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Curve25519 and Curve448 for the Internet Key Exchange Protocol Version 2 (IKEv2) Key Agreement

Abstract

This document describes the use of Curve25519 and Curve448 for ephemeral key exchange in the Internet Key Exchange Protocol Version 2 (IKEv2).

Status of This Memo

This is an Internet Standards Track document.

This document is a product of the Internet Engineering Task Force (IETF). It represents the consensus of the IETF community. It has received public review and has been approved for publication by the Internet Engineering Steering Group (IESG). Further information on Internet Standards is available in Section 2 of RFC 7841.

Information about the current status of this document, any errata, and how to provide feedback on it may be obtained at http://www.rfc-editor.org/info/rfc8031.

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1. Introduction

The "Elliptic Curves for Security" document [RFC7748] describes two elliptic curves, Curve25519 and Curve448, as well as the X25519 and X448 functions for performing key agreement using Diffie-Hellman operations with these curves. The curves and functions are designed for both performance and security.

Elliptic curve Diffie-Hellman [RFC5903] has been specified for the Internet Key Exchange Protocol Version 2 (IKEv2) [RFC7296] for almost ten years. RFC 5903 and its predecessor specified the so-called NIST curves. The state of the art has advanced since then. More modern curves allow faster implementations while making it much easier to write constant-time implementations that are resilient to time-based side-channel attacks. This document defines two such curves for use in IKEv2. See [Curve25519] for details about the speed and security of the Curve25519 function.

1.1. Conventions Used in This Document

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].

2. Curve25519 and Curve448

Implementations of Curve25519 and Curve448 in IKEv2 SHALL follow the steps described in this section. All cryptographic computations are done using the X25519 and X448 functions defined in [RFC7748]. All related parameters (for example, the base point) and the encoding (in particular, pruning the least/most significant bits and using little-endian encoding) are compliant with [RFC7748].

An ephemeral Diffie-Hellman key exchange using Curve25519 or Curve448 is performed as follows: each party picks a secret key d uniformly at random and computes the corresponding public key. "X" is used below to denote either X25519 or X448, and "G" is used to denote the corresponding base point:

```
pub_mine = X(d, G)
```

Parties exchange their public keys (see Section 3.1) and compute a shared secret:

```
SHARED_SECRET = X(d, pub_peer)
```

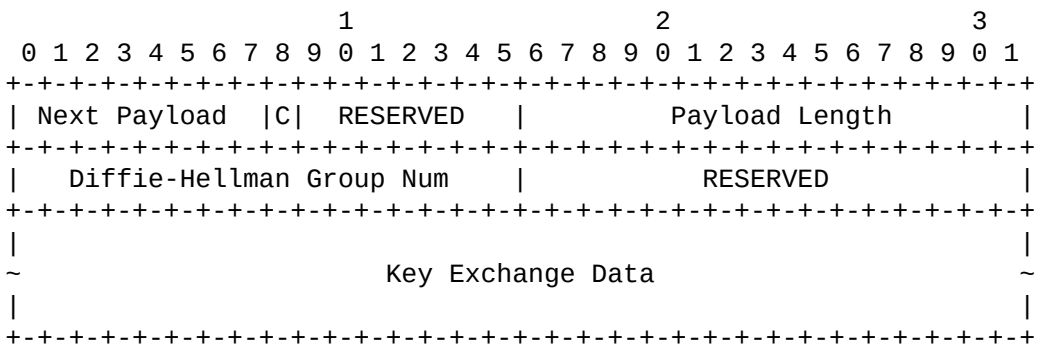
This shared secret is used directly as the value denoted g^ir in Section 2.14 of RFC 7296. It is 32 octets when Curve25519 is used and 56 octets when Curve448 is used.

3. Use and Negotiation in IKEv2

The use of Curve25519 and Curve448 in IKEv2 is negotiated using a Transform Type 4 (Diffie-Hellman group) in the Security Association (SA) payload of either an IKE_SA_INIT or a CREATE_CHILD_SA exchange. The value 31 is used for the group defined by Curve25519 and the value 32 is used for the group defined by Curve448.

3.1. Key Exchange Payload

The diagram for the Key Exchange payload from Section 3.4 of RFC 7296 is copied below for convenience:



- Payload Length - For Curve25519, the public key is 32 octets, so the Payload Length field will be 40. For Curve448, the public key is 56 octets, so the Payload Length field will be 64.

- The Diffie-Hellman Group Num is 31 for Curve25519 or 32 for Curve448.

- The Key Exchange Data is the 32 or 56 octets as described in Section 6 of [RFC7748].

3.2. Recipient Tests

Receiving and handling of incompatible point formats MUST follow the considerations described in Section 5 of [RFC7748]. In particular, receiving entities MUST mask the most-significant bit in the final byte for X25519 (but not X448), and implementations MUST accept non-canonical values.

4. Security Considerations

Curve25519 and Curve448 are designed to facilitate the production of high-performance constant-time implementations. Implementors are encouraged to use a constant-time implementation of the functions. This point is of crucial importance, especially if the implementation chooses to reuse its ephemeral key pair in many key exchanges for performance reasons.

Curve25519 is intended for the ~128-bit security level, comparable to the 256-bit random ECP Groups (group 19) defined in RFC 5903, also known as NIST P-256 or secp256r1. Curve448 is intended for the ~224-bit security level.

While the NIST curves are advertised as being chosen verifiably at random, there is no explanation for the seeds used to generate them. In contrast, the process used to pick Curve25519 and Curve448 is fully documented and rigid enough so that independent verification can and has been done. This is widely seen as a security advantage because it prevents the generating party from maliciously manipulating the parameters.

Another family of curves available in IKE that were generated in a fully verifiable way is the Brainpool curves [RFC6954]. For example, brainpoolP256 (group 28) is expected to provide a level of security comparable to Curve25519 and NIST P-256. However, due to the use of pseudorandom prime, it is significantly slower than NIST P-256, which is itself slower than Curve25519.

5. IANA Considerations

IANA has assigned two values for the names "Curve25519" and "Curve448" in the IKEv2 "Transform Type 4 - Diffie-Hellman Group Transform IDs" and has listed this document as the reference. The Recipient Tests field should also point to this document:

Number	Name	Recipient Tests	Reference
31	Curve25519	RFC 8031, Section 3.2	RFC 8031
32	Curve448	RFC 8031, Section 3.2	RFC 8031

Table 1: New Transform Type 4 Values

6. References

6.1. 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>.

[RFC7296] Kaufman, C., Hoffman, P., Nir, Y., Eronen, P., and T. Kivinen, "Internet Key Exchange Protocol Version 2 (IKEv2)", STD 79, RFC 7296, DOI 10.17487/RFC7296, October 2014, <http://www.rfc-editor.org/info/rfc7296>.

[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>.

6.2. Informative References

[Curve25519] Bernstein, J., "Curve25519: New Diffie-Hellman Speed Records", Public Key Cryptography - PKC 2006, Lecture Notes in Computer Science (LNCS), Vol. 3958, pp. 207-228, DOI 10.1007/11745853_14, February 2006, <http://dx.doi.org/10.1007/11745853_14>.

[RFC5903] Fu, D. and J. Solinas, "Elliptic Curve Groups modulo a Prime (ECP Groups) for IKE and IKEv2", RFC 5903, DOI 10.17487/RFC5903, June 2010, <http://www.rfc-editor.org/info/rfc5903>.

[RFC6954] Merkle, J. and M. Lochter, "Using the Elliptic Curve Cryptography (ECC) Brainpool Curves for the Internet Key Exchange Protocol Version 2 (IKEv2)", RFC 6954, DOI 10.17487/RFC6954, July 2013, <http://www.rfc-editor.org/info/rfc6954>.

Appendix A. Numerical Example for Curve25519

Suppose we have both the initiator and the responder generating private keys by generating 32 random octets. As usual in IKEv2 and its extension, we will denote Initiator values with the suffix _i and responder values with the suffix _r:

```
random_i = 75 1f b4 30 86 55 b4 76 b6 78 9b 73 25 f9 ea 8c
           dd d1 6a 58 53 3f f6 d9 e6 00 09 46 4a 5f 9d 94

random_r = 0a 54 64 52 53 29 0d 60 dd ad d0 e0 30 ba cd 9e
           55 01 ef dc 22 07 55 a1 e9 78 f1 b8 39 a0 56 88
```

These numbers need to be fixed by unsetting some bits as described in Section 5 of RFC 7748. This affects only the first and last octets of each value:

```
fixed_i =  70 1f b4 30 86 55 b4 76 b6 78 9b 73 25 f9 ea 8c
           dd d1 6a 58 53 3f f6 d9 e6 00 09 46 4a 5f 9d 54

fixed_r =  08 54 64 52 53 29 0d 60 dd ad d0 e0 30 ba cd 9e
           55 01 ef dc 22 07 55 a1 e9 78 f1 b8 39 a0 56 48
```

The actual private keys are considered to be encoded in little-endian format:

```
d_i = 549D5F4A460900E6D9F63F53586AD1DD8CEAF925739B78B676B4558630B41F70

d_r = 4856A039B8F178E9A1550722DCEF01559ECDBA30E0D0ADDD600D295352645408
```

The public keys are generated from this using the formula in Section 2:

```
pub_i = X25519(d_i, G) =
           48 d5 dd d4 06 12 57 ba 16 6f a3 f9 bb db 74 f1
           a4 e8 1c 08 93 84 fa 77 f7 90 70 9f 0d fb c7 66

pub_r = X25519(d_r, G) =
           0b e7 c1 f5 aa d8 7d 7e 44 86 62 67 32 98 a4 43
           47 8b 85 97 45 17 9e af 56 4c 79 c0 ef 6e ee 25
```

And this is the value of the Key Exchange Data field in the Key Exchange payload described in Section 3.1. The shared value is calculated as in Section 2:

```
SHARED_SECRET = X25519(d_i, pub_r) = X25519(d_r, pub_i) =
           c7 49 50 60 7a 12 32 7f-32 04 d9 4b 68 25 bf b0
           68 b7 f8 31 9a 9e 37 08-ed 3d 43 ce 81 30 c9 50
```

Acknowledgements

Curve25519 was designed by D. J. Bernstein and the parameters for Curve448 ("Goldilocks") were defined by Mike Hamburg. The specification of algorithms, wire format, and other considerations are documented in RFC 7748 by Adam Langley, Mike Hamburg, and Sean Turner.

The example in Appendix A was calculated using the master version of OpenSSL, retrieved on August 4th, 2016.

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