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Use of the ML-DSA Signature Algorithm in the Cryptographic Message Syntax (CMS)

Abstract

The Module-Lattice-Based Digital Signature Algorithm (ML-DSA), as defined by NIST in FIPS 204, is a post-quantum digital signature scheme that aims to be secure against an adversary in possession of a Cryptographically Relevant Quantum Computer (CRQC). This document specifies the conventions for using the ML-DSA signature algorithm with the Cryptographic Message Syntax (CMS). In addition, the algorithm identifier syntax is provided.

Status of This Memo

This is an Internet Standards Track document.

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1. Introduction

The Module-Lattice-Based Digital Signature Algorithm (ML-DSA) is a post-quantum digital signature algorithm standardised by the US National Institute of Standards and Technology (NIST) as part of their post-quantum cryptography standardisation process. It offers smaller signatures and significantly faster runtimes than SLH-DSA [FIPS205], an alternative post-quantum signature algorithm also standardised by NIST. This document specifies the use of ML-DSA in the CMS at three security levels: ML-DSA-44, ML-DSA-65, and ML-DSA-87. See [Appendix B](#) of [RFC9881] for more information on the security levels and key sizes of ML-DSA.

Prior to standardisation, ML-DSA was known as Dilithium. ML-DSA and Dilithium are not compatible.

For each of the ML-DSA parameter sets, an algorithm identifier OID has been specified.

[FIPS204] also specifies a pre-hashed variant of ML-DSA, called HashML-DSA. Use of HashML-DSA in the CMS is not specified in this document. See [Section 3.1](#) for more details.

1.1. Conventions and Definitions

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

2. ML-DSA Algorithm Identifiers

Many ASN.1 data structure types use the AlgorithmIdentifier type to identify cryptographic algorithms. In the CMS, AlgorithmIdentifiers are used to identify ML-DSA signatures in the signed-data content type. They may also appear in X.509 certificates used to verify those signatures. The same AlgorithmIdentifiers are used to identify ML-DSA public keys and signature algorithms. [RFC9881] describes the use of ML-DSA in X.509 certificates. The AlgorithmIdentifier type is defined as follows:

```
AlgorithmIdentifier{ALGORITHM-TYPE, ALGORITHM-TYPE:AlgorithmSet} ::=
    SEQUENCE {
        algorithm  ALGORITHM-TYPE.&id( {AlgorithmSet} ),
        parameters ALGORITHM-TYPE.
                    &Params( {AlgorithmSet}{@algorithm} ) OPTIONAL
    }
```

NOTE: The above syntax is from [RFC5911] and is compatible with the 2021 ASN.1 syntax [X680]. See [RFC5280] for the 1988 ASN.1 syntax.

The fields in the AlgorithmIdentifier type have the following meanings:

algorithm: The algorithm field contains an OID that identifies the cryptographic algorithm in use. The OIDs for ML-DSA are described below.

parameters: The parameters field contains parameter information for the algorithm identified by the OID in the algorithm field. Each ML-DSA parameter set is identified by its own algorithm OID, so there is no relevant information to include in this field. As such, parameters **MUST** be omitted when encoding an ML-DSA AlgorithmIdentifier.

The object identifiers for ML-DSA are defined in the NIST Computer Security Objects Register [CSOR], and are reproduced here for convenience.

```
sigAlgs OBJECT IDENTIFIER ::= { joint-iso-itu-t(2) country(16)
    us(840) organization(1) gov(101) csor(3) nistAlgorithms(4) 3 }

id-ml-dsa-44 OBJECT IDENTIFIER ::= { sigAlgs 17 }

id-ml-dsa-65 OBJECT IDENTIFIER ::= { sigAlgs 18 }

id-ml-dsa-87 OBJECT IDENTIFIER ::= { sigAlgs 19 }
```

3. Signed-Data Conventions

3.1. Pure Mode Versus Pre-Hash Mode

[RFC5652] specifies that digital signatures for CMS are produced using a digest of the message to be signed and the signer's private key. At the time RFC 5652 was published, all signature algorithms supported in the CMS required a message digest to be calculated externally to that algorithm, which would then be supplied to the algorithm implementation when calculating and verifying signatures. Since then, EdDSA [RFC8032], SLH-DSA [FIPS205] and ML-DSA have also been standardised, and these algorithms support both a "pure" and a "pre-hash" mode. In the pre-hash mode, a message digest (the "pre-hash") is calculated separately and supplied to the signature algorithm as described above. In the pure mode, the message to be signed or verified is instead supplied directly to the signature algorithm. When EdDSA [RFC8419] and SLH-DSA [RFC9814] are used with CMS, only the pure mode of those algorithms is specified. This is because in most situations, CMS signatures are computed over a set of signed attributes that contain a hash of the content, rather than being computed over the message content itself. Since signed attributes are typically small, use of pre-hash modes in the CMS wouldn't significantly reduce the size of the data to be signed, and hence offers no benefit. This document follows that convention and does not specify the use of ML-DSA's pre-hash mode ("HashML-DSA") in the CMS.

3.2. Signature Generation and Verification

[RFC5652] describes the two methods that are used to calculate and verify signatures in the CMS. One method is used when signed attributes are present in the signedAttrs field of the relevant SignerInfo, and another is used when signed attributes are absent. Each method produces a different "message digest" to be supplied to the signature algorithm in question, but because the pure mode of ML-DSA is used, the "message digest" is in fact the entire message. Use of signed attributes is preferred, but the conventions for signed-data without signed attributes is also described below for completeness.

When signed attributes are absent, ML-DSA (pure mode) signatures are computed over the content of the signed-data. As described in Section 5.4 of [RFC5652], the "content" of a signed-data is the value of the encapContentInfo eContent OCTET STRING. The tag and length octets are not included.

When signed attributes are included, ML-DSA (pure mode) signatures are computed over the complete DER encoding of the SignedAttrs value contained in the SignerInfo's signedAttrs field. As described in [Section 5.4](#) of [\[RFC5652\]](#), this encoding includes the tag and length octets, but an EXPLICIT SET OF tag is used rather than the IMPLICIT [0] tag that appears in the final message. At a minimum, the signedAttrs field **MUST** include a content-type attribute and a message-digest attribute. The message-digest attribute contains a hash of the content of the signed-data, where the content is as described for the absent signed attributes case above. Recalculation of the hash value by the recipient is an important step in signature verification.

[Section 4](#) of [\[RFC9814\]](#) describes how, when the content of a signed-data is large, performance may be improved by including signed attributes. This is as true for ML-DSA as it is for SLH-DSA, although ML-DSA signature generation and verification is significantly faster than SLH-DSA.

ML-DSA has a context string input that can be used to ensure that different signatures are generated for different application contexts. When using ML-DSA as specified in this document, the context string is set to the empty string.

3.3. SignerInfo Content

When using ML-DSA, the fields of a SignerInfo are used as follows:

digestAlgorithm: Per [Section 5.3](#) of [\[RFC5652\]](#), the digestAlgorithm field identifies the message digest algorithm used by the signer and any associated parameters. Each ML-DSA parameter set has a collision strength parameter, represented by the "λ" (GREEK SMALL LETTER LAMDA, U+03BB) symbol in [\[FIPS204\]](#). When signers utilise signed attributes, their choice of digest algorithm may impact the overall security level of their signature. Selecting a digest algorithm that offers λ bits of security strength against second preimage attacks and collision attacks is sufficient to meet the security level offered by a given parameter set, so long as the digest algorithm produces at least $2 * \lambda$ bits of output. The overall security strength offered by an ML-DSA signature calculated over signed attributes is constrained by either the digest algorithm's strength or the strength of the ML-DSA parameter set, whichever is lower. Verifiers **MAY** reject a signature if the signer's choice of digest algorithm does not meet the security requirements of their choice of ML-DSA parameter set. [Table 1](#) shows appropriate SHA-2 and SHA-3 digest algorithms for each parameter set.

SHA-512 [\[FIPS180\]](#) **MUST** be supported for use with the variants of ML-DSA in this document. SHA-512 is suitable for all ML-DSA parameter sets and provides an interoperable option for legacy CMS implementations that wish to migrate to use post-quantum cryptography, but that may not support use of SHA-3 derivatives at the CMS layer. However, other hash functions **MAY** also be supported; in particular, SHAKE256 **SHOULD** be supported, as this is the digest algorithm used internally in ML-DSA. When SHA-512 is used, the id-sha512 [\[RFC5754\]](#) digest algorithm identifier is used and the parameters field **MUST** be omitted. When SHAKE256 is used, the id-shake256 [\[RFC8702\]](#) digest algorithm identifier is used and the parameters field **MUST** be omitted. SHAKE256 produces 512 bits of output when used as a message digest algorithm in the CMS.

When signing using ML-DSA without including signed attributes, the algorithm specified in the `digestAlgorithm` field has no meaning, as ML-DSA computes signatures over entire messages rather than externally computed digests. As such, the considerations above and in [Table 1](#) do not apply. Nonetheless, in this case implementations **MUST** specify SHA-512 as the `digestAlgorithm` in order to minimise the likelihood of an interoperability failure. When processing a `SignerInfo` signed using ML-DSA, if no signed attributes are present, implementations **MUST** ignore the content of the `digestAlgorithm` field.

Signature Algorithm	Digest Algorithms
ML-DSA-44	SHA-256, SHA-384, SHA-512, SHA3-256, SHA3-384, SHA3-512, SHAKE128, SHAKE256
ML-DSA-65	SHA-384, SHA-512, SHA3-384, SHA3-512, SHAKE256
ML-DSA-87	SHA-512, SHA3-512, SHAKE256

Table 1: Suitable Digest Algorithms for ML-DSA

`signatureAlgorithm`: The `signatureAlgorithm` field **MUST** contain one of the ML-DSA signature algorithm OIDs, and the `parameters` field **MUST** be absent. The algorithm OID **MUST** be one of the following OIDs described in [Section 2](#):

Signature Algorithm	Algorithm Identifier OID
ML-DSA-44	id-ml-dsa-44
ML-DSA-65	id-ml-dsa-65
ML-DSA-87	id-ml-dsa-87

Table 2: Signature Algorithm Identifier OIDs for ML-DSA

`signature`: The `signature` field contains the signature value resulting from the use of the ML-DSA signature algorithm identified by the `signatureAlgorithm` field. The ML-DSA (pure mode) signature-generation operation is specified in Section 5.2 of [\[FIPS204\]](#), and the signature-verification operation is specified in Section 5.3 of [\[FIPS204\]](#). Note that [Section 5.6](#) of [\[RFC5652\]](#) places further requirements on the successful verification of a signature.

4. Security Considerations

The security considerations in [\[RFC5652\]](#) and [\[RFC9881\]](#) apply to this specification.

Security of the ML-DSA private key is critical. Compromise of the private key will enable an adversary to forge arbitrary signatures.

ML-DSA depends on high-quality random numbers that are suitable for use in cryptography. The use of inadequate pseudo-random number generators (PRNGs) to generate such values can significantly undermine the security properties offered by a cryptographic algorithm. For instance, an attacker may find it much easier to reproduce the PRNG environment that produced any private keys, searching the resulting small set of possibilities, rather than brute-force searching the whole key space. The generation of random numbers of a sufficient level of quality for use in cryptography is difficult; see Section 3.6.1 of [FIPS204] for some additional information.

By default, ML-DSA signature generation uses randomness from two sources: fresh random data generated during signature generation, and precomputed random data included in the signer's private key. This is referred to as the "hedged" variant of ML-DSA. Inclusion of both sources of random data can help mitigate against faulty random number generators, side-channel attacks, and fault attacks. [FIPS204] also permits creating deterministic signatures using just the precomputed random data in the signer's private key. The same verification algorithm is used to verify both hedged and deterministic signatures, so this choice does not affect interoperability. The signer **SHOULD NOT** use the deterministic variant of ML-DSA on platforms where side-channel attacks or fault attacks are a concern. Side-channel attacks and fault attacks against ML-DSA are an active area of research [WNGD2023] [KPLG2024]. Future protection against these styles of attack may involve interoperable changes to the implementation of ML-DSA's internal functions. Implementers **SHOULD** consider implementing such protection measures if it would be beneficial for their particular use cases.

To avoid algorithm substitution attacks, the CMSAlgorithmProtection attribute defined in [RFC6211] **SHOULD** be included in signed attributes.

5. Operational Considerations

If ML-DSA signing is implemented in a hardware device such as a hardware security module (HSM) or a portable cryptographic token, implementers might want to avoid sending the full content to the device for performance reasons. By including signed attributes, which necessarily includes the message-digest attribute and the content-type attribute as described in Section 5.3 of [RFC5652], the much smaller set of signed attributes are sent to the device for signing.

Additionally, the pure variant of ML-DSA does support a form of pre-hash via external calculation of the "μ" (GREEK SMALL LETTER MU, U+03BC) "message representative" value described in Section 6.2 of [FIPS204]. This value may "optionally be computed in a different cryptographic module" and supplied to the hardware device, rather than requiring the entire message to be transmitted. Appendix D of [RFC9881] describes use of external μ calculations in further detail.

6. IANA Considerations

For the ASN.1 module in Appendix A, IANA has assigned the following object identifier in the "SMI Security for S/MIME Module Identifier (1.2.840.113549.1.9.16.0)" registry:

Decimal	Description	Reference
83	id-mod-ml-dsa-2024	RFC 9882

Table 3: Object Identifier Assignments

7. References

7.1. Normative References

- [CSOR] NIST, "Computer Security Objects Register (CSOR)", 13 June 2025, <<https://csrc.nist.gov/projects/computer-security-objects-register/algorithm-registration>>.
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7.2. Informative References

- [FIPS180] NIST, "Secure Hash Standard", NIST FIPS 180-4, DOI 10.6028/NIST.FIPS.180-4, August 2015, <<https://nvlpubs.nist.gov/nistpubs/FIPS/NIST.FIPS.180-4.pdf>>.

-
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Appendix A. ASN.1 Module

```
<CODE BEGINS>
ML-DSA-Module-2024
{ iso(1) member-body(2) us(840) rsadsi(113549) pkcs(1) pkcs9(9)
  id-smime(16) id-mod(0) id-mod-ml-dsa-2024(83) }

DEFINITIONS IMPLICIT TAGS ::= BEGIN

EXPORTS ALL;

IMPORTS SIGNATURE-ALGORITHM, SMIME-CAPS
FROM AlgorithmInformation-2009 -- in [RFC5911]
{ iso(1) identified-organization(3) dod(6) internet(1)
  security(5) mechanisms(5) pkix(7) id-mod(0)
  id-mod-algorithmInformation-02(58) }

sa-ml-dsa-44, sa-ml-dsa-65, sa-ml-dsa-87
FROM X509-ML-DSA-2024 -- From [RFC9881]
{ iso(1) identified-organization(3) dod(6) internet(1)
  security(5) mechanisms(5) pkix(7) id-mod(0)
  id-mod-x509-ml-dsa-2024(119) } ;

--
-- Expand the signature algorithm set used by CMS [RFC5911]
--

SignatureAlgorithmSet SIGNATURE-ALGORITHM ::= {
  sa-ml-dsa-44 |
  sa-ml-dsa-65 |
  sa-ml-dsa-87,
  ... }

SMimeCaps SMIME-CAPS ::= {
  sa-ml-dsa-44.&smimeCaps |
  sa-ml-dsa-65.&smimeCaps |
  sa-ml-dsa-87.&smimeCaps,
  ... }

END
<CODE ENDS>
```

Appendix B. Examples

This appendix contains example signed-data encodings. They can be verified using the example public keys and certificates specified in [Appendix C](#) of [\[RFC9881\]](#).

The following is an example of a signed-data with a single ML-DSA-44 signer, with signed attributes included:

-----BEGIN CMS-----

MIIKsAYJKoZIhvcNAQcCoIIKoTCCCP0CAQExDTALBg1ghkgBZQMEAgMwQwYJKoZI
hvcNAQcBoDYENE1MLURTQS00NCBzaWduZWQ0ZGF0YSBleGFtcGx1IHdpdGggc2ln
bmVkiGF0dHJpYnV0ZXMXggpCMIIKPGIBATA6MCIXDTALBgNVBAoTBELFVEYxETAP
BgNVBAMTCExBTVBTIFdHahQVn/5vIv1cxCxSTfb9XiJQ3jjzTjALBg1ghkgBZQME
Ag0gazAYBgkqhkiG9w0BCQMxCwYJKoZIhvcNAQcBME8GCSqGSIb3DQEJBDFCBEAL
v5NoEkfe30kMRW4rKXw97hdFLivtQ/OVU4Pc/DrfWm3d7P0pIXNQ4WCwyGDTWKwi
dWwCHZ9E3CT0Twj2gI/UMAsGCWCsAF1AwQDEQSCCXTzX9ZSUYiiAjJ2USF/0b1K
fyTnaJTCFymSXY/ZOE0++0F6BZ9HUQweqTlrfXUmp0L1YK+8Hd/zCmyjboKZZmCA
KY4rPlbi4W9ndcowgSgawGixVs0vOBimudg4B5Tbo43c0RwIPW6FdDrCa9eKgcGh
bMIFTYFF7f9J3suzYmcj7H99nDjd3d9P0qPW0J2NWz64UoxZP8iH0u78gd46yIwB
Rz9VYerD0BS0kZiU2kQUXGhCKm0og0ES8Vg1TfV3esn7xeLb0hn4uyrpS0Bx5bdc
3BLRxvWdic+ha0SFQns5uSrduRjXTaLi88tnVWknzfidCzKubzIxJ/7CMcEcXxu+
L+dUOVXZvATV3Fiddk9re8x54Z7gb0kHEyemJnf9uq+084pGB/LrIH5x+ZyYdzlZ
Ys1a7XqEONK/VIuwD2E7UHcYDSROZAYRMFGoyqGKdwVD6/W1E1DYND6eX7Vqss4H
jDuDi7qsha2j4oHet5JQWYecSxSUsmwp+5E9S6p3g/30w4iA1EGQLGZV1H76m+4+
JYWnHapiFFPQ4nxly+C6c6+hDaX+KONZdM/lt0eaJnxq9Nzrprw/ieIqX8A70v9t
1MLVwd7W8Gc4auZec/8WrnDI/f7qaSU0Kt+kNN0ok2maZvLYbDyaDS1UyK4IXvqA
FR5fbSgFmy7SY2TDc4k8JJ/KdBqSg8k0/tRemBiXE/YfltddyZqsD+vhoz5RXhl0
DvyZbQwxW67bdgr6TgRKexRuWQOTR9CAWNitmPzmZDRqIXIhtbg3jtoXujTg4003
/tjhr+ZxCv5zsgcbUiJBicSHRuc1W1er0CRu+fknwXZBgF73WtFhDfDq8u9a00e
jBTW4xMAXVfv3coIaknsDP+Di9LtvSxXhLsMaRr9bFZnfhcF04/00w+rGwbZ8114
y8Ech//OPjYQxmFvXaqV9r2Fz6KkslwlerMq/MjFUjt6vNcxHaGEID/m+xzSJAB
5/BzW0qkIBFoWIDHTkYo9wie7QI6cbgM7qbpTxJAbauPU0VYf2VUTTuGxVtb4aNQ
zMDYSBjHVDjZ3/o+kmkjrlBxl+Jvx7Qe10G0VNHKMP70wMIXj50txvWqRV1TXIvm
p5Qv/NFJWQJTJWDv608Mt5/4lbGqJB07v9T7gfvxd1LWXmmd1X/T8oPg9rFI6rGNP
Nz7xoxs8xkAa+sBcoPmNQyk9q9srER8Fwi3eBGNuFuAq8nKfn+2LXh/Iuhxk6BFc
a1wC4Qa5PV4uiKjsUrKyWwux12Z3dAbtLI f9HNStu1157KaiJ/XLKcsUsDVAcq8L
GJHpuT000Y/2Ai/JkE6CjJH9nEXQLGxWHadD0gJrQA8rnwV0ccex7RjX7xkhh/0d
b3HxL2f0Ft6lyWgFK1uZKpLrp1fk6+U1hXk+EuUfdayrT0t5poNo1RXaohINP7m
ZZj1yqGhWlbq0xkZt7xantZ5FB1QuT9hT5FiY4TFoB1Z5LJlXvLpM/QFB/4n9ZJi
fqjKA6wMCWxBpsu4+Z0faQkwvRZ+9+08QIM1QaRqyMoZeSVh622QmUjuAw7EyYY
KRR/sPkLe1SFxWfg6mcqrnABRGy2kHs2a63j4MIpev1DonKNWPbbBSzkqncPYpb6
MHXQTiL1/uqbl/vUE1NucQxvzsaCIDP0ULQiZLS5PU018rjWa3BbE0ner4MyAT2s
QXj5fXHYmuT69JppafV9omZa30d2mUDDtz9Wy2xGRE8MvSrawsRNE5Hucc/tXZu1
Bz0GPARTzKB3lgrXuQU9CyYSM3T387tM1o1AXm0J0/H4bhAbAqFeFnL1Wm/gFWFr
ocpVPNwAWRQj7NdteRMX/qE8nWMjG11ax7w13BPa8pDwC+6lPnVfGDzBNlWbZThz
oXtjGTTRuFi1Zpy6BgVAPuVZcxXC6Pg8Eeod01XH4pPKtPJ+tkCWLrnxzMur7oAP
i5P3UZ/AEXrLiMw/f6o1tVVDWvGD9T50eemgB4fRzSG/0Sxu1WpMBm1va1v56Gym
U0u59MHb6jR2NpsGBRu1J/5FVoxghvitSA4ggAhkLmIndoNcW0ThHJx67WBJH78h
gVHhjQBuaxWrlfocyqdrNw4B9iVAEx/sxldvF9pIvlsnRXKore8RF9p40fYz7GGc
2+cbtdgCVyfpnt2u2reyvPg0AzW/Moms+AXs+LaxzHt6mrWIJOsuNtLwrwTEJu1t
GkQibWZwDlG+wb885YvMxAoAXU9s88jSWzEyfUS4ksMgG2CVrmfewHeFuLIFR9D1
LZkFSmQTgWLKwdJw73XUgF0qHxzMTBkLoTAIQasTZKjC160zCbWzV5e/PT7hqvQk
ic07PJLIjA41uhGnSyA2ELYQYKQFcTakY5eHYaDHDJgMZTTKMn+k1SHYHCBYkzH
ToSoodOW7ezgzjKJMAp3A/egYFrChpOdmiCkE6ot20CW8Ju9vxKQMWAXXe1FoA7
j3tVsqIUdvTjzyAGINsVU8ihKaSSt08khn0ftb/aUj7eN36FHMwMeNH2LhXbwSJI
++u4GWW3woD8ZUyo1mpH7xLmBrci7Phs7gFpHtJeIZpPBeG5MuEDpvzCHHBBrvUA
Ek8zuLLGYdlbb2PWGM6A3M+efSnjaY6JQS3GURQLA9BWMtu5S5L3+ytm0F00w0VCA
hq2BN+vNwXm1XWqlEG1sbpAUBngWkpyipUT3GBBvjp+Ak3RIlciLQGCZ1I1Xeg1E
W9K8YhhLo490h3GDuf4CZgPULSHXqKcCr91VDpff/kcxwVeXITQiFVykwjfe11XT
gnxR3zQRP61P3aisQxwsaKgHKGzD5idGAzGQuwVgAs95xA/ka1ccMe8a5da+bKP/
9QqnAFFtArVZpso0Xcy2D/iusW2bcBjiSANM4GnZwsyphF0WIK89aq/411WIz3zc
Xf1JIW80fAy47VF8W340bSgc24A0rQlZ38TEGLIcvqPvSMTQRVud12S9PgGo8cpP
J5+lm7FzJftRSTwYsaSwt0UM1hvvXbvcWf03g8XMJbof8cWH7QeEPcan+ygxbtt
ArQ5Dk+BE4Rv/MBJUvi5E30IBHxWXx60TWsljFDjBwt8bPVk7YMaBWMMy4KZw5jU
nRakavONHDQDizfy7U0IRAEjKTxKTFaRk56+y839PF2TlP63w00UFzAyQVvKZ2uR

```

zs/Q7xYbHEBpepGfq7C0w9Tp7fgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
DhYkNA==
-----END CMS-----

```

```

SEQUENCE {
  # signedData
  OBJECT_IDENTIFIER { 1.2.840.113549.1.7.2 }
  [0] {
    SEQUENCE {
      INTEGER { 1 }
      SET {
        SEQUENCE {
          # sha512
          OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.2.3 }
        }
      }
      SEQUENCE {
        # data
        OBJECT_IDENTIFIER { 1.2.840.113549.1.7.1 }
        [0] {
          OCTET_STRING { "ML-DSA-44 signed-data example with sig
ned attributes" }
        }
      }
      SET {
        SEQUENCE {
          INTEGER { 1 }
          SEQUENCE {
            SEQUENCE {
              SET {
                SEQUENCE {
                  # organizationName
                  OBJECT_IDENTIFIER { 2.5.4.10 }
                  PrintableString { "IETF" }
                }
              }
              SET {
                SEQUENCE {
                  # commonName
                  OBJECT_IDENTIFIER { 2.5.4.3 }
                  PrintableString { "LAMPS WG" }
                }
              }
            }
          }
          INTEGER { `159ffe6f22fd5cc42c524df6fd5e28d0de38f34e` }
        }
      }
      SEQUENCE {
        # sha512
        OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.2.3 }
      }
      [0] {
        SEQUENCE {
          # contentType
          OBJECT_IDENTIFIER { 1.2.840.113549.1.9.3 }
          SET {

```

```
# data
OBJECT_IDENTIFIER { 1.2.840.113549.1.7.1 }
}
SEQUENCE {
  # messageDigest
  OBJECT_IDENTIFIER { 1.2.840.113549.1.9.4 }
  SET {
    OCTET_STRING { `0bbf93681247c4dce90c456e2b297c3d
ee17452e2bed43f3955383dcfc3adf5a6dddecf3a9231350e160b0c860d358ac
22756c1c1d9f44dc24f44f08f6808fd4` }
  }
}
SEQUENCE {
  OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.3.17 }
}
OCTET_STRING { `f35fd6525188a202327651217fd1bd4a7f24e7
6894c21729925d8fd9384d3efb417a059f47510c1ea9396b7d7526a4e2e560af
bc1ddff30a6ca36e8299666080298e2b3e56c8e16f6775ca3081281ac068b156
c3af3818a6b9d8380794dba38ddc391c083d6e85743ac26bd78a81c1a16cc205
4d8145edff49decbb3626723ec7f7d9c325ddddf4f3aa3d6d09d8d5b3eb8528c
593fc8873aeefc81de3ac88c01473f5561eac338148e919894da44145c68422a
63a880e112f158354df5777ac9fbc5e2db3a19f8bb2ae948e071e5b742dc12d1
c6f59d89cfa168e485427b39b92adbb918d74da2e2f3cb67556927cdf89d0b32
ae6f323127fec231c11c5f1bbe2fe7543955d9bc04d5dc521d764f6b7bcc79e1
9ee06f49071327a62677fdbaa4f38a4607f2eb207e71f99c9877395962cd5a
ed7a8438d2bf548bb00f613b5077180d244e6406113051a8caa18a770543ebf5
b51250d8343e9e5fb56ab2ce078c3b838bbaac85ada3e281deb792505987824b
1494b26c29fb913d4baa7783fdf4c388809441902c6655d47efa9bee3e2585a7
1daa621453d0e27c65cbe0ba73afa10da5fe28e37374cfe5b7479a267c6af4dc
eba6bc3f89e22a5fc03b3aff6dd4c2d5c1ded6f067386ae65e73ff16ae70c8fd
feea6925342adfa434dd282b699a66f2d86c3c9a0d2954c8ae085efa80151e5f
6d28059b2ed26364c373893c249fca741a9283c934fed45e98189713f61f96d7
5dc99aac0febe1a33e515e19740efc996d0c315baedb760afa4e044a7b146e58
e41347d08058d8ad98fce664346a231221b5b8378eda17b894e0e0e3b7fed8e1
afe6710afe73b2071b522241882b07461b9cd56d5eace091bbe7e49f05d90601
7bdd6b458437c3abcbdb6b4d1e8c14d6e313005d57efddca086a49ec0cff838b
d2edbec5f184bb0c691afd6c56677e171f538fced30fab1966d9f25d78cbc102
87ffce3e3610c6616f5daa95f6bd85cfa2a4b25cf095eaccabf3231548edeaf3
5cc476861080ff9bec73489001e7f0735b4aa42011685880c74e4628f7089eed
023a71b80ceea6e94f12406dab8f5345587f65544d3b86c55b5be1a350ccc0d8
4818c75438d9dffa3e926923ae507197e26fc7b41e94e18e54d84a30fecec0c2
178f9d2dc6f5aa4559535c8be6a7942ffcd1495904c9583bfad3c32de7fe256c
6a8904eeeff53ee07f1bddd4b5979a67755ff4fca0f83dac523aac634f373ef1
a31b3cc6401afac05ca0f98d43293dabdb2b111f05c22dde0469d416e02af272
9f9fed8b5e1fc8ba1c64e8115c6b5c02e106b93d5e2e88a8ec52b2b25b0bb1d7
66777406ed2c87fd1cd4adbb5979eca6a227f5cb902b14b0354072af0b1891e9
b93d0e398ff6022fc9904e828c91fd9c45d02e0c561da743d2026b400f2b9f05
4e71c7b1ed18d7ef192187fd1d6f71f12dfd9f385b7a9725a014ad6e64aa4bae
9d5f93af94d61c64f84b947dd6b2ad33ade69a0da254576a884834fee66598f5
caa1a15a56ead31919b7bc5a9ed679141d50b93f614f91626384c5a01d59e4b2
655ef2e933f40507fe27f592627eaaa3280eb03025b1069b2ee3e64e7da424c2
f459fbd8ef1020c950691ab232865e49587adb6426523b80c3b13261829147f
b0f90b7b54855f0160ea672aae7001446cb6907b366bade3e0c2297afd43a272
8d58f6db052ce4aa770f6296fa3075d04e22f5feea9b97fbd412536e710c6fce
c6822033f450b42264b4b93d43b5f2b8d66b705b10e9deaf8332013dac4178f9
7f11d89ae4faf49a6969f57da2665adf47769940c3b73f56cb6c46444f0cbd2a
```

[illegible]

The following is an example of a signed-data with a single ML-DSA-65 signer, with signed attributes included:

```
-----BEGIN CMS-----
MIIOKQYJKoZIhvcNAQcCoIIIOGjCCDhYCAQExDTALBglghkgBZQMEAgMwQwYJKoZI
hvcNAQcBoDYENE1MLURTS02NSBzaWduZWQzZGF0YSBleGFtcGx1IHdpdGggc2ln
bmVkJGF0dHJpYnV0ZXMxgg27MIINTwIBATA6MCIXDTALBgNVBAoTBElFVEYxETAP
BgNVBAMTCExBTBTIFdHaHVNv5vIv1cxXSTfb9XijQ3jjzTjALBglghkgBZQME
AgOgazAYBgkqhkiG9w0BCQMxCwYJKoZIhvcNAQcBME8GCsSgSIB3DQEJBDFCBEDV
dAiINSOokqad8+saH0VVYKw/LS+Cgc4/BqVt0oKfFyTuZAR1cSmheu9HfN8aRDoS
Igwz94jCpe4gULONjqqoAMsGCWCSGAF1AwQDEUGSCD01SnJA5z0CK/J0mfklniShg
BjzE2z3H3oafJHtLTAItJw07niA2s4tqmU9LFVU4dn+bXALcLNXXOY057rdKy/V4W
u+tbqgWNNUKwBSWAZw/4htJXrN9tb7T+fSTn9A9XFmps2GMAi15n9vp4cjia49YS
FoSnumwGrK0WVQ2/pdFgyULdyvk96VUZnihoKmRq4bxNLPt9b14qJZA75FpzItIF
```

Q5Ngzx6rbNyCUbuUxx+ut+IgCAqfbdynWxROD01vW3nbZ72ZZcnejvvvMSWyLQIE
/3aszLIkJ8GDsRt2UxyDc/o0DP04ULboC8B4AQq2qH1+MWILU+QTUm/+Jwg7tVjJ
5r+7kcpQT0J/kGexd86GwsuWQcNjNRZvstyMozrbz5jLahT+XLPBJH4lZWIKTi4
41RC5JRQajZ/Eh9+UYxtsp1wWnNZwXhp4BvMouKB/GtT7CfYB12b4yGGeyxjA7kR
Jip6PiPJUP03MX580kqFkoiDJs1/HpINHdLEIGip83xbEley/KaV2j0u0njyUMdI
FMFebivD0hSEVW6biU7FKFCgNeFxsG3Ls6qabp/kqakZno1fpVU8jTeFpapilZoL
0a/wp/xUiuUTJfARjjq0Z5A+HxVhkhLwykt14KC3v/jcp8URzDxw7/h8LNzEeo1P
C6eT3psEzPN0L3TqJRNCGsDYtrtl0NoT0Zpj7Vj//8cAg4rj1aZiYkIuytJwLvxx
dkLaq2MbJoiCq/OwnRFeARSdwt2viAf+MyI/GU3n1A4mEwM4NsYVJxRZzbUisekJ
L+6cb4T5pnw1wZHySECw3YiHLYHRYHpi9Moi6ldy7HZBNT3z7G00+Z0yA0HSKek1
HD7K6K7L0GL6s9gy/hd779s4DxhLFg2is5xfJ6wcvYDg+wgy8vCoQc/D9SchL98M
DjQlh+x0Z8iqoTJ+z0mYB4fCKxqtiq3ufkrRGKHvkWDEyeTXAWV1/k3sZtEGkmX6
nan2U/Gfqv7ilYel083kb1CRLXeUbEXhBoqBuIAIaTbDwbTRJk38mNAF/14QwPle
IaQ0hwDZ/EAb7IICi64+RKdDGQvYid4jIjy3wuhdz6iCM5vwmVT/K81o67QG0MZj
aCT22unxJk0Se9nwb8T0uEzqRpHtTQftBK+0/nYPZMx3AGjuU6wabb7eR1ux9DVk
QFz0ykykN7gle89bcEjNr6wZ6GtY9qkmkY861+PWVTj4380aSZxNgJibnKhQ3jH5
tr93/r+Jcs0I8a2Vj94y/ufTDAE3uEX9Z3MarceQ9FDcGq5CWQYXR5Cf3oWh0Rii
PC0/qZ6LGmiXV0d8bYYQ1XFxgUpdsLlnb7IyVEt7QJ2CrQfyT1e12bz1c0iCeImt
bQbhWaf550uvkyRpDS/eqHFV/yFMqMurdCvxuKmfEWNgZayG+LhwgPHK5xDfAHwi
ItT2e+G0mVUNecsMutvc5DrP9MTQkU8RUhPx0kiuQi3/Nc5vWIULR1a/MeV1lwuB
l4ZCKyowZ2KW51M3StHgAngy0gbFfil2X9y0P+fGwGvNZTILiQLCnWgZ39Bpm05u
fcQH19aN/Arjnxpgaysx8TilzpIFK06Id40aTH5Pt18vMvhnVa/WzXGIy8YkuzAb
lt2IXcZhd3g41s1Cjmr0r20bUfxH/AvFQp60FssB+A411tSp/whzqdanvofjFdz7
yhS1ZTXBHgwJAv0eLEzZ+0B6Q8jiVbzHf0X5g50QRPuGj7pQLiSxPV3GeYHsNqn3
wdiW6gNnEEM8ST9VGIihSVZQ1H86d1S//wNMNLs1957JdQECUgdqpDT+8fya3P4G
/nVz7FU+Go5Zc7IK5FrNhK57JiTuU5INHN8Z1bm+w0oglCk0aZFU0Sf9Qxrhaus+
nYQofSG0zEoB0LyEzjVccbgA5bw75ZsaaMjRIGRotWTXtrMfBoMLNxBmVGAkqluL
7Wm3U1bKG43gcg7sIS2zdh069HD6aUqt+VKDTd2WG7FGMgC6MADwIbVN14E5AcBJ
19kKKQK08f+vrsxpSNY8XRKk5ShnT0ig0vRIoWIAgKn4YJu46YjZ2WorSfuaKNx/
+o1nWjhlCRsf3o010TpwYlhp7C1ok9/t7kCZS8L8Kv0UZ8K36VL0E+4LeKycAZk3
Y4ziBJMW8wDG3tU10QQZfZSKyBEgyCiugr8tXsJAKPLy8U38YtxDtwAgwcXTkDiN
85YXK5AreJR8sr33LZZI3Y0qiCIJVMQWfcSnrcwdSUXDuqXyG979qJr7aRiwt5iH
X2GJqubN0XdpC6Y4KSSTZx4sYs2Ts9/HWFbixGAgshyz2zLC/0FTR1fiBZF2Zf
7tgoJcF0FqKxJUq4BW0JNk4C/RwpSV5cMiU/rpkwojMJ7HnxV6k+18ZqIUQJ7hWU
cGQm1BP3kd4dueatyC2rvw3UrLfcttiLbAqYTHVo7UHYhpKX1vLZ5p1tPKKz5mb1
zxhnenB3BRKj31+Fq0UE3luHur63W1cLSnqvGFhUcyz47pjZ7VntZrjMu3QyQbeg
bNv/PROC0wp3EYo+C5/AS2H03quY6oW+0Ix1iWw16EzUDCVdnXT3bmnmqNJEN1Hgs
eyiKcmbTX+1378KIYjVY5DE6eYDTyzpc0lxcg8Vb4eM7q2cdmts+jZLTH6Xq/xLQ
Kq93FkNvx8bkC83F8zXor8MbEptzjQcjZI+adJrTTdUDrIDAF3s0ddlgK5Lr15cR
np5p1napwi/VXweRqXTkYqjmZsfCKAe5AaleTfSBnPSCsczIXAVTTQC1CoQfxoM
8jjfzhPzHr/kHaktGQ0mS66L8/Gw/eVDxfgRj876exDl+J5Hp1+2+pHafw8jH00/
EkPn9R/78P70H2P8XVrYsdIeGM0Bq32jJNgDCT6YARq1HkrUBi1LKGHYniLWFsXw
2mp5Lx/61WSJ3jH0NQ1enyWVwb0iZo2jQxVjccaC+2hKgQgJZNVUr4zBPxcequ5V
rEl29BcXNgEWL5lywVIxYijFULcxyw9g/Z1LTJbBofZ38zqhCxftKjfraCp+pZaM
jP1+PgZ4CD/Q2uqt2d+0cThjvrru9C1PFk6ssAuGN6DXQnnL3MoFKwL4eCw0UdVR
a9C8ZW7D+ax16gQBmD3hQB/K/4bdQFD3tQRsLoG1DR4Mi10GIvMxj5wdbglrNAeS
1rKMN5M3bJ/Zv4mXE+nfWehBFw4A+gDP3LR21579/WJy3TWG0FIK7Gc23BxhAuJY
hWE80C/NmuHhZp7n2u0mydFpkiGA4HcQaJti3Cw9bwMCoJmKQdvUZG+bJYNBLW/3
v/lo4Ireg30JE18wi0TXsqvtqoAfVoERh4ZQMYMz4PDooxG0KqDgHyDfY3AEU506
KAVCjquMuCazq/B8CTMSqg2HrufMBVg0S4mzfwiCK6CdZsHbzMWy7yy28Bn5/Vfa
r/tBXMESqvfz2RZmYk2mgoaxHxYwbDT/tH01EBkSuXG243J5VUbd0DGcny16s43a
GQ2mLRz7KqCAK/QXgy7yU/quguVy6bUsSZxxwnpCv09fCg8VZkThuME19DKe68bt
b1xrzc4jXKLpa5C6LGiy4+BYVRV9NsZL0Z6RDcIIKYA7wnjutMNdYRBg86ukvdC
q4CKWpGVH9851yS+PP0Yhvo0cfMpKVg1EoPuCX4qFEX9Qt8Rs1vxEpUE3djYykuE
WKvzH+yS1h0TnNnHIGNVGSoZVVt4rV+Rn2Sh3DZbR6U5tFcCK6FziH/wwQ7FL4YU
v4uCF1xLZtMkulYE9a7SRvUYqeX88CEQQ57zQasJa+a/puljswL7UV/QBnmnM44g
NmRyyHSD0bZp1X2hKr6cbQ6IDACM0YLBqveN0x478tW65D/e3EdQip4LKPf3TB/2
NabF50gr/XPeh9eMKJzCEFA2NBzy20yjr6uHGprkd4Yd7iMzBz/DD9P/4dE61AXGA

```

vALm0S8mrv8p6S1ln2lrYjYptdELG6FbAm5ZFRWD9XDQUCmbDp8qQkw4q7nFSLTx
lzu6lQIiB7weAoJ0/WyhrD75GTcp7W9e0pcmqQL6YMYTIlvRSoq0aK4l4nz+7eUY
tCuJjGDmj/+2kHV0ZUF/p8fzZmsWBcgpMUJnPo0hTUZ3oQqxsNYFiXZDStVtyA7b
hS80X6kE08652tGQop6jIx3WEUs/vqSa/h1BHVW3a0d29Rqw0Tf1o6BoIoDdcci
4NlIgwVFxFhzqxy9QvQF0nuaPIaCZFF8vTxaMSVD7JVmvAG2QJXQXfseyttHnaut
i3iV/dQfCk6q5AF3FfLWmpbv7xGzgAqEQLJbWGTgzkWhrUd4XSxMuz3Fdr2miYqZ
bKeW7WTYzheWIByiulhuxh9UYf0GDxAYY4m5EGV5pek6xgwhMj1YYmVobHng4g8n
YK0x3QAAAAAAAAAAAAAAAAAAAAAAAAAAAAECxASHiQ=
-----END CMS-----

```

```

SEQUENCE {
  # signedData
  OBJECT_IDENTIFIER { 1.2.840.113549.1.7.2 }
  [0] {
    SEQUENCE {
      INTEGER { 1 }
      SET {
        SEQUENCE {
          # sha512
          OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.2.3 }
        }
      }
      SEQUENCE {
        # data
        OBJECT_IDENTIFIER { 1.2.840.113549.1.7.1 }
        [0] {
          OCTET_STRING { "ML-DSA-65 signed-data example with sig
ned attributes" }
        }
      }
      SET {
        SEQUENCE {
          INTEGER { 1 }
          SEQUENCE {
            SEQUENCE {
              SET {
                SEQUENCE {
                  # organizationName
                  OBJECT_IDENTIFIER { 2.5.4.10 }
                  PrintableString { "IETF" }
                }
              }
              SET {
                SEQUENCE {
                  # commonName
                  OBJECT_IDENTIFIER { 2.5.4.3 }
                  PrintableString { "LAMPS WG" }
                }
              }
            }
          }
          INTEGER { `159ffe6f22fd5cc42c524df6fd5e28d0de38f34e` }
        }
      }
      SEQUENCE {
        # sha512
        OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.2.3 }
      }
    }
  }
}

```

```

    }
    [0] {
      SEQUENCE {
        # contentType
        OBJECT_IDENTIFIER { 1.2.840.113549.1.9.3 }
        SET {
          # data
          OBJECT_IDENTIFIER { 1.2.840.113549.1.7.1 }
        }
      }
      SEQUENCE {
        # messageDigest
        OBJECT_IDENTIFIER { 1.2.840.113549.1.9.4 }
        SET {
          OCTET_STRING { `d5740888352a0e92a69df3eb1a1ce555
60ac3f2d2f8281ce3f06a56d3a8285cb24ee6404757129a17aef477cdf1a443a
12220e30cfde2308f7b88142ce9e3aa8` }
        }
      }
    }
    SEQUENCE {
      OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.3.18 }
    }
    OCTET_STRING { `529c9039cce0a4fc9d267e4967892860063cc4
db31f7a1a7c91ed2d3008b49c0eee7880dace2daa653d2df555389fe6d700b9
0b357398634e7badd2b2fd5e16bbeb5ba865963542b0052580670ff886d257ac
df6d6fb4fe7d24e7f40f577cca6cd8631a8b5e67f6fa7872389ae3d61216848d
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[illegible]

The following is an example of a signed-data with a single ML-DSA-87 signer, with signed attributes included:

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nlhHsZ7Gc1AVnnwLYYAq8BnXRerrkTIPvE4FbXzcJCL/IcTBQzyPM8sTDJnaDvcw

```

2aUopkGXL9Cm8nreEnSxTAh0T9qRcWA9XDivGHDR0C171T1uEcL4ErM06YZReJN
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1+UJO20/xN4BEiktT2yN0NzsGjJET15vjpnE/wAAAAAAAAAAAAAAAAAAAAAKMEh4i
KDI8
-----END CMS-----

```

```

SEQUENCE {
  # signedData
  OBJECT_IDENTIFIER { 1.2.840.113549.1.7.2 }
  [0] {
    SEQUENCE {
      INTEGER { 1 }
      SET {
        SEQUENCE {
          # sha512
          OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.2.3 }
        }
      }
      SEQUENCE {
        # data
        OBJECT_IDENTIFIER { 1.2.840.113549.1.7.1 }
        [0] {
          OCTET_STRING { "ML-DSA-87 signed-data example with sig
ned attributes" }
        }
      }
      SET {
        SEQUENCE {
          INTEGER { 1 }
          SEQUENCE {
            SEQUENCE {
              SET {
                SEQUENCE {
                  # organizationName
                  OBJECT_IDENTIFIER { 2.5.4.10 }
                  PrintableString { "IETF" }
                }
              }
            }
            SET {
              SEQUENCE {
                # commonName
                OBJECT_IDENTIFIER { 2.5.4.3 }
                PrintableString { "LAMPS WG" }
              }
            }
          }
          INTEGER { `159ffe6f22fd5cc42c524df6fd5e28d0de38f34e` }
        }
      }
    }
  }
}

```

```

SEQUENCE {
  # sha512
  OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.2.3 }
}
[0] {
  SEQUENCE {
    # contentType
    OBJECT_IDENTIFIER { 1.2.840.113549.1.9.3 }
    SET {
      # data
      OBJECT_IDENTIFIER { 1.2.840.113549.1.7.1 }
    }
  }
  SEQUENCE {
    # messageDigest
    OBJECT_IDENTIFIER { 1.2.840.113549.1.9.4 }
    SET {
      OCTET_STRING { `024f5ef2846bda2220e542208acfd715
ddd3b8e111e8390d62864b1dc128c0a2c9b74567b0b955c617f002204d27d887
95699e065f016ae31c6d0a4b42662264` }
    }
  }
}
SEQUENCE {
  OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.3.19 }
}
OCTET_STRING { `9863de9a87725f55d7963b509e9a5496df4646
97c42d6b93d355de27d9c70f3188c57aa479288cb5b8aa993a728f9e75ec12ca
fdc25be154dc691f1580ab1a43f2692a526453d82c9dd1aeaa35c2116c0de25e
d2e34f2ea594c7b2d409db4911e546e0e2953f0ea7301b0f2f4e111398215521
5833e49dc5c67bb74a846e7685d477be4d32734fc0c4f7bbb42d78a18467aee1
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23e4613a82c124fc7f9cb8124e8ab57078bdf4c3ed2998c22a331e3dddffdc52
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```

2d877a3dc09c8059f4a5de5c031fa162b2ead125eee7de53fb585d83b5c2cc56
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bff31149f1ca3fa94f52234e052f280ae3e6e3e85e1bcd8b73db19c4191e3160

$$\left. \begin{array}{l} \{ \\ \} \end{array} \right\}$$

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