

Internet Engineering Task Force
Internet-Draft
Intended status: Standards Track
Expires: March 7, 2020

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September 4, 2019

Secure Shell (SSH) Key Exchange Method using Curve25519 and Curve448
draft-ietf-curdle-ssh-curves-12

Abstract

This document describes the specification for using Curve25519 and Curve448 key exchange methods in the Secure Shell (SSH) protocol.

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1. Introduction

Secure Shell (SSH) [RFC4251] is a secure remote login protocol. The key exchange protocol described in [RFC4253] supports an extensible set of methods. [RFC5656] defines how elliptic curves are integrated into this extensible SSH framework, and this document reuses the Elliptic Curve Diffie-Hellman (ECDH) key exchange protocol messages defined in section 7.1 "ECDH Message Numbers" [RFC5656]. Other parts of [RFC5656], such as Elliptic Curve Menezes-Qu-Vanstone (ECMQV) key agreement, and Elliptic Curve Digital Signature Algorithm (ECDSA) are not considered in this document.

This document describes how to implement key exchange based on Curve25519 and Curve448 [RFC7748] in SSH. For Curve25519 with SHA-256 [RFC6234] and [SHS], the algorithm described is equivalent to the privately defined algorithm "curve25519-sha256@libssh.org", which at the time of publication was implemented and widely deployed in libssh [libssh] and OpenSSH [OpenSSH]. The Curve448 key exchange method is similar but uses SHA-512 [RFC6234] and [SHS].

2. Requirements Language

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.

3. Key Exchange Methods

The key exchange procedure is similar to the ECDH method described in chapter 4 of [RFC5656], though with a different wire encoding used for public values and the final shared secret. Public ephemeral keys are encoded for transmission as standard SSH strings.

The protocol flow, the SSH_MSG_KEX_ECDH_INIT and SSH_MSG_KEX_ECDH_REPLY messages, and the structure of the exchange hash are identical to chapter 4 of [RFC5656].

The method names registered by this document are "curve25519-sha256" and "curve448-sha512".

The methods are based on Curve25519 and Curve448 scalar multiplication, as described in [RFC7748]. Private and public keys are generated as described therein. Public keys are defined as strings of 32 bytes for Curve25519 and 56 bytes for Curve448.

Key-agreement schemes "curve25519-sha256" and "curve448-sha512" perform the Diffie-Hellman protocol using the functions X25519 and X448, respectively. Implementations SHOULD compute these functions using the algorithms described in [RFC7748]. When they do so, implementations MUST check whether the computed Diffie-Hellman shared secret is the all-zero value and abort if so, as described in Section 6 of [RFC7748]. Alternative implementations of these functions SHOULD abort when either input forces the shared secret to one of a small set of values, as described in Section 7 of [RFC7748]. Clients and servers MUST also abort if the length of the received public keys are not the expected lengths. An abort for these purposes is defined as a disconnect (SSH_MSG_DISCONNECT) of the session and SHOULD use the SSH_DISCONNECT_KEY_EXCHANGE_FAILED reason for the message [IANA-REASON]. No further validation is required beyond what is described in [RFC7748]. The derived shared secret is 32 bytes when "curve25519-sha256" is used and 56 bytes when "curve448-sha512" is used. The encodings of all values are defined in [RFC7748]. The hash used is SHA-256 for "curve25519-sha256" and SHA-512 for "curve448-sha512".

3.1. Shared Secret Encoding

The following step differs from [RFC5656], which uses a different conversion. This is not intended to modify that text generally, but only to be applicable to the scope of the mechanism described in this document.

The shared secret, K , is defined in [RFC4253] and [RFC5656] as an integer encoded as a multiple precision integer (mpint). Curve25519/448 outputs a binary string X , which is the 32 or 56 byte point obtained by scalar multiplication of the other side's public key and the local private key scalar. The 32 or 56 bytes of X are converted into K by interpreting the octets as an unsigned fixed-length integer encoded in network byte order.

The integer K is then encoded as an mpint using the process described in section 5 of [RFC4251] and the resulting bytes are fed as described in [RFC4253] to the key exchange method's hash function to generate encryption keys.

When performing the X25519 or X448 operations, the integer values there will be encoded into byte strings by doing a fixed-length unsigned little-endian conversion, per [RFC7748]. It is only later when these byte strings are then passed to the ECDH function in SSH that the bytes are re-interpreted as a fixed-length unsigned big-endian integer value K , and then later that K value is encoded as a variable-length signed "mpint" before being fed to the hash algorithm used for key generation. The mpint K is then fed along with other data to the key exchange method's hash function to generate encryption keys.

4. Acknowledgements

The "curve25519-sha256" key exchange method is identical to the "curve25519-sha256@libssh.org" key exchange method created by Aris Adamantiadis and implemented in libssh and OpenSSH.

Thanks to the following people for review and comments: Denis Bider, Damien Miller, Niels Moeller, Matt Johnston, Eric Rescorla, Ron Frederick, Stefan Buehler.

5. Security Considerations

The security considerations of [RFC4251], [RFC5656], and [RFC7748] are inherited.

Curve25519 with SHA-256 provides strong (~128 bits) security and is efficient on a wide range of architectures, and has properties that allows better implementation properties compared to traditional elliptic curves. Curve448 with SHA-512 provides stronger (~224 bits) security with similar implementation properties, but has not received the same cryptographic review as Curve25519, and is slower (larger key material and larger secure hash algorithm), but it is provided as a hedge to combat unforeseen analytical advances against Curve25519 and SHA-256 due to the larger number of security bits.

The way the derived binary secret string is encoded into a mpint before it is hashed (i.e., adding or removing zero-bytes for encoding) raises the potential for a side-channel attack which could determine the length of what is hashed. This would leak the most significant bit of the derived secret, and/or allow detection of when the most significant bytes are zero. For backwards compatibility reasons it was decided not to address this potential problem.

This document provides "curve25519-sha256" as the preferred choice, but suggests that the "curve448-sha512" is implemented to provide more than 128 bits of security strength should that become a requirement.

6. IANA Considerations

IANA is requested to add "curve25519-sha256" and "curve448-sha512" to the "Key Exchange Method Names" registry for SSH [IANA-KEX] that was created in RFC 4250 section 4.10 [RFC4250].

7. References

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