4t
Rst9q0cS2bkX+ABpBnsoLdW4kS9RUsKF1wqVbfCM4GypxYj8x+yXNXWENANxachFItd1
Gw7MbYEZxWvuAMjcyGepXDsQ8kHWKPWjF62pdPKHEZkTHOemXHfIbYQ2dJlrOcaJpeFm
v9uLP0llxjJ94LyQd6HG9wVPwQ3kRTsQO9/GAauSbagaTTc8GKH2ZK3GRsLYD/DPOdRM
uLExnr/Kvn8HrG/6NDm7dmdOhrVXx8zuLSg1Xbcl6CC90Gk+OY/M0voEKorALb/nRVW3
FizUscqttMfRSIIkwY3dz8+wbPhLxQIhc7bSijXrM+NL685yumbQr5OfE1kNmewD/+M6
6PeVRD/Jiu7a/jIrL8E0s6Azwivbcj+YlXzdjJNgACtsilUtJk/eTS+csnjyuOeRkeiz
xOc2XKMZgrRtYM+17Hsmlk1x+yk2X5ybwRfkyBHkcDv16WrfhVmviPXoub5XDIhpox+e
LULdKlhnaPEIMAATXyyDuXE5XODRQ1sgEuBlVx9VqcbKwnGkI20/xuePARyggWqi4uWF
XyE0cBtd8jW7nEvYKuyngyI+owy5me5xsu42B8S6KKvpX+BvGgcC4SpkoH3l7XkrMrRG
9Ds5onuJJS8ydixEUoN7gKiMKgpB1sPWfK2GLagtimsLngqwh0weVDU2ba8Gju8LpLwW
rdWSOWeTPGwfyotNvlOhjZuwJJCDZE2G/z1rRlSMqt6tLrZ0GQBin5d55cJqIlYk8frV
H0alqPoWmV3PRwsFChHC285Mykh9YiB/NNcX/fPZs938i53P5lz0VQy+3J8h271c0zXJ
vVGyMX0YSiT6doODNxQnZd7wUwPPu3IEy7h6wONpwB8OWxR0oVXQ9BJSFrVNKM4zaUjK
lKYiX4GZSMS1EJi/kCV2Pg3t70Gun8VWquHvkDnZJPuER3UmGUK2wgAN6eoYd1ubdBKg
Rdb8NpkePEQNNh2GDlj+tMFT8VowvkipDOr0Yh6ujUu3IH7MZ173MzdScrgrRYOU55Dz
SHYYKUaPXE5PaE8VjMNTD2mmTg==",
"x5c": "MIIPjDCCBgKgAwIBAgIUJlQdv4mcH
hc3/t8Q7z6J5fQH/BcwCwYJYIZIAWUDBAMRMDYxDTALBgNVBAoMBElFVEYxDjAMBgNVB
AsMBUxBTVBTMRUwEwYDVQQDDAxpZC1NTC1EU0EtNDQwHhcNMjUxMDA5MTQxMDA2WhcNM
zUxMDEwMTQxMDA2WjA2MQ0wCwYDVQQKDARJRVRGMQ4wDAYDVQQLDAVMQU1QUzEVMBMGA
1UEAwwMaWQtTUwtRFNBLTQ0MIIFMjALBglghkgBZQMEAxEDggUhABt2px0XzIubfGWjP
tm7/Jb3QyWgp0mshh1VOGRN+ed13dOCZXiZYsSPp4f5rcx5XoNwxH2wOKTFDK/9OErRf
mi1URKiPuj/o+D+pDwhkX2gFR0BuYLKCqOahskjpcSyh7YBHmntWMgfD/wGWxLULQeqq
/S5XdoF+8HeMPljtQndIAPqWGhtNgfCsSgdqPVl1SbX4u7r/f13hdJXQ/iPrhsYEwfbp
9WqJp5XEQ5m1Yni/1qMUkD9pwsQdl4SevARaj08tKXNsz1vZfUPXM18jOYr4j4ITXN6M
kp7kQYUuxjBnd3kGVUFYRFpQegmIDSts+bUGnZjxsa3uHpigCLmyeAiou2S1U7yzKtBY
50FZdnTfxvMW/XMmsY9GOQboqho/37hTdl8Y9+DJkyGD0JeM1ElWbCpQv5I4bz+UJsN0
pOCO6LycAxTYCszgJKSZfjoKX6CExAQVkkGN3N4ahcQH1q/f0Z6Bmwbv8g750+zJ/mpQ
oZApdKrvzHkfamsZbJDhVLPeZcdWDztSlIWgn7QmSAu40Hg0oDTBvmNvIUkGgUgqs+98
KKYwD+41ueIY4idLyXI2wcFlnjSJULbHNRK/duPtTbUmCPB76CpeiSTTJrJb4pIJJTJy
PhGxzi1o+8aEmcyd7ZGOvilR3Ubt1ipLbblyA4bMXsVPM0y0Puk23vy2On4Gk3gzCTrA
SFD0h7OLUbLfatHEtm5F/gAaQZ7KC3VuJEvUVLChdcKlW3wjOBsqcWI/MfslzV1hDQDc
WnIRSLXdRsOzG2BGcVr7gDI3MhnqVw7EPJB1ij1oxetqXTyhxGZExznplx3yG2ENnSZa
znGiaXhZr/biz9JZcYyfeC8kHehxvcFT8EN5EU7EDvfxgGrkm2oGk03PBih9mStxkbC2
A/wzznUTLixMZ6/yr5/B6xv+jQ5u3ZnToa1V8fM7i0oNV23JeggvdBpPjmPzNL6BCqKw
C2/50VVtxYs1LHKrbTH0UiCJMGN3c/PsGz4S8UCIXO20oo16zPjS+vOcrpm0K+TnxNZD
ZnsA//jOuj3lUQ/yYru2v4yKy/BNLOgM8Ir23I/mJV83YyTYAArbIpVLSZP3k0vnLJ48
rjnkZHos8TnNlyjGYK0bWDPtex7JpZNcfspNl+cm8EX5MgR5HA79elq34VZr4j16Lm+V
wyIaaMfni1C3SpYZ2jxCDAAE18sg7lxOVzg0UNbIBLgZVcfVanGysJxpCNtP8bnjwEco
IFqouLlhV8hNHAbXfI1u5xL2Crsp4MiPqMMuZnucbLuNgfEuiir6V/gbxoHAuEqZKB95
e15KzK0RvQ7OaJ7iSUvMnYsRFKDe4CojCoKQdbD1nythi2oLYprC54KsIdMHlQ1Nm2vB
o7vC6S8Fq3VkjlnkzxsH8qLTb5ToY2bsCSQg2RNhv89a0ZUjKrerS62dBkAYp+XeeXCa
iJWJPH61R9Gpaj6Fpldz0cLBQoRwtvOTMpIfWIgfzTXF/3z2bPd/Iudz+Zc9FUMvtyfI
du9XNM1yb1RsjF9GEok+naDgzcUJ2Xe8FMDz7tyBMu4esDjacAfDlsUdKFV0PQSUha1T

SjOM2lIypSmIl+BmUjEtRCYv5Aldj4N7e9Brp/FVqrh75A52ST7hEd1JhlCtsIADenqG
Hdbm3QSoEXW/DaZHjxEDTYdhg5Y/rTBU/FaML5IqQzq9GIero1LtyB+zGde9zM3UnK4K
0WDlOeQ80h2GClGj1xOT2hPFYzDUw9ppk6jEjAQMA4GA1UdDwEB/wQEAwIHgDALBglgh
kgBZQMEAxEDggl1AP5s7F6sK7v/M9ouMGUEgebraBklY8G+4vEbyM1rARhDx7s0XKVec
HE0bh5WTekoLeMyslob2cIRaYSXY/Ai53DhoWkWKx3K9AcosiwgYZ2T266tFvgGkTpNG
8xdRLELRVg1KikYhmlaH/I7I8DpEf8cvtFT1xwyNBoKdYNaRzkgkvW6zBXNQAqmgs4gY
7OEyVTFMgMoW9ZfMndBqmkxQYcrdp5+CLxZjoWzfC/OmXHlVYNHm2BdsYeswKLpTvI22
iv7qf86iAiApoNapp9ZCyISL2FVImYEscxLG0Tfwk6wyySdjkS/TTd66tqbdj+13EVNP
O4j5AJw/A1DR0+NIJMlfGIJNCS7V2VF0mJoYHnB2OjugkVuwaq+6tTYUBqunecIP65pj
KTCkUpQv3fm1uEtmwLmeV/MfTF03dJGPCPBXePT/Wnm4yO9LReJCsgwXmyEEDz0u4wo7
Mo1wVMXLMMT0Thi3jcTrFcB7nc4uWto+p1ihWg5ojgwv4ml6cnHAT7sRAbr3RuYN2rFf
nqdGWhvr+Xy2g8SCwgD9x38/YXTKhxbfCJB6LNkCBx0E81Qv6vqcoPjJFsO0AoKNtgWf
ClXOidpFkGr73W9AfokKo0g8xWbpPvcjPtQbop3x4OnxCs9rhCpwH46BW4PnfIV8obay
3wbi/OL2rSigVfRJJhpgF965mDGQWxNkO0ESG4eBdQsZcM33qjMluNLUUph9AJm+zBtw
d6OCGWV0VyxBzEEWmdTyaiZ7ORbH5O1/gwXIFJptKHUSoMZ9rlOhFpsJ6UvsHabPT3w9
mWodTWkMFl69e2pDxJdZKJLTyHh9Pi0EJEKiCDLGGwG8iobjkp7OUAweQgC9ucO7Lhjc
dK2OK3m0JB0rzTSCt3/eX+GDvU58rrcg+4gARcXec/O2trOGZL/JSYmWKqVGGD8XFfqE
j/FNBs0OKuB8TRoEysCzG9bcJUY6i3nTeznh7LUQdl1E1QWPFbglUlp9fXh5PccFH7pG
Gj9gg+RkUt7au4TPugpi5ovCThg949ji9Dz7zdH2f85evZ/OPNe3tmC56865nbWLHW4c
r6w6owgEusi83tNK+RkKZBGpjPsqqQsr2iGSiO0XgdOUPph8QyKCgNpq6/sBZyZcSPIb
rYvkilneZlopxukRKAUeZPwQpxFiu9N/5T/MACzqlnRHMAcdgmqi+ai6fzl5ZdignfkZ
VLXmEbXVvsr+FKAX2Whz/rMd2PCCW0p+yYu2GsqiQhe/jrFF6CLwRrorp/LwXGiHyCVL
uw1xRzxc2aYjb34fm+0CTtBzb0yWE3sa3Yiw7gLsXAWC+OMUwyHj/U5ocm+2FAjbAieZ
/ehpnP5s6jT2wsNkgbNFthRDtIApW5FkCRZ8vF0pJmioRIdH1ZDlQmKfz4BtR1clsMtt
7t4FAfHtWvAyeBXkHJp918oGP6ulMntc4ofTEgL7cpXqho8QFGu1PmERTLroAQAQe4C5
OLPyOmiV3vJUba56jAeF5a/e0jyMYjlWP4lEjMSJeQnQsHm3OiPmSPZOf7ahkkkq+rYq
GCmz5qg4SAjO95Guubbs5AfqxPfmsBis7oC/L1NmTo7tmgTXlfR4KhxOhaTgjmdZ7DXy
Qa2cvOpkc+aJuxahW9OvA+AE4ycW1lh+SuWSUQ2b9G39GSqWM7IH0m07++6N4W0/+THB
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Appendix F. Intellectual Property Considerations

The following IPR Disclosure relates to this document:

https://datatracker.ietf.org/ipr/3588/

Appendix G. Contributors and Acknowledgements

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