

Network Working Group
Internet-Draft
Intended status: Standards Track
Expires: May 4, 2017

S. Josefsson
SJD AB
J. Schaad
August Cellars
October 31, 2016

Algorithm Identifiers for Ed25519, Ed25519ph, Ed448, Ed448ph, X25519 and X448 for use in the Internet X.509 Public Key Infrastructure
[draft-ietf-curdle-pkix-02](#)

Abstract

This document specifies algorithm identifiers and ASN.1 encoding formats for Elliptic Curve constructs using the Curve25519 and Curve448 curves. The signature algorithms covered are Ed25519, Ed25519ph, Ed448 and Ed448ph. The key agreement algorithm covered are X25519 and X448. The Encoding for Public Key, Private Key and EdDSA digital signature structures is provided.

Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of [BCP 78](#) and [BCP 79](#).

Internet-Drafts are working documents of the Internet Engineering Task Force (IETF). Note that other groups may also distribute working documents as Internet-Drafts. The list of current Internet-Drafts is at <http://datatracker.ietf.org/drafts/current/>.

Internet-Drafts are draft documents valid for a maximum of six months and may be updated, replaced, or obsoleted by other documents at any time. It is inappropriate to use Internet-Drafts as reference material or to cite them other than as "work in progress."

This Internet-Draft will expire on May 4, 2017.

Copyright Notice

Copyright (c) 2016 IETF Trust and the persons identified as the document authors. All rights reserved.

This document is subject to [BCP 78](#) and the IETF Trust's Legal Provisions Relating to IETF Documents (<http://trustee.ietf.org/license-info>) in effect on the date of publication of this document. Please review these documents carefully, as they describe your rights and restrictions with respect to this document. Code Components extracted from this document must

Internet-Draft

Safe curves for X.509

October 2016

include Simplified BSD License text as described in Section 4.e of the Trust Legal Provisions and are provided without warranty as described in the Simplified BSD License.

Table of Contents

1.	Introduction	2
2.	Requirements Terminology	3
3.	Curve25519 and Curve448 Algorithm Identifiers	3
4.	Subject Public Key Fields	4
5.	Key Usage Bits	4
6.	EdDSA Signatures	5
7.	Private Key Format	6
8.	Human Readable Algorithm Names	7
9.	ASN.1 Module	8
10.	Examples	10
10.1.	Example Ed25519 Public Key	10
10.2.	Example X25519 Certificate	11
10.3.	Example Ed25519 Private Key	13
11.	Acknowledgements	13
12.	IANA Considerations	13
13.	Security Considerations	13
14.	References	14
14.1.	Normative References	14
14.2.	Informative References	15
	Authors' Addresses	15

[1.](#) Introduction

In [[RFC7748](#)], the elliptic curves Curve25519 and Curve448 are described. They are designed with performance and security in mind. The curves may be used for Diffie-Hellman and Digital Signature operations.

[[RFC7748](#)] describes the operations on these curves for the Diffie-Hellman operation. A convention has developed that when these two curves are used with the Diffie-Hellman operation, they are referred to as X25519 and X448. This RFC defines the ASN.1 Object Identifiers (OIDs) for the operations X25519 and X448 along with the parameters. The use of these OIDs is described for public and private keys.

In [[I-D.irtf-cfrg-eddsa](#)] the elliptic curve signature system Edwards-curve Digital Signature Algorithm (EdDSA) is described along with a

recommendation for the use of the Curve25519 and Curve448. EdDSA has defined two modes, the PureEdDSA mode without pre-hashing, and the HashEdDSA mode with pre-hashing. The Ed25519ph and Ed448ph algorithm definitions specify the one-way hash function that is used for pre-hashing. The convention used for identifying the algorithm/curve

combinations are to use the Ed25519 and Ed448 for the PureEdDSA mode, with Ed25519ph and Ed448ph for the HashEdDSA mode. The use of the OIDs is described for public keys, private keys and signatures.

[2.](#) Requirements 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 [[RFC2119](#)].

[3.](#) Curve25519 and Curve448 Algorithm Identifiers

Certificates conforming to [[RFC5280](#)] can convey a public key for any public key algorithm. The certificate indicates the algorithm through an algorithm identifier. This algorithm identifier is an OID and optionally associated parameters.

The AlgorithmIdentifier type, which is included for convenience, is defined as follows:

```
AlgorithmIdentifier ::= SEQUENCE {
    algorithm    OBJECT IDENTIFIER,
    parameters  ANY DEFINED BY algorithm OPTIONAL
}
```

The fields in AlgorithmIdentifier have the following meanings:

- o algorithm identifies the cryptographic algorithm with an object identifier. This is one of the OIDs defined below.
- o parameters, which are optional, are the associated parameters for the algorithm identifier in the algorithm field. When the 1997 syntax for AlgorithmIdentifier was initially defined, it omitted the OPTIONAL key word. The optionality of the parameters field was later recovered via a defect report, but by then many people thought that the field was mandatory. For this reason, a small

number of implementations may still require the field to be present.

In this document we defined six new OIDs for identifying the different curve/algorithm pairs. The curves being Curve25519 and Curve448. The algorithms being ECDH, EdDSA in pure mode and EdDSA in pre-hash mode. For all of the OIDs, the parameters MUST be absent. Implementations SHOULD NOT accept a parameters value of NULL.

The same algorithm identifiers are used for identifying a public key, identifying a private key and identifying a signature (for the four

EdDSA related OIDs). Additional encoding information is provided below for each of these locations.

```
id-X25519    OBJECT IDENTIFIER ::= { 1 3 101 110 }
id-X448      OBJECT IDENTIFIER ::= { 1 3 101 111 }
id-Ed25519   OBJECT IDENTIFIER ::= { 1 3 101 112 }
id-Ed448     OBJECT IDENTIFIER ::= { 1 3 101 113 }
id-Ed25519ph OBJECT IDENTIFIER ::= { 1 3 101 114 }
id-Ed448ph   OBJECT IDENTIFIER ::= { 1 3 101 115 }
```

[4.](#) Subject Public Key Fields

In the X.509 certificate, the `subjectPublicKeyInfo` field has the `SubjectPublicKeyInfo` type, which has the following ASN.1 syntax:

```
SubjectPublicKeyInfo ::= SEQUENCE {
    algorithm          AlgorithmIdentifier,
    subjectPublicKey   BIT STRING
}
```

The fields in `SubjectPublicKeyInfo` have the following meanings:

- o `algorithm` is the algorithm identifier and parameters for the public key (see above).
- o `subjectPublicKey` contains the byte stream of the public key. While the encoded public keys for the current algorithms are all an even number of octets, future curves could change that.

Both [[RFC7748](#)] and [[I-D.irtf-cfrg-eddsa](#)] define the public key value as being a byte string. It should be noted that the public key is computed differently for each of these documents, thus the same private key will not produce the same public key.

The following is an example of a public key encoded using the textual encoding defined in [[RFC7468](#)].

```
-----BEGIN PUBLIC KEY-----  
MCowBQYDK2VwAyEAGb9ECWmEzF6FQbrBZ9w7lshQhqowtrbLDFw4rXAxZmE=  
-----END PUBLIC KEY-----
```

[5.](#) Key Usage Bits

The intended application for the key is indicated in the keyUsage certificate extension.

If the keyUsage extension is present in a certificate that indicates id-X25119 or id-X448 in SubjectPublicKeyInfo, then the following MUST be present:

keyAgreement;

one of the following MAY also be present:

encipherOnly; or
decipherOnly.

If the keyUsage extension is present in an end-entity certificate that indicates id-EdDSA25519, id-EdDSA25519ph, id-EdDSA448 or id-EdDSA448ph, then the keyUsage extension MUST contain one or both of the following values:

nonRepudiation; and
digitalSignature.

If the keyUsage extension is present in a certification authority certificate that indicates id-EdDSA25519 or id-EdDSA448, then the keyUsage extension MUST contain one or more of the following values:

nonRepudiation;
digitalSignature;
keyCertSign; and
cRLSign.

CAs MUST NOT use the pre-hash versions of the EdDSA algorithms for the creation of certificates or CRLs. This is implied by the fact that those algorithms are not listed in the previous paragraph. Additionally OCSP responders SHOULD NOT use the pre-hash versions of the EdDSA algorithms when generating OCSP responses. No restriction is placed on generation of OCSP requests.

AAs MUST NOT use the pre-hash versions of the EdDSA algorithms for the creation of attribute certificates or attribute CRLs [[RFC5755](#)].

[6.](#) EdDSA Signatures

Signatures can be placed in a number of different ASN.1 structures. The top level structure for a certificate is given below as being illustrative of how signatures are frequently encoded with an algorithm identifier and a location for the signature.

```
Certificate ::= SEQUENCE {  
    tbsCertificate      TBSCertificate,  
    signatureAlgorithm  AlgorithmIdentifier,  
    signatureValue      BIT STRING }
```

The same algorithm identifiers are used for signatures as are used for public keys. When used to identify signature algorithms, the parameters MUST be absent.

The data to be signed is prepared for EdDSA. Then, a private key operation is performed to generate the signature value. This value is the opaque value ENC(R) || ENC(S) described in section 3.3 of [[I-D.irtf-cfrg-eddsa](#)]. The octet string representing the signature is encoded directly in the BIT STRING without adding any additional ASN.1 wrapping. For the Certificate structure, the signature value

is wrapped in the 'signatureValue' BIT STRING field.

When the pre-hash versions of the EdDSA signature algorithms are used, the hash function used for the pre-hash is defined by the algorithm. This means that the pre-hash function is implicitly included in the algorithm identifier rather than being explicit as done in [RFC3279].

In [I-D.irtf-cfrg-eddsa], a parameter was defined for a context value, specific to an application, to be provided to the signing operation. This value is used to force different signatures to be generated for different applications. Along with the definition of the context comes a recommendation that contexts only be used if all of the signature algorithms used for an application have the ability to accept a context string. For this reason, applications MUST NOT define the use a context value with the signatures created for these OIDs. New OIDs would be defined in the event that context values appear to provide additional value.

7. Private Key Format

Asymmetric Key Packages [RFC5958] describes how encode a private key in a structure that both identifies what algorithm the private key is for, but allows for the public key and additional attributes about the key to be included as well. For illustration, the ASN.1 structure OneAsymmetricKey is replicated below. The algorithm specific details of how a private key is encoded is left for the document describing the algorithm itself.

```
OneAsymmetricKey ::= SEQUENCE {
    version Version,
    privateKeyAlgorithm PrivateKeyAlgorithmIdentifier,
    privateKey PrivateKey,
    attributes [0] Attributes OPTIONAL,
    ...,
    [[2: publicKey [1] PublicKey OPTIONAL ]],
    ...
}
```

```
}
```

```
PrivateKey ::= OCTET STRING
```

```
PublicKey ::= OCTET STRING
```

For the keys defined in this document, the private key is always an opaque byte sequence. The ASN.1 type `EdPrivateKey` is defined in this document to hold the byte sequence. Thus when encoding a `OneAsymmetricKey` object, the private key is wrapped in an `EdPrivateKey` object and then placed in the 'privateKey' field.

```
EdPrivateKey ::= OCTET STRING
```

To encode a EdDSA, X25519 or X448 private key, the "privateKey" field will hold the encoded private key. The "privateKeyAlgorithm" field uses the `AlgorithmIdentifier` structure. The structure is encoded as defined above. If present, the "publicKey" field will hold the encoded key as defined in [\[RFC7748\]](#) and [\[I-D.irtf-cfrg-eddsa\]](#). public key.

The following is an example of a private key encoded using the textual encoding defined in [\[RFC7468\]](#).

```
-----BEGIN PRIVATE KEY-----  
MC4CAQAwBQYDK2VwBCIEINTuctv5E1hK1bbY8fdp+K06/nwoy/HU++CXqI9EdVhC  
-----END PRIVATE KEY-----
```

[8.](#) Human Readable Algorithm Names

For the purpose of consistent cross-implementation naming this section establishes human readable names for the algorithms specified in this document. Implementations SHOULD use these names when referring to the algorithms. If there is a strong reason to deviate from these names -- for example, if the implementation has a different naming convention and wants to maintain internal consistency -- it is encouraged to deviate as little as possible from the names given here.

or X448 when the curve is not known or relevant.

When the curve is known, use the more specific string of X25519 or X448.

Use the string "EdDSA" when referring to a signing public key or signature when the curve is not known or relevant.

When the curve is known, use a more specific string. For the id-EdDSA25519 value use the string "Ed25519". For the id-EdDSA25519ph value use the string "Ed25519ph". For id-EdDSA448 use "Ed448". For id-EdDSA448ph use "Ed448ph".

9. ASN.1 Module

For reference purposes, the ASN.1 syntax is presented as an ASN.1 module here.

```
-- ASN.1 Module
```

```
Safecurves-pkix-0 {1 3 101 120}
```

```
DEFINITIONS EXPLICIT TAGS ::=
BEGIN
```

```
IMPORTS
```

```
    SIGNATURE-ALGORITHM, KEY-AGREE, PUBLIC-KEY, KEY-WRAP,
    KeyUsage, AlgorithmIdentifier
    FROM AlgorithmInformation-2009
```

```
    { iso(1) identified-organization(3) dod(6) internet(1) security(5)
      mechanisms(5) pkix(7) id-mod(0)
      id-mod-algorithmInformation-02(58) }
```

```
mda-sha512
```

```
FROM PKIX1-PSS-OAEP-Algorithms-2009
```

```
    { iso(1) identified-organization(3) dod(6) internet(1)
      security(5) mechanisms(5) pkix(7) id-mod(0)
      id-mod-pkix1-rsa-pkalgs-02(54) }
```

```
kwa-aes128-wrap, kwa-aes256-wrap
```

```
FROM CMSAesRsaes0aep-2009
```

```
    { iso(1) member-body(2) us(840) rsadsi(113549) pkcs(1) pkcs-9(9)
      smime(16) modules(0) id-mod-cms-aes-02(38) }
```

```
;
```

```
id-edwards-curve-algs OBJECT IDENTIFIER ::= { 1 3 101 }
```

```
id-X25519      OBJECT IDENTIFIER ::= { id-edwards-curve-algs 110 }
id-X448        OBJECT IDENTIFIER ::= { id-edwards-curve-algs 111 }
id-EdDSA25519 OBJECT IDENTIFIER ::= { id-edwards-curve-algs 112 }
id-EdDSA25519-ph OBJECT IDENTIFIER ::= { id-edwards-curve-algs 114 }
id-EdDSA448    OBJECT IDENTIFIER ::= { id-edwards-curve-algs 113 }
id-EdDSA448-ph OBJECT IDENTIFIER ::= { id-edwards-curve-algs 115 }
```

```
sa-EdDSA25519 SIGNATURE-ALGORITHM ::= {
  IDENTIFIER id-EdDSA25519
  PARAMS ARE absent
  PUBLIC-KEYS {pk-EdDSA25519}
  SMIME-CAPS { IDENTIFIED BY id-EdDSA25519 }
}
```

```
pk-EdDSA25519 PUBLIC-KEY ::= {
  IDENTIFIER id-EdDSA25519
  -- KEY no ASN.1 wrapping --
  PARAMS ARE absent
  CERT-KEY-USAGE {digitalSignature, nonRepudiation,
                  keyCertSign, cRLSign}
  PRIVATE-KEY EdPrivateKey
}
```

```
sa-EdDSA25519-ph SIGNATURE-ALGORITHM ::= {
  IDENTIFIER id-EdDSA25519-ph
  PARAMS ARE absent
  HASHES { mda-sha512 }
  PUBLIC-KEYS {pk-EdDSA25519-ph}
  SMIME-CAPS { IDENTIFIED BY id-EdDSA25519-ph }
}
```

```
pk-EdDSA25519-ph PUBLIC-KEY ::= {
  IDENTIFIER id-EdDSA25519-ph
  -- KEY no ASN.1 wrapping --
  PARAMS ARE absent
  CERT-KEY-USAGE {digitalSignature, nonRepudiation}
  PRIVATE-KEY EdPrivateKey
}
```

```
kaa-X25519 KEY-AGREE ::= {
  IDENTIFIER id-X25519
  PARAMS ARE absent
  PUBLIC-KEYS {pk-X25519}
  UKM -- TYPE no ASN.1 wrapping -- ARE preferredPresent
  SMIME-CAPS {
```

```
TYPE AlgorithmIdentifier{KEY-WRAP, {KeyWrapAlgorithms}}
IDENTIFIED BY id-X25519 }
```

```
}

pk-X25519 PUBLIC-KEY ::= {
  IDENTIFIER id-X25519
  -- KEY no ASN.1 wrapping --
  PARAMS ARE absent
  CERT-KEY-USAGE { keyAgreement }
  PRIVATE-KEY EdPrivateKey
}

KeyWrapAlgorithms KEY-WRAP ::= {
  kwa-aes128-wrap | kwa-aes256-wrap,
  ...
}

kaa-X488 KEY-AGREE ::= {
  IDENTIFIER id-X448
  PARAMS ARE absent
  PUBLIC-KEYS {pk-X448}
  UKM -- TYPE no ASN.1 wrapping -- ARE preferredPresent
  SMIME-CAPS {
    TYPE AlgorithmIdentifier{KEY-WRAP, {KeyWrapAlgorithms}}
    IDENTIFIED BY id-X448 }
}

pk-X448 PUBLIC-KEY ::= {
  IDENTIFIER id-X448
  -- KEY no ASN.1 wrapping --
  PARAMS ARE absent
  CERT-KEY-USAGE { keyAgreement }
  PRIVATE-KEY EdPrivateKey
}

EdPrivateKey ::= OCTET STRING
```

END

[10.](#) Examples

This section contains illustrations of EdDSA public keys and certificates, illustrating parameter choices.

[10.1.](#) Example Ed25519 Public Key

An example of a Ed25519 public key:

Public Key Information:

Public Key Algorithm: EdDSA25519

Algorithm Security Level: High

Public Key Usage:

Public Key ID: 9b1f5eeded043385e4f7bc623c5975b90bc8bb3b

-----BEGIN PUBLIC KEY-----

MCowBQYDK2VwAyEAGb9ECWmEzF6FQbrBZ9w7lshQhqowtrbLDFw4rXAxZmE=

-----END PUBLIC KEY-----

[10.2.](#) Example X25519 Certificate

An example of a self issued PKIX certificate using Ed25519 to sign a X25519 public key would be:

```
0 300: SEQUENCE {
4 223:   SEQUENCE {
7   3:     [0] {
9    1:     INTEGER 2
      :     }
12   8:     INTEGER 56 01 47 4A 2A 8D C3 30
22   5:     SEQUENCE {
24   3:     OBJECT IDENTIFIER
      :     EdDSA 25519 signature algorithm { 1 3 101 112 }
      :     }
29  25:     SEQUENCE {
31  23:     SET {
33  21:     SEQUENCE {
35   3:     OBJECT IDENTIFIER commonName (2 5 4 3)
40  14:     UTF8String 'IETF Test Demo'
```

```

      :      }
      :      }
      :      }
56 30: SEQUENCE {
58 13:     UTCTime 01/08/2016 12:19:24 GMT
73 13:     UTCTime 31/12/2040 23:59:59 GMT
      :      }
88 25: SEQUENCE {
90 23:     SET {
92 21:         SEQUENCE {
94  3:             OBJECT IDENTIFIER commonName (2 5 4 3)
99 14:             UTF8String 'IETF Test Demo'
      :             }
      :         }
      :     }
115 42: SEQUENCE {

```

```

117  5: SEQUENCE {
119  3:     OBJECT IDENTIFIER
      :     ECDH 25519 key agreement { 1 3 101 110 }
      :     }
124 33: BIT STRING
      :     85 20 F0 09 89 30 A7 54 74 8B 7D DC B4 3E F7 5A
      :     0D BF 3A 0D 26 38 1A F4 EB A4 A9 8E AA 9B 4E 6A
      :     }
159 69: [3] {
161 67:     SEQUENCE {
163 15:         SEQUENCE {
165  3:             OBJECT IDENTIFIER basicConstraints (2 5 29 19)
170  1:             BOOLEAN TRUE
173  5:             OCTET STRING, encapsulates {
175  3:                 SEQUENCE {
177  1:                     BOOLEAN FALSE
      :                     }
      :                 }
      :             }
180 14:     SEQUENCE {
182  3:         OBJECT IDENTIFIER keyUsage (2 5 29 15)
187  1:         BOOLEAN FALSE
190  4:         OCTET STRING, encapsulates {
192  2:             BIT STRING 3 unused bits
      :             '10000'B (bit 4)

```

```

      :           }
      :           }
196 32: SEQUENCE {
198  3:   OBJECT IDENTIFIER subjectKeyIdentifier (2 5 29 14)
203  1:   BOOLEAN FALSE
206 22:   OCTET STRING, encapsulates {
208 20:   OCTET STRING
      :           9B 1F 5E ED ED 04 33 85 E4 F7 BC 62 3C 59 75 B9
      :           0B C8 BB 3B
      :           }
      :         }
      :       }
      :     }
      :   }
230  5: SEQUENCE {
232  3:   OBJECT IDENTIFIER
      :     EdDSA 25519 signature algorithm { 1 3 101 112 }
      :   }
237 65: BIT STRING
      :   AF 23 01 FE DD C9 E6 FF C1 CC A7 3D 74 D6 48 A4
      :   39 80 82 CD DB 69 B1 4E 4D 06 EC F8 1A 25 CE 50
      :   D4 C2 C3 EB 74 6C 4E DD 83 46 85 6E C8 6F 3D CE
      :   1A 18 65 C5 7A C2 7B 50 A0 C3 50 07 F5 E7 D9 07

```

```

      : }

```

-----BEGIN CERTIFICATE-----

```

MIIBLDCB36ADAgECAghWAUDKKo3DMDAFBgMrZXAwGTEXMBUGA1UEAwwOSUVURiBUZX
N0IERlbW8wHhcNMTYwODAxMTIxOTI0WhcNNDAxMjMxMjM1OTU5WjAZMRCwFQYDVQQD
DA5JRVRGIFRlc3QgRGVtbzAqMAUGAytlbGhAIUg8AmJMKdUdIt93LQ+91oNvzoNJj
ga90ukqY6qm05qo0UwQzAPBgNVHRMBAf8EBTADAQEAMA4GA1UdDwEBAAQEAWIDCDAg
BgNVHQ4BAQAEFgQUmx9e7e0EM4Xk97xiPF1luQvIuzswBQYDK2VwA0EAryMB/t3J5v
/BzKc9dNZIpDmAgS3babFOTQbs+Bo1z1DUwsPrdGx03YNGhW7Ibz30Ghh1xXrCe1Cg
w1AH9efZBw==

```

-----END CERTIFICATE-----

[10.3.](#) Example Ed25519 Private Key

An example of an Ed25519 private key:

-----BEGIN PRIVATE KEY-----

```

MC4CAQAwBQYDK2VwBCIEINTuctv5E1hK1bbY8fdp+K06/nwoy/HU++CXqI9EdVhC

```

-----END PRIVATE KEY-----

11. Acknowledgements

Text and/or inspiration were drawn from [[RFC5280](#)], [[RFC3279](#)], [[RFC4055](#)], [[RFC5480](#)], and [[RFC5639](#)].

The following people discussed the document and provided feedback: Klaus Hartke, Ilari Liusvaara, Erwann Abalea, Rick Andrews, Rob Stradling, James Manger, Nikos Mavrogiannopoulos, Russ Housley, David Benjamin, and Alex Wilson.

A big thank you to Symantec for kindly donating the OIDs used in this draft.

12. IANA Considerations

None.

13. Security Considerations

The security considerations of [[RFC5280](#)], [[RFC7748](#)], and [[I-D.irtf-cfrg-eddsa](#)] apply accordingly.

The procedures for going from a private key to a public key is different for when used with Diffie-Helman and when used with Edwards Signatures. This means that the same public key cannot be used for both ECDH and EdDSA.

In the original design of Ed25519 signatures, there was a known attack between the pure and the pre-hash version of the signatures. This has since been corrected in the final version of the design. The initial problem meant that there was a known attack, and therefore a known reason to forbid the use of Ed25519 keys with the Ed25519ph signature scheme and visa versa. With the change in the design this attack has been prevented. This does not mean that the same Ed25519 key should be used with both schemes, there still may be attacks where collisions can be found. For this reason, the same keys are not to be used for the pure and pre-hash versions of the scheme. This applies to both curve 25519 and curve 448.

14. References

14.1. Normative References

- [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", [BCP 14](#), [RFC 2119](#), DOI 10.17487/RFC2119, March 1997, <<http://www.rfc-editor.org/info/rfc2119>>.
- [RFC5280] Cooper, D., Santesson, S., Farrell, S., Boeyen, S., Housley, R., and W. Polk, "Internet X.509 Public Key Infrastructure Certificate and Certificate Revocation List (CRL) Profile", [RFC 5280](#), DOI 10.17487/RFC5280, May 2008, <<http://www.rfc-editor.org/info/rfc5280>>.
- [RFC5480] Turner, S., Brown, D., Yiu, K., Housley, R., and T. Polk, "Elliptic Curve Cryptography Subject Public Key Information", [RFC 5480](#), DOI 10.17487/RFC5480, March 2009, <<http://www.rfc-editor.org/info/rfc5480>>.
- [RFC7748] Langley, A., Hamburg, M., and S. Turner, "Elliptic Curves for Security", [RFC 7748](#), DOI 10.17487/RFC7748, January 2016, <<http://www.rfc-editor.org/info/rfc7748>>.
- [I-D.irtf-cfrg-eddsa]
Josefsson, S. and I. Liusvaara, "Edwards-curve Digital Signature Algorithm (EdDSA)", [draft-irtf-cfrg-eddsa-08](#) (work in progress), August 2016.
- [RFC5958] Turner, S., "Asymmetric Key Packages", [RFC 5958](#), DOI 10.17487/RFC5958, August 2010, <<http://www.rfc-editor.org/info/rfc5958>>.

14.2. Informative References

- [RFC3279] Bassham, L., Polk, W., and R. Housley, "Algorithms and Identifiers for the Internet X.509 Public Key

Infrastructure Certificate and Certificate Revocation List (CRL) Profile", [RFC 3279](#), DOI 10.17487/RFC3279, April 2002, <<http://www.rfc-editor.org/info/rfc3279>>.

- [RFC4055] Schaad, J., Kaliski, B., and R. Housley, "Additional Algorithms and Identifiers for RSA Cryptography for use in the Internet X.509 Public Key Infrastructure Certificate and Certificate Revocation List (CRL) Profile", [RFC 4055](#), DOI 10.17487/RFC4055, June 2005, <<http://www.rfc-editor.org/info/rfc4055>>.
- [RFC5639] Lochter, M. and J. Merkle, "Elliptic Curve Cryptography (ECC) Brainpool Standard Curves and Curve Generation", [RFC 5639](#), DOI 10.17487/RFC5639, March 2010, <<http://www.rfc-editor.org/info/rfc5639>>.
- [RFC5755] Farrell, S., Housley, R., and S. Turner, "An Internet Attribute Certificate Profile for Authorization", [RFC 5755](#), DOI 10.17487/RFC5755, January 2010, <<http://www.rfc-editor.org/info/rfc5755>>.
- [RFC7468] Josefsson, S. and S. Leonard, "Textual Encodings of PKIX, PKCS, and CMS Structures", [RFC 7468](#), DOI 10.17487/RFC7468, April 2015, <<http://www.rfc-editor.org/info/rfc7468>>.

Authors' Addresses

Simon Josefsson
SJD AB

Email: simon@josefsson.org

Jim Schaad
August Cellars

Email: ietf@augustcellars.com