Stream: Internet Engineering Task Force (IETF)
RFC: 8732
Updates: 4462
Category: Standards Track
Published: February 2020
ISSN: 2070-1721
Authors: S. Sorce *Red Hat, Inc.* H. Kario *Red Hat, Inc.*

RFC 8732
Generic Security Service Application Program Interface (GSS-API) Key Exchange with SHA-2

Abstract

This document specifies additions and amendments to RFC 4462. It defines a new key exchange method that uses SHA-2 for integrity and deprecates weak Diffie-Hellman (DH) groups. The purpose of this specification is to modernize the cryptographic primitives used by Generic Security Service (GSS) key exchanges.

Status of This Memo

Copyright Notice

Table of Contents

1. Introduction

Secure Shell (SSH) Generic Security Service Application Program Interface (GSS-API) methods [RFC4462] allow the use of GSS-API [RFC2743] for authentication and key exchange in SSH. [RFC4462] defines three exchange methods all based on DH groups and SHA-1. This document updates [RFC4462] with new methods intended to support environments that desire to use the SHA-2 cryptographic hash functions.

2. Rationale

Due to security concerns with SHA-1 [RFC6194] and with modular exponentiation (MODP) groups with less than 2048 bits [NIST-SP-800-131Ar2], we propose the use of hashes based on SHA-2 [RFC6234] with DH group14, group15, group16, group17, and group18 [RFC3526]. Additionally, we add support for key exchange based on Elliptic Curve Diffie-Hellman with the NIST P-256, P-384, and P-521 [SEC2v2], as well as the X25519 and X448 [RFC7748] curves. Following the practice of [RFC8268], only SHA-256 and SHA-512 hashes are used for DH groups. For NIST curves, the same curve-to-hashing algorithm pairing used in [RFC5656] is adopted for consistency.

3. Document Conventions

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.

4. New Diffie-Hellman Key Exchange Methods

This document adopts the same naming convention defined in [RFC4462] to define families of methods that cover any GSS-API mechanism used with a specific Diffie-Hellman group and SHA-2 hash combination.

Key Exchange Method Name	Implementation Recommendations
gss-group14-sha256-*	**SHOULD/RECOMMENDED**
gss-group15-sha512-*	**MAY/OPTIONAL**
gss-group16-sha512-*	**SHOULD/RECOMMENDED**
gss-group17-sha512-*	**MAY/OPTIONAL**
gss-group18-sha512-*	**MAY/OPTIONAL**

Table 1: New Key Exchange Algorithms

Each key exchange method prefix is registered by this document. The IESG is the change controller of all these key exchange methods; this does NOT imply that the IESG is considered to be in control of the corresponding GSS-API mechanism.

Each method in any family of methods (Table 2) specifies GSS-API-authenticated Diffie-Hellman key exchanges as described in Section 2.1 of [RFC4462]. The method name for each method (Table 1) is the concatenation of the family name prefix with the base64 encoding of the MD5 hash [RFC1321] of the ASN.1 DER encoding [ISO-IEC-8825-1] of the corresponding GSS-API mechanism's OID. Base64 encoding is described in Section 4 of [RFC4648].

Family Name Prefix	Hash Function	Group	Reference
gss-group14-sha256-	SHA-256	2048-bit MODP	Section 3 of [RFC3526]
gss-group15-sha512-	SHA-512	3072-bit MODP	Section 4 of [RFC3526]
gss-group16-sha512-	SHA-512	4096-bit MODP	Section 5 of [RFC3526]
gss-group17-sha512-	SHA-512	6144-bit MODP	Section 6 of [RFC3526]
gss-group18-sha512-	SHA-512	8192-bit MODP	Section 7 of [RFC3526]

Table 2: Family Method References

5. New Elliptic Curve Diffie-Hellman Key Exchange Methods

In [RFC5656], new SSH key exchange algorithms based on elliptic curve cryptography are introduced. We reuse much of Section 4 of [RFC5656] to define GSS-API-authenticated Elliptic Curve Diffie-Hellman (ECDH) key exchanges.

Additionally, we also utilize the curves defined in [RFC8731] to complement the three classic NIST-defined curves required by [RFC5656].

5.1. Generic GSS-API Key Exchange with ECDH

This section reuses much of the scheme defined in Section 2.1 of [RFC4462] and combines it with the scheme defined in Section 4 of [RFC5656]; in particular, all checks and verification steps prescribed in Section 4 of [RFC5656] apply here as well.

The key-agreement schemes "ECDHE-Curve25519" and "ECDHE-Curve448" perform the Diffie-Hellman protocol using the functions X25519 and X448, respectively. Implementations **MUST** 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 the client or the server input forces the shared secret to one of a small set of values, as described in Sections 6 and 7 of [RFC7748].

This section defers to [RFC7546] as the source of information on GSS-API context establishment operations, Section 3 being the most relevant. All security considerations described in [RFC7546] apply here, too.

The parties each generate an ephemeral key pair, according to Section 3.2.1 of [SEC1v2]. Keys are verified upon receipt by the parties according to Section 3.2.3.1 of [SEC1v2].

For NIST curves, the keys use the uncompressed point representation and **MUST** be converted using the algorithm in Section 2.3.4 of [SEC1v2]. If the conversion fails or the point is transmitted using the compressed representation, the key exchange **MUST** fail.

A GSS context is established according to Section 4 of [RFC5656]; the client initiates the establishment using GSS_Init_sec_context(), and the server responds to it using GSS_Accept_sec_context(). For the negotiation, the client **MUST** set mutual_req_flag and integ_req_flag to "true". In addition, deleg_req_flag **MAY** be set to "true" to request access delegation, if requested by the user. Since the key exchange process authenticates only the host, the setting of anon_req_flag is immaterial to this process. If the client does not support the "gssapi-keyex" user authentication method described in Section 4 of [RFC4462], or does not intend to use that method in conjunction with the GSS-API context established during key exchange, then anon_req_flag **SHOULD** be set to "true". Otherwise, this flag **MAY** be set to "true" if the client wishes to hide its identity. This key exchange process will exchange only a single message token once the context has been established; therefore, the replay_det_req_flag and sequence_req_flag **SHOULD** be set to "false".

The client **MUST** include its public key with the first message it sends to the server during this process; if the server receives more than one key or none at all, the key exchange **MUST** fail.

During GSS context establishment, multiple tokens may be exchanged by the client and the server. When the GSS context is established (major_status is GSS_S_COMPLETE), the parties check that mutual_state and integ_avail are both "true". If not, the key exchange **MUST** fail.

Once a party receives the peer's public key, it proceeds to compute a shared secret K. For NIST curves, the computation is done according to Section 3.3.1 of [SEC1v2], and the resulting value z is converted to the octet string K using the conversion defined in Section 2.3.5 of [SEC1v2]. For curve25519 and curve448, the algorithms in Section 6 of [RFC7748] are used instead.

To verify the integrity of the handshake, peers use the hash function defined by the selected key exchange method to calculate H:

H = hash(V_C || V_S || I_C || I_S || K_S || Q_C || Q_S || K).

The server uses the GSS_GetMIC() call with H as the payload to generate a Message Integrity Code (MIC). The GSS_VerifyMIC() call is used by the client to verify the MIC.

If any GSS_Init_sec_context() or GSS_Accept_sec_context() returns a major_status other than GSS_S_COMPLETE or GSS_S_CONTINUE_NEEDED, or any other GSS-API call returns a major_status other than GSS_S_COMPLETE, the key exchange **MUST** fail. The same recommendations expressed in Section 2.1 of [RFC4462] are followed with regard to error reporting.

The following is an overview of the key exchange process:

```
    Client                                                Server
    ------                                                ------
    Generates ephemeral key pair.
    Calls GSS_Init_sec_context().
    SSH_MSG_KEXGSS_INIT  --------------->

                                               Verifies received key.
(Optional)                  <------------- SSH_MSG_KEXGSS_HOSTKEY

(Loop)
|                                    Calls GSS_Accept_sec_context().
|                           <------------ SSH_MSG_KEXGSS_CONTINUE
|   Calls GSS_Init_sec_context().
|   SSH_MSG_KEXGSS_CONTINUE ------------>

                                     Calls GSS_Accept_sec_context().
                                       Generates ephemeral key pair.
                                             Computes shared secret.
                                                    Computes hash H.
                                        Calls GSS_GetMIC( H ) = MIC.
                            <------------ SSH_MSG_KEXGSS_COMPLETE

    Verifies received key.
    Computes shared secret.
    Computes hash H.
    Calls GSS_VerifyMIC( MIC, H ).
```

This is implemented with the following messages:

The client sends:

```
    byte      SSH_MSG_KEXGSS_INIT
    string    output_token (from GSS_Init_sec_context())
    string    Q_C, client's ephemeral public key octet string
```

The server may respond with:

```
    byte     SSH_MSG_KEXGSS_HOSTKEY
    string   server public host key and certificates (K_S)
```

The server sends:

```
    byte     SSH_MSG_KEXGSS_CONTINUE
    string   output_token (from GSS_Accept_sec_context())
```

Each time the client receives the message described above, it makes another call to GSS_Init_sec_context().

The client sends:

```
    byte      SSH_MSG_KEXGSS_CONTINUE
    string    output_token (from GSS_Init_sec_context())
```

As the final message, the server sends the following if an output_token is produced:

```
    byte      SSH_MSG_KEXGSS_COMPLETE
    string    Q_S, server's ephemeral public key octet string
    string    mic_token (MIC of H)
    boolean   TRUE
    string    output_token (from GSS_Accept_sec_context())
```

If no output_token is produced, the server sends:

```
    byte      SSH_MSG_KEXGSS_COMPLETE
    string    Q_S, server's ephemeral public key octet string
    string    mic_token (MIC of H)
    boolean   FALSE
```

The hash H is computed as the HASH hash of the concatenation of the following:

```
    string    V_C, the client's version string (CR, NL excluded)
    string    V_S, server's version string (CR, NL excluded)
    string    I_C, payload of the client's SSH_MSG_KEXINIT
    string    I_S, payload of the server's SSH_MSG_KEXINIT
    string    K_S, server's public host key
    string    Q_C, client's ephemeral public key octet string
    string    Q_S, server's ephemeral public key octet string
    mpint     K,   shared secret
```

This value is called the "exchange hash", and it is used to authenticate the key exchange. The exchange hash **SHOULD** be kept secret. If no SSH_MSG_KEXGSS_HOSTKEY message has been sent by the server or received by the client, then the empty string is used in place of K_S when computing the exchange hash.

Since this key exchange method does not require the host key to be used for any encryption operations, the SSH_MSG_KEXGSS_HOSTKEY message is **OPTIONAL**. If the "null" host key algorithm described in Section 5 of [RFC4462] is used, this message **MUST NOT** be sent.

If the client receives an SSH_MSG_KEXGSS_CONTINUE message after a call to GSS_Init_sec_context() has returned a major_status code of GSS_S_COMPLETE, a protocol error has occurred, and the key exchange **MUST** fail.

If the client receives an SSH_MSG_KEXGSS_COMPLETE message and a call to GSS_Init_sec_context() does not result in a major_status code of GSS_S_COMPLETE, a protocol error has occurred, and the key exchange **MUST** fail.

5.2. ECDH Key Exchange Methods

Key Exchange Method Name	Implementation Recommendations
gss-nistp256-sha256-*	**SHOULD/RECOMMENDED**
gss-nistp384-sha384-*	**MAY/OPTIONAL**
gss-nistp521-sha512-*	**MAY/OPTIONAL**
gss-curve25519-sha256-*	**SHOULD/RECOMMENDED**
gss-curve448-sha512-*	**MAY/OPTIONAL**

Table 3: New Key Exchange Methods

Each key exchange method prefix is registered by this document. The IESG is the change controller of all these key exchange methods; this does NOT imply that the IESG is considered to be in control of the corresponding GSS-API mechanism.

Each method in any family of methods (Table 4) specifies GSS-API-authenticated Elliptic Curve Diffie-Hellman key exchanges as described in Section 5.1. The method name for each method (Table 3) is the concatenation of the family method name with the base64 encoding of the MD5 hash [RFC1321] of the ASN.1 DER encoding [ISO-IEC-8825-1] of the corresponding GSS-API mechanism's OID. Base64 encoding is described in Section 4 of [RFC4648].

Family Name Prefix	Hash Function	Parameters / Function Name	Definition
gss-nistp256-sha256-	SHA-256	secp256r1	Section 2.4.2 of [SEC2v2]
gss-nistp384-sha384-	SHA-384	secp384r1	Section 2.5.1 of [SEC2v2]
gss-nistp521-sha512-	SHA-512	secp521r1	Section 2.6.1 of [SEC2v2]
gss-curve25519-sha256-	SHA-256	X22519	Section 5 of [RFC7748]
gss-curve448-sha512-	SHA-512	X448	Section 5 of [RFC7748]

Table 4: Family Method References

6. Deprecated Algorithms

Because they have small key lengths and are no longer strong in the face of brute-force attacks, the algorithms in the following table are considered deprecated and **SHOULD NOT** be used.

Key Exchange Method Name	Implementation Recommendations
gss-group1-sha1-*	**SHOULD NOT**
gss-group14-sha1-*	**SHOULD NOT**
gss-gex-sha1-*	**SHOULD NOT**

Table 5: Deprecated Algorithms

7. IANA Considerations

This document augments the SSH key exchange message names that were defined in [RFC4462] (see and Section 6); IANA has listed this document as reference for those entries in the "SSH Protocol Parameters" [IANA-KEX-NAMES] registry.

In addition, IANA has updated the registry to include the SSH key exchange message names described in Sections 4 and 5.

Key Exchange Method Name	Reference
gss-group1-sha1-*	RFC 8732
gss-group14-sha1-*	RFC 8732
gss-gex-sha1-*	RFC 8732
gss-group14-sha256-*	RFC 8732
gss-group15-sha512-*	RFC 8732
gss-group16-sha512-*	RFC 8732
gss-group17-sha512-*	RFC 8732
gss-group18-sha512-*	RFC 8732
gss-nistp256-sha256-*	RFC 8732
gss-nistp384-sha384-*	RFC 8732
gss-nistp521-sha512-*	RFC 8732

Key Exchange Method Name	Reference
gss-curve25519-sha256-*	RFC 8732
gss-curve448-sha512-*	RFC 8732

Table 6: Additions/Changes to the Key Exchange Method Names Registry

8. Security Considerations

8.1. New Finite Field DH Mechanisms

Except for the use of a different secure hash function and larger DH groups, no significant changes have been made to the protocol described by [RFC4462]; therefore, all the original security considerations apply.

8.2. New Elliptic Curve DH Mechanisms

Although a new cryptographic primitive is used with these methods, the actual key exchange closely follows the key exchange defined in [RFC5656]; therefore, all the original security considerations, as well as those expressed in [RFC5656], apply.

8.3. GSS-API Delegation

Some GSS-API mechanisms can act on a request to delegate credentials to the target host when the deleg_req_flag is set. In this case, extra care must be taken to ensure that the acceptor being authenticated matches the target the user intended. Some mechanism implementations (such as commonly used krb5 libraries) may use insecure DNS resolution to canonicalize the target name; in these cases, spoofing a DNS response that points to an attacker-controlled machine may result in the user silently delegating credentials to the attacker, who can then impersonate the user at will.

9. References

9.1. Normative References

[RFC1321] Rivest, R., "The MD5 Message-Digest Algorithm", RFC 1321, DOI 10.17487/RFC1321, April 1992, <https://www.rfc-editor.org/info/rfc1321>.

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <https://www.rfc-editor.org/info/rfc2119>.

[RFC2743] Linn, J., "Generic Security Service Application Program Interface Version 2, Update 1", RFC 2743, DOI 10.17487/RFC2743, January 2000, <https://www.rfc-editor.org/info/rfc2743>.

[RFC3526] Kivinen, T. and M. Kojo, "More Modular Exponential (MODP) Diffie-Hellman groups for Internet Key Exchange (IKE)", RFC 3526, DOI 10.17487/RFC3526, May 2003, <https://www.rfc-editor.org/info/rfc3526>.

[RFC4462] Hutzelman, J., Salowey, J., Galbraith, J., and V. Welch, "Generic Security Service Application Program Interface (GSS-API) Authentication and Key Exchange for the Secure Shell (SSH) Protocol", RFC 4462, DOI 10.17487/RFC4462, May 2006, <https://www.rfc-editor.org/info/rfc4462>.

[RFC4648] Josefsson, S., "The Base16, Base32, and Base64 Data Encodings", RFC 4648, DOI 10.17487/RFC4648, October 2006, <https://www.rfc-editor.org/info/rfc4648>.

[RFC5656] Stebila, D. and J. Green, "Elliptic Curve Algorithm Integration in the Secure Shell Transport Layer", RFC 5656, DOI 10.17487/RFC5656, December 2009, <https://www.rfc-editor.org/info/rfc5656>.

[RFC7546] Kaduk, B., "Structure of the Generic Security Service (GSS) Negotiation Loop", RFC 7546, DOI 10.17487/RFC7546, May 2015, <https://www.rfc-editor.org/info/rfc7546>.

[RFC7748] Langley, A., Hamburg, M., and S. Turner, "Elliptic Curves for Security", RFC 7748, DOI 10.17487/RFC7748, January 2016, <https://www.rfc-editor.org/info/rfc7748>.

[RFC8174] Leiba, B., "Ambiguity of Uppercase vs Lowercase in RFC 2119 Key Words", BCP 14, RFC 8174, DOI 10.17487/RFC8174, May 2017, <https://www.rfc-editor.org/info/rfc8174>.

[RFC8731] Adamantiadis, A., Josefsson, S., and M. Baushke, "Secure Shell (SSH) Key Exchange Method Using Curve25519 and Curve448", RFC 8731, DOI 10.17487/RFC8731, February 2020, <https://www.rfc-editor.org/info/rfc8731>.

[SEC1v2] Standards for Efficient Cryptography Group, "SEC 1: Elliptic Curve Cryptography", Version 2.0, May 2009.

[SEC2v2] Standards for Elliptic Cryptography Group, "SEC 2: Recommended Elliptic Curve Domain Parameters", Version 2.0, January 2010.

9.2. Informative References

[IANA-KEX-NAMES] IANA, "Secure Shell (SSH) Protocol Parameters: Key Exchange Method Names", <https://www.iana.org/assignments/ssh-parameters/>.

[ISO-IEC-8825-1] ITU-T, "Information technology -- ASN.1 encoding rules: Specification of Basic Encoding Rules (BER), Canonical Encoding Rules (CER) and Distinguished Encoding Rules (DER)", ISO/IEC 8825-1:2015, ITU-T Recommendation X.690, November 2015, <http://standards.iso.org/ittf/PubliclyAvailableStandards/c068345_ISO_IEC_8825-1_2015.zip>.

[NIST-SP-800-131Ar2] NIST, "Transitioning of the Use of Cryptographic Algorithms and Key Lengths", DOI 10.6028/NIST.SP.800-131Ar2, NIST Special Publication 800-131A

Revision 2, November 2015, <https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-131Ar2.pdf>.

[RFC6194] Polk, T., Chen, L., Turner, S., and P. Hoffman, "Security Considerations for the SHA-0 and SHA-1 Message-Digest Algorithms", RFC 6194, DOI 10.17487/RFC6194, March 2011, <https://www.rfc-editor.org/info/rfc6194>.

[RFC6234] Eastlake 3rd, D. and T. Hansen, "US Secure Hash Algorithms (SHA and SHA-based HMAC and HKDF)", RFC 6234, DOI 10.17487/RFC6234, May 2011, <https://www.rfc-editor.org/info/rfc6234>.

[RFC8268] Baushke, M., "More Modular Exponentiation (MODP) Diffie-Hellman (DH) Key Exchange (KEX) Groups for Secure Shell (SSH)", RFC 8268, DOI 10.17487/RFC8268, December 2017, <https://www.rfc-editor.org/info/rfc8268>.

Authors' Addresses

Simo Sorce
Red Hat, Inc.
140 Broadway, 24th Floor
New York, NY 10025
United States of America
Email: simo@redhat.com

Hubert Kario
Red Hat, Inc.
Purkynova 115
612 00 Brno
Czech Republic
Email: hkario@redhat.com