Use of the Elliptic Curve Diffie-Hellman Key Agreement Algorithm with X25519 and X448 in the Cryptographic Message Syntax (CMS)

Abstract

This document describes the conventions for using Elliptic Curve Diffie-Hellman (ECDH) key agreement algorithm using curve25519 and curve448 in the Cryptographic Message Syntax (CMS).

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1. Introduction

This document describes the conventions for using Elliptic Curve Diffie-Hellman (ECDH) key agreement using curve25519 and curve448 [CURVES] in the Cryptographic Message Syntax (CMS) [CMS]. Key agreement is supported in three CMS content types: the enveloped-data content type [CMS], authenticated-data content type [CMS], and the authenticated-enveloped-data content type [AUTHENV].

The conventions for using some Elliptic Curve Cryptography (ECC) algorithms in CMS are described in [CMSECC]. These conventions cover the use of ECDH with some curves other than curve25519 and curve448 [CURVES]. Those other curves are not deprecated, but support for curve25519 and curve448 is encouraged.

Using curve25519 with Diffie-Hellman key agreement is referred to as X25519. Using curve448 with Diffie-Hellman key agreement is referred to as X448.

1.1. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [STDWORDS].

1.2. ASN.1

CMS values are generated using ASN.1 [X680], which uses the Basic Encoding Rules (BER) and the Distinguished Encoding Rules (DER) [X690].

2. Key Agreement

In 1976, Diffie and Hellman described a means for two parties to agree upon a shared secret value in manner that prevents eavesdroppers from learning the shared secret value [DH1976]. This secret may then be converted into pairwise symmetric keying material for use with other cryptographic algorithms. Over the years, many variants of this fundamental technique have been developed. This document describes the conventions for using Ephemeral-Static Elliptic Curve Diffie-Hellman (ECDH) key agreement using X25519 and X448 [CURVES].

The originator uses an ephemeral public/private key pair that is generated on the same elliptic curve as the public key of the recipient. The ephemeral key pair is used for a single CMS protected content type, and then it is discarded. The originator obtains the
recipient’s static public key from the recipient’s certificate [PROFILE].

X25519 is described in Section 6.1 of [CURVES], and X448 is described in Section 6.2 of [CURVES]. Since curve25519 and curve448 have cofactors of 8 and 4, respectively, an input point of small order will eliminate any contribution from the other party’s private key. As described in Section 7 of [CURVES], implementations SHOULD detect this situation by checking for the all-zero output.

In [CURVES], the shared secret value that is produced by ECDH is called K. (In some other specifications, the shared secret value is called Z.) A key derivation function (KDF) is used to produce a pairwise key-encryption key from the shared secret value (K), the length of the key-encryption key, and the DER-encoded ECC-CMS-SharedInfo structure [CMSECC].

The ECC-CMS-SharedInfo definition from [CMSECC] is repeated here for convenience.

ECC-CMS-SharedInfo ::= SEQUENCE {
    keyInfo          AlgorithmIdentifier,
    entityUInfo [0] EXPLICIT OCTET STRING OPTIONAL,
    suppPubInfo [2] EXPLICIT OCTET STRING }

The ECC-CMS-SharedInfo keyInfo field contains the object identifier of the key-encryption algorithm and associated parameters. This algorithm will be used to wrap the content-encryption key. For example, the AES Key Wrap algorithm [AESKW] does not need parameters, so the algorithm identifier parameters are absent.

The ECC-CMS-SharedInfo entityUInfo field optionally contains additional keying material supplied by the sending agent. Note that [CMS] requires implementations to accept a KeyAgreeRecipientInfo SEQUENCE that includes the ukm field. If the ukm field is present, the ukm is placed in the entityUInfo field. The ukm value need not be longer than the key-encryption key that will be produced by the KDF. When present, the ukm ensures that a different key-encryption key is generated, even when the originator ephemeral private key is improperly used more than once.

The ECC-CMS-SharedInfo suppPubInfo field contains the length of the generated key-encryption key, in bits, represented as a 32-bit number in network byte order. For example, the key length for AES-256 [AES] would be 0x00000100.
2.1. ANSI-X9.63-KDF

The ANSI-X9.63-KDF key derivation function is a simple construct based on a one-way hash function described in ANS X9.63 [X963]. This KDF is also described in Section 3.6.1 of [SEC1].

Three values are concatenated to produce the input string to the KDF:
1. The shared secret value generated by ECDH, K.
2. The iteration counter, starting with one, as described below.
3. The DER-encoded ECC-CMS-SharedInfo structure.

To generate a key-encryption key (KEK), the KDF generates one or more KM blocks, with the counter starting at 0x00000001, and incrementing the counter for each subsequent KM block until enough material has been generated. The 32-bit counter is represented in network byte order. The KM blocks are concatenated left to right, and then the leftmost portion of the result is used as the pairwise key-encryption key, KEK:

\[
KM(i) = \text{Hash}(K \ || \ \text{INT32(counter=i)} \ || \ \text{DER(ECC-CMS-SharedInfo)})
\]

\[
KEK = KM(\text{counter}=1) \ || \ KM(\text{counter}=2) \ ...
\]

2.2. HKDF

The HMAC-based Extract-and-Expand Key Derivation Function (HKDF) is a robust construct based on a one-way hash function described in RFC 5869 [HKDF]. HKDF is comprised of two steps: HKDF-Extract followed by HKDF-Expand.

Three values are used as inputs to the HKDF:
1. The shared secret value generated by ECDH, K.
2. The length in octets of the keying data to be generated.
3. The DER-encoded ECC-CMS-SharedInfo structure.

The ECC-CMS-SharedInfo structure optionally includes the ukm. If the ukm is present, the ukm is also used as the HKDF salt.

The length of the generated key-encryption key is used two places, once in bits, and once in octets. The ECC-CMS-SharedInfo structure includes the length of the generated key-encryption key in bits. The HKDF-Expand function takes an argument for the length of the generated key-encryption key in octets.
In summary, to produce the pairwise key-encryption key, KEK:

if ukm is provided, then salt = ukm, else salt = zero
PRK = HKDF-Extract(salt, K)
KEK = HKDF-Expand(PRK, DER(ECC-CMS-SharedInfo), SizeInOctets(KEK))

3. Enveloped-data Conventions

The CMS enveloped-data content type [CMS] consists of an encrypted content and wrapped content-encryption keys for one or more recipients. The ECDH key agreement algorithm is used to generate a pairwise key-encryption key between the originator and a particular recipient. Then, the key-encryption key is used to wrap the content-encryption key for that recipient. When there is more than one recipient, the same content-encryption key MUST be wrapped for each of them.

A compliant implementation MUST meet the requirements for constructing an enveloped-data content type in Section 6 of [CMS].

A content-encryption key MUST be randomly generated for each instance of an enveloped-data content type. The content-encryption key is used to encrypt the content.

3.1. EnvelopedData Fields

The enveloped-data content type is ASN.1 encoded using the EnvelopedData syntax. The fields of the EnvelopedData syntax MUST be populated as described in [CMS]; for the recipients that use X25519 or X448 the RecipientInfo kari choice MUST be used.

3.2. KeyAgreeRecipientInfo Fields

The fields of the KeyAgreeRecipientInfo syntax MUST be populated as described in this section when X25519 or X448 is employed for one or more recipients.

The KeyAgreeRecipientInfo version MUST be 3.

The KeyAgreeRecipientInfo originator provides three alternatives for identifying the originator’s public key, and the originatorKey alternative MUST be used. The originatorKey MUST contain an ephemeral key for the originator. The originatorKey algorithm field MUST contain the id-X25519 or the id-X448 object identifier. The originator’s ephemeral public key MUST be encoded as an OCTET STRING.

The object identifiers for X25519 and X448 have been assigned in
When using X25519, the public key contains exactly 32 octets, and the id-X25519 object identifier is used:

\[ \text{id-X25519 OBJECT IDENTIFIER ::= \{ 1 3 101 110 \}} \]

When using X448, the public key contains exactly 56 octets, and the id-X448 object identifier is used:

\[ \text{id-X448 OBJECT IDENTIFIER ::= \{ 1 3 101 111 \}} \]

KeyAgreeRecipientInfo ukm is optional. Note that [CMS] requires implementations to accept a KeyAgreeRecipientInfo SEQUENCE that includes the ukm field. If present, the ukm is placed in the entityUInfo field of the ECC-CMS-SharedInfo as input to the KDF. The ukm value need not be longer than the key-encryption key produced by the KDF.

KeyAgreeRecipientInfo keyEncryptionAlgorithm MUST contain the object identifier of the key-encryption algorithm that will be used to wrap the content-encryption key. The conventions for using AES-128, AES-192, and AES-256 in the key wrap mode are specified in [CMSAES].

KeyAgreeRecipientInfo recipientEncryptedKeys includes a recipient identifier and encrypted key for one or more recipients. The RecipientEncryptedKey KeyAgreeRecipientIdentifier MUST contain either the issuerAndSerialNumber identifying the recipient’s certificate or the RecipientKeyIdentifier containing the subject key identifier from the recipient’s certificate. In both cases, the recipient’s certificate contains the recipient’s static X25519 or X448 public key. RecipientEncryptedKey EncryptedKey MUST contain the content-encryption key encrypted with the pairwise key-encryption key using the algorithm specified by the KeyWrapAlgorithm.

4. Authenticated-data Conventions

The CMS authenticated-data content type [CMS] consists an authenticated content, a message authentication code (MAC), and encrypted authentication keys for one or more recipients. The ECDH key agreement algorithm is used to generate a pairwise key-encryption key between the originator and a particular recipient. Then, the key-encryption key is used to wrap the authentication key for that recipient. When there is more than one recipient, the same authentication key MUST be wrapped for each of them.
A compliant implementation MUST meet the requirements for constructing an authenticated-data content type in Section 9 of [CMS].

A authentication key MUST be randomly generated for each instance of an authenticated-data content type. The authentication key is used to compute the MAC over the content.

4.1. AuthenticatedData Fields

The authenticated-data content type is ASN.1 encoded using the AuthenticatedData syntax. The fields of the AuthenticatedData syntax MUST be populated as described in [CMS]; for the recipients that use X25519 or X448 the RecipientInfo kari choice MUST be used.

4.2. KeyAgreeRecipientInfo Fields

The fields of the KeyAgreeRecipientInfo syntax MUST be populated as described in Section 3.2 of this document.

5. Authenticated-Enveloped-data Conventions

The CMS authenticated-enveloped-data content type [AUTHENV] consists of an authenticated and encrypted content and encrypted content-authenticated-encryption keys for one or more recipients. The ECDH key agreement algorithm is used to generate a pairwise key-encryption key between the originator and a particular recipient. Then, the key-encryption key is used to wrap the content-authenticated-encryption key for that recipient. When there is more than one recipient, the same content-authenticated-encryption key MUST be wrapped for each of them.

A compliant implementation MUST meet the requirements for constructing an authenticated-data content type in Section 2 of [AUTHENV].

A content-authenticated-encryption key MUST be randomly generated for each instance of an authenticated-enveloped-data content type. The content-authenticated-encryption key key is used to authenticate and encrypt the content.

5.1. AuthEnvelopedData Fields

The authenticated-enveloped-data content type is ASN.1 encoded using the AuthEnvelopedData syntax. The fields of the AuthEnvelopedData syntax MUST be populated as described in [AUTHENV]; for the recipients that use X25519 or X448 the RecipientInfo kari choice MUST be used.
5.2. KeyAgreeRecipientInfo Fields

The fields of the KeyAgreeRecipientInfo syntax MUST be populated as described in Section 3.2 of this document.

6. Certificate Conventions

RFC 5280 [PROFILE] specifies the profile for using X.509 Certificates in Internet applications. A recipient static public key is needed for X25519 or X448, and the originator obtains that public key from the recipient’s certificate. The conventions for carrying X25519 and X448 public keys are specified in [ID.curdle-pkix].

7. Key Agreement Algorithm Identifiers

The following object identifiers are assigned in [CMSECC] to indicate ECDH with ANSI-X9.63-KDF using various one-way hash functions. These are expected to be used as AlgorithmIdentifiers with a parameter that specifies the key-encryption algorithm. These are repeated here for convenience.

\[
\text{secg-scheme OBJECT IDENTIFIER ::= }
\text{ { iso(1) identified-organization(3) certicom(132) schemes(1) } }
\]
\[
\text{ dhSinglePass-stdDH-sha256kdf-scheme OBJECT IDENTIFIER ::= }
\text{ { secg-scheme 11 1 } }
\]
\[
\text{ dhSinglePass-stdDH-sha384kdf-scheme OBJECT IDENTIFIER ::= }
\text{ { secg-scheme 11 2 } }
\]
\[
\text{ dhSinglePass-stdDH-sha512kdf-scheme OBJECT IDENTIFIER ::= }
\text{ { secg-scheme 11 3 } }
\]

The following object identifiers are assigned to indicate ECDH with HKDF using various one-way hash functions. These are expected to be used as AlgorithmIdentifiers with a parameter that specifies the key-encryption algorithm.

\[
\text{smime-alg OBJECT IDENTIFIER ::= }
\text{ { iso(1) member-body(2) us(840) rsadsi(113549) pkcs(1)
pkcs-9(9) smime(16) alg(3) } }
\]
\[
\text{ dhSinglePass-stdDH-hkdf-sha256-scheme OBJECT IDENTIFIER ::= }
\text{ { smime-alg TBD1 } }
\]
\[
\text{ dhSinglePass-stdDH-hkdf-sha384-scheme OBJECT IDENTIFIER ::= }
\text{ { smime-alg TBD2 } }
\]
dhSinglePass-stdDH-hkdf-sha512-scheme OBJECT IDENTIFIER ::= {
    smime-alg TBD3 }

8. SMIMECapabilities Attribute Conventions

A sending agent MAY announce to other agents that it supports ECDH key agreement using the SMIMECapabilities signed attribute in a signed message [SMIME] or a certificate [CERTCAP]. Following the pattern established in [CMSECC], the SMIMECapabilities associated with ECDH carries a DER-encoded object identifier that identifies support for ECDH in conjunction with a particular KDF, and it includes a parameter that names the key wrap algorithm.

The following SMIMECapabilities values (in hexadecimal) from [CMSECC] might be of interest to implementations that support X25519 and X448:

- ECDH with ANSI-X9.63-KDF using SHA-256; uses AES-128 key wrap:
  30 15 06 06 2B 81 04 01 0B 01 30 0B 06 09 60 86 48 01 65 03 04 01 05

- ECDH with ANSI-X9.63-KDF using SHA-384; uses AES-128 key wrap:
  30 15 06 06 2B 81 04 01 0B 02 30 0B 06 09 60 86 48 01 65 03 04 01 05

- ECDH with ANSI-X9.63-KDF using SHA-512; uses AES-128 key wrap:
  30 15 06 06 2B 81 04 01 0B 03 30 0B 06 09 60 86 48 01 65 03 04 01 05

- ECDH with ANSI-X9.63-KDF using SHA-256; uses AES-256 key wrap:
  30 15 06 06 2B 81 04 01 0B 01 30 0B 06 09 60 86 48 01 65 03 04 01 2D

- ECDH with ANSI-X9.63-KDF using SHA-384; uses AES-256 key wrap:
  30 15 06 06 2B 81 04 01 0B 02 30 0B 06 09 60 86 48 01 65 03 04 01 2D

- ECDH with ANSI-X9.63-KDF using SHA-512; uses AES-256 key wrap:
  30 15 06 06 2B 81 04 01 0B 03 30 0B 06 09 60 86 48 01 65 03 04 01 2D

The following SMIMECapabilities values (in hexadecimal) based on the algorithm identifiers in Section 7 of this document might be of interest to implementations that support X25519 and X448:

- ECDH with HKDF using SHA-256; uses AES-128 key wrap:
  TBD
ECDH with HKDF using SHA-384; uses AES-128 key wrap: TBD
ECDH with HKDF using SHA-512; uses AES-128 key wrap: TBD
ECDH with HKDF using SHA-256; uses AES-256 key wrap: TBD
ECDH with HKDF using SHA-384; uses AES-256 key wrap: TBD
ECDH with HKDF using SHA-512; uses AES-256 key wrap: TBD

9. Security Considerations

Please consult the security considerations of [CMS] for security considerations related to the enveloped-data content type and the authenticated-data content type.

Please consult the security considerations of [AUTHENV] for security considerations related to the authenticated-enveloped-data content type.

Please consult the security considerations of [CURVES] for security considerations related to the use of X25519 and X448.

The originator uses an ephemeral public/private key pair that is generated on the same elliptic curve as the public key of the recipient. The ephemeral key pair is used for a single CMS protected content type, and then it is discarded. If the originator wants to be able to decrypt the content (for enveloped-data and authenticated-enveloped-data) or check the authentication (for authenticated-data), then the originator needs to treat themselves as a recipient.

As specified in [CMS], implementations MUST support processing of the KeyAgreeRecipientInfo ukm field; this ensures that interoperability is not a concern whether the ukm is present or absent. The ukm is placed in the entityUInfo field of the ECC-CMS-SharedInfo structure. When present, the ukm ensures that a different key-encryption key is generated, even when the originator ephemeral private key is improperly used more than once.
10. IANA Considerations

One object identifier for the ASN.1 module in the Appendix needs to be assigned in the SMI Security for S/MIME Module Identifiers (1.2.840.113549.1.9.16.0) [IANA-MOD] registry:

\[
\text{id-mod-cms-ecdh-alg-2017 \text{ OBJECT IDENTIFIER ::= \{}}
\text{ iso(1) member-body(2) us(840) rsadsi(113549) pkcs(1)}
\text{ pkcs-9(9) smime(16) mod(0) TBD0}\]

Three object identifiers for the Key Agreement Algorithm Identifiers in Sections 7 need to be assigned in the SMI Security for S/MIME Algorithms (1.2.840.113549.1.9.16.3) [IANA-ALG] registry:

\[
\text{smime-alg \text{ OBJECT IDENTIFIER ::= \{}}
\text{ iso(1) member-body(2) us(840) rsadsi(113549) pkcs(1)}
\text{ pkcs-9(9) smime(16) alg(3) }}
\]

\[
\text{dhSinglePass-stdDH-hkdf-sha256-scheme \text{ OBJECT IDENTIFIER ::= \{}}
\text{ smime-alg TBD1}\]

\[
\text{dhSinglePass-stdDH-hkdf-sha384-scheme \text{ OBJECT IDENTIFIER ::= \{}}
\text{ smime-alg TBD2}\]

\[
\text{dhSinglePass-stdDH-hkdf-sha512-scheme \text{ OBJECT IDENTIFIER ::= \{}}
\text{ smime-alg TBD3}\]

11. Normative References


12. Informative References


[IANA-MOD] https://www.iana.org/assignments/smi-numbers/smi-numbers.xhtml#security-smime-0.

Appendix: ASN.1 Module

CMSECDHAlgs-2017
{ iso(1) member-body(2) us(840) rsadsi(113549) pkcs(1) pkcs-9(9)
  smime(16) modules(0) id-mod-cms-ecdh-alg-2017(TBD0) }

DEFINITIONS IMPLICIT TAGS ::= BEGIN

-- EXPORTS ALL

IMPORTS

KeyWrapAlgorithm
  FROM CryptographicMessageSyntaxAlgorithms-2009 -- in [CMSASN1]
  { iso(1) member-body(2) us(840) rsadsi(113549) pkcs(1)
    pkcs-9(9) smime(16) modules(0) id-mod-cmsalg-2001-02(37) }

KEY-AGREE, SMIME-CAPS
  FROM AlgorithmInformation-2009 -- in [CMSASN1]
  { iso(1) identified-organization(3) dod(6) internet(1)
    security(5) mechanisms(5) pkix(7) id-mod(0)
    id-mod-algorithmInformation-02(58) } dhSinglePass-stdDH-sha256kdf-scheme,
dhSinglePass-stdDH-sha384kdf-scheme,
dhSinglePass-stdDH-sha512kdf-scheme,
kaa-dhSinglePass-stdDH-sha256kdf-scheme,
kaa-dhSinglePass-stdDH-sha384kdf-scheme,
kaa-dhSinglePass-stdDH-sha512kdf-scheme,
cap-kaa-dhSinglePass-stdDH-sha256kdf-scheme,
cap-kaa-dhSinglePass-stdDH-sha384kdf-scheme,
cap-kaa-dhSinglePass-stdDH-sha512kdf-scheme
  FROM CMSECCAlgs-2009-02 -- in [CMSECC]
  { iso(1) member-body(2) us(840) rsadsi(113549) pkcs(1)
    pkcs-9(9) smime(16) modules(0)
    id-mod-cms-ecc-alg-2009-02(46) }

;
-- -- Object Identifiers
--

smime-alg OBJECT IDENTIFIER ::= {
    iso(1) member-body(2) us(840) rsadsi(113549) pkcs(1)
    pkcs-9(9) smime(16) alg(3) }

dhSinglePass-stdDH-hkdf-sha256-scheme OBJECT IDENTIFIER ::= { smime-alg TBD1 }

dhSinglePass-stdDH-hkdf-sha384-scheme OBJECT IDENTIFIER ::= { smime-alg TBD2 }

dhSinglePass-stdDH-hkdf-sha512-scheme OBJECT IDENTIFIER ::= { smime-alg TBD3 }

-- -- Extend the Key Agreement Algorithms in [CMSECC] --

KeyAgreementAlgs KEY-AGREE ::= { ...
    kaa-dhSinglePass-stdDH-sha256kdf-scheme |
    kaa-dhSinglePass-stdDH-sha384kdf-scheme |
    kaa-dhSinglePass-stdDH-sha512kdf-scheme |
    kaa-dhSinglePass-stdDH-hkdf-sha256-scheme |
    kaa-dhSinglePass-stdDH-hkdf-sha384-scheme |
    kaa-dhSinglePass-stdDH-hkdf-sha512-scheme } |

kaa-dhSinglePass-stdDH-hkdf-sha256-scheme KEY-AGREE ::= { IDENTIFIER dhSinglePass-stdDH-hkdf-sha256-scheme |
    PARAMS TYPE KeyWrapAlgorithm ARE required |
    UKM -- TYPE unencoded data -- ARE preferredPresent |
    SMIME-CAPS cap-kaa-dhSinglePass-stdDH-hkdf-sha256-scheme } |

    PARAMS TYPE KeyWrapAlgorithm ARE required |
    UKM -- TYPE unencoded data -- ARE preferredPresent |
    SMIME-CAPS cap-kaa-dhSinglePass-stdDH-hkdf-sha384-scheme } |

    PARAMS TYPE KeyWrapAlgorithm ARE required |
    UKM -- TYPE unencoded data -- ARE preferredPresent |
    SMIME-CAPS cap-kaa-dhSinglePass-stdDH-hkdf-sha512-scheme } 

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--
-- Extend the S/MIME CAPS in [CMSECC]
--

SMimeCAPS SMIME-CAPS ::= { ..., 
    kaa-dhSinglePass-stdDH-sha256kdf-scheme.&smimeCaps | 
    kaa-dhSinglePass-stdDH-sha384kdf-scheme.&smimeCaps | 
    kaa-dhSinglePass-stdDH-sha512kdf-scheme.&smimeCaps | 
    kaa-dhSinglePass-stdDH-hkdf-sha256-scheme.&smimeCaps | 
    kaa-dhSinglePass-stdDH-hkdf-sha384-scheme.&smimeCaps | 
    kaa-dhSinglePass-stdDH-hkdf-sha512-scheme.&smimeCaps }

    cap-kaa-dhSinglePass-stdDH-hkdf-sha256-scheme SMIME-CAPS ::= { 
        TYPE KeyWrapAlgorithm 
        IDENTIFIED BY dhSinglePass-stdDH-hkdf-sha256-scheme }

    cap-kaa-dhSinglePass-stdDH-hkdf-sha384-scheme SMIME-CAPS ::= { 
        TYPE KeyWrapAlgorithm 
        IDENTIFIED BY dhSinglePass-stdDH-hkdf-sha384-scheme }

    cap-kaa-dhSinglePass-stdDH-hkdf-sha512-scheme SMIME-CAPS ::= { 
        TYPE KeyWrapAlgorithm 
        IDENTIFIED BY dhSinglePass-stdDH-hkdf-sha512-scheme }

END

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