           Generic Security Service Application Program Interface (GSS-API)
          Authentication and Key Exchange for the Secure Shell (SSH) Protocol

Status of This Memo

   This document specifies an Internet standards track protocol for the
   Internet community, and requests discussion and suggestions for
   improvements. Please refer to the current edition of the "Internet
   Official Protocol Standards" (STD 1) for the standardization state
   and status of this protocol. Distribution of this memo is unlimited.

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Abstract

   The Secure Shell protocol (SSH) is a protocol for secure remote login
   and other secure network services over an insecure network.

   The Generic Security Service Application Program Interface (GSS-API)
   provides security services to callers in a mechanism-independent
   fashion.

   This memo describes methods for using the GSS-API for authentication
   and key exchange in SSH. It defines an SSH user authentication
   method that uses a specified GSS-API mechanism to authenticate a
   user, and a family of SSH key exchange methods that use GSS-API to
   authenticate a Diffie-Hellman key exchange.

   This memo also defines a new host public key algorithm that can be
   used when no operations are needed using a host's public key, and a
   new user authentication method that allows an authorization name to
   be used in conjunction with any authentication that has already
   occurred as a side-effect of GSS-API-based key exchange.

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1. Introduction

   This document describes the methods used to perform key exchange and
   user authentication in the Secure Shell protocol using the GSS-API.
   To do this, it defines a family of key exchange methods, two user
   authentication methods, and a new host key algorithm. These
   definitions allow any GSS-API mechanism to be used with the Secure
   Shell protocol.

   This document should be read only after reading the documents
   describing the SSH protocol architecture [SSH-ARCH], transport layer
   protocol [SSH-TRANSPORT], and user authentication protocol
   [SSH-USERAUTH]. This document freely uses terminology and notation
   from the architecture document without reference or further
   explanation.

1.1. SSH Terminology

   The data types used in the packets are defined in the SSH
   architecture document [SSH-ARCH]. It is particularly important to
   note the definition of string allows binary content.

   The SSH_MSG_USERAUTH_REQUEST packet refers to a service; this service
   name is an SSH service name and has no relationship to GSS-API
   service names. Currently, the only defined service name is
   "ssh-connection", which refers to the SSH connection protocol
   [SSH-CONNECT].

1.2. Key Words

   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 [KEYWORDS].

2. GSS-API-Authenticated Diffie-Hellman Key Exchange

   This section defines a class of key exchange methods that combine the
   Diffie-Hellman key exchange from Section 8 of [SSH-TRANSPORT] with
   mutual authentication using GSS-API.

   Since the GSS-API key exchange methods described in this section do
   not require the use of public key signature or encryption algorithms,
   they MAY be used with any host key algorithm, including the "null"
   algorithm described in Section 5.

2.1. Generic GSS-API Key Exchange

The following symbols are used in this description:

o C is the client, and S is the server

o p is a large safe prime, g is a generator for a subgroup of GF(p),
   and q is the order of the subgroup

o V_S is S's version string, and V_C is C's version string

o I_C is C's KEXINIT message, and I_S is S's KEXINIT message

1. C generates a random number x (1 < x < q) and computes e = g^x
    mod p.

2. C calls GSS_Init_sec_context(), using the most recent reply token
    received from S during this exchange, if any. For this call, the
    client MUST set mutual_req_flag to "true" to request that mutual
    authentication be performed. It also MUST set integ_req_flag to
    "true" to request that per-message integrity protection be
    supported for this context. 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, 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. Since the key exchange process will
    involve the exchange of only a single token once the context has
    been established, it is not necessary that the GSS-API context
    support detection of replayed or out-of-sequence tokens. Thus,
    replay_det_req_flag and sequence_req_flag need not be set for
    this process. These flags SHOULD be set to "false".

    * If the resulting major_status code is GSS_S_COMPLETE and the
       mutual_state flag is not true, then mutual authentication has
       not been established, and the key exchange MUST fail.

    * If the resulting major_status code is GSS_S_COMPLETE and the
       integ_avail flag is not true, then per-message integrity
       protection is not available, and the key exchange MUST fail.

    * If the resulting major_status code is GSS_S_COMPLETE and both
       the mutual_state and integ_avail flags are true, the resulting
       output token is sent to S.

    *   If the resulting major_status code is GSS_S_CONTINUE_NEEDED,
        the output_token is sent to S, which will reply with a new
        token to be provided to GSS_Init_sec_context().

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

    *   It is an error if the call does not produce a token of non-
        zero length to be sent to the server. In this case, the key
        exchange MUST fail.

   3. S calls GSS_Accept_sec_context(), using the token received from
       C.

    *   If the resulting major_status code is GSS_S_COMPLETE and the
        mutual_state flag is not true, then mutual authentication has
        not been established, and the key exchange MUST fail.

    *   If the resulting major_status code is GSS_S_COMPLETE and the
        integ_avail flag is not true, then per-message integrity
        protection is not available, and the key exchange MUST fail.

    *   If the resulting major_status code is GSS_S_COMPLETE and both
        the mutual_state and integ_avail flags are true, then the
        security context has been established, and processing
        continues with step 4.

    *   If the resulting major_status code is GSS_S_CONTINUE_NEEDED,
        then the output token is sent to C, and processing continues
        with step 2.

    *   If the resulting major_status code is GSS_S_COMPLETE, but a
        non-zero-length reply token is returned, then that token is
        sent to the client.

   4. S generates a random number y $(0 < y < q)$ and computes $f = g^y$
       mod p. It computes $K = e ^ y$ mod p, and H = hash(V_C || V_S ||
       I_C || I_S || K_S || e || f || K). It then calls GSS_GetMIC() to
       obtain a GSS-API message integrity code for H. S then sends f
       and the message integrity code (MIC) to C.

   5. This step is performed only (1) if the server's final call to
       GSS_Accept_sec_context() produced a non-zero-length final reply
       token to be sent to the client and (2) if no previous call by the
       client to GSS_Init_sec_context() has resulted in a major_status
       of GSS_S_COMPLETE. Under these conditions, the client makes an

        additional call to GSS_Init_sec_context() to process the final
        reply token. This call is made exactly as described above.
        However, if the resulting major_status is anything other than
        GSS_S_COMPLETE, or a non-zero-length token is returned, it is an
        error and the key exchange MUST fail.

   6.   C computes K = f^x mod p, and H = hash(V_C || V_S || I_C || I_S
        || K_S || e || f || K). It then calls GSS_VerifyMIC() to verify
        that the MIC sent by S matches H. If the MIC is not successfully
        verified, the key exchange MUST fail.

   Either side MUST NOT send or accept e or f values that are not in the
   range [1, p-1]. If this condition is violated, the key exchange
   fails.

   If any call to 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 fails. In
   this case, several mechanisms are available for communicating error
   information to the peer before terminating the connection as required
   by [SSH-TRANSPORT]:

   o   If the key exchange fails due to any GSS-API error on the server
       (including errors returned by GSS_Accept_sec_context()), the
       server MAY send a message informing the client of the details of
       the error. In this case, if an error token is also sent (see
       below), then this message MUST be sent before the error token.

   o   If the key exchange fails due to a GSS-API error returned from the
       server's call to GSS_Accept_sec_context(), and an "error token" is
       also returned, then the server SHOULD send the error token to the
       client to allow completion of the GSS security exchange.

   o   If the key exchange fails due to a GSS-API error returned from the
       client's call to GSS_Init_sec_context(), and an "error token" is
       also returned, then the client SHOULD send the error token to the
       server to allow completion of the GSS security exchange.

   As noted in Section 9, it may be desirable under site security policy
   to obscure information about the precise nature of the error; thus,
   it is RECOMMENDED that implementations provide a method to suppress
   these messages as a matter of policy.

   This is implemented with the following messages. The hash algorithm
   for computing the exchange hash is defined by the method name, and is
   called HASH. The group used for Diffie-Hellman key exchange and the
   underlying GSS-API mechanism are also defined by the method name.

After the client's first call to GSS_Init_sec_context(), it sends the
following:

```
    byte        SSH_MSG_KEXGSS_INIT
    string      output_token (from GSS_Init_sec_context())
    mpint       e
```

Upon receiving the SSH_MSG_KEXGSS_INIT message, the server MAY send
the following message, prior to any other messages, to inform the
client of its host key.

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

Since this key exchange method does not require the host key to be
used for any encryption operations, this message is OPTIONAL. If the
"null" host key algorithm described in Section 5 is used, this
message MUST NOT be sent. If this message is sent, the server public
host key(s) and/or certificate(s) in this message are encoded as a
single string, in the format specified by the public key type in use
(see [SSH-TRANSPORT], Section 6.6).

In traditional SSH deployments, host keys are normally expected to
change infrequently, and there is often no mechanism for validating
host keys not already known to the client. As a result, the use of a
new host key by an already-known host is usually considered an
indication of a possible man-in-the-middle attack, and clients often
present strong warnings and/or abort the connection in such cases.

By contrast, when GSS-API-based key exchange is used, host keys sent
via the SSH_MSG_KEXGSS_HOSTKEY message are authenticated as part of
the GSS-API key exchange, even when previously unknown to the client.
Further, in environments in which GSS-API-based key exchange is used
heavily, it is possible and even likely that host keys will change
much more frequently and/or without advance warning.

Therefore, when a new key for an already-known host is received via
the SSH_MSG_KEXGSS_HOSTKEY message, clients SHOULD NOT issue strong
warnings or abort the connection, provided the GSS-API-based key
exchange succeeds.

In order to facilitate key re-exchange after the user's GSS-API
credentials have expired, client implementations SHOULD store host
keys received via SSH_MSG_KEXGSS_HOSTKEY for the duration of the
session, even when such keys are not stored for long-term use.

Each time the server's call to GSS_Accept_sec_context() returns a
major_status code of GSS_S_CONTINUE_NEEDED, it sends the following
reply to the client:

          byte   SSH_MSG_KEXGSS_CONTINUE
          string   output_token (from GSS_Accept_sec_context())

If the client receives this 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.

Each time the client receives the message described above, it makes
another call to GSS_Init_sec_context(). It then sends the following:

          byte   SSH_MSG_KEXGSS_CONTINUE
          string   output_token (from GSS_Init_sec_context())

The server and client continue to trade these two messages as long as
the server's calls to GSS_Accept_sec_context() result in major_status
codes of GSS_S_CONTINUE_NEEDED. When a call results in a
major_status code of GSS_S_COMPLETE, it sends one of two final
messages.

If the server's final call to GSS_Accept_sec_context() (resulting in
a major_status code of GSS_S_COMPLETE) returns a non-zero-length
token to be sent to the client, it sends the following:

          byte   SSH_MSG_KEXGSS_COMPLETE
          mpint   f
          string   per_msg_token (MIC of H)
          boolean   TRUE
          string   output_token (from GSS_Accept_sec_context())

If the client receives this 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 server's final call to GSS_Accept_sec_context() (resulting in
a major_status code of GSS_S_COMPLETE) returns a zero-length token or
no token at all, it sends the following:

          byte   SSH_MSG_KEXGSS_COMPLETE
          mpint   f
          string   per_msg_token (MIC of H)
          boolean   FALSE

If the client receives this message when no call to
GSS_Init_sec_context() has yet resulted in a major_status code of
GSS_S_COMPLETE, a protocol error has occurred and the key exchange
MUST fail.

If either the client's call to GSS_Init_sec_context() or the server's
call to GSS_Accept_sec_context() returns an error status and produces
an output token (called an "error token"), then the following SHOULD
be sent to convey the error information to the peer:

```
        byte        SSH_MSG_KEXGSS_CONTINUE
        string      error_token
```

If a server sends both this message and an SSH_MSG_KEXGSS_ERROR
message, the SSH_MSG_KEXGSS_ERROR message MUST be sent first, to
allow clients to record and/or display the error information before
processing the error token. This is important because a client
processing an error token will likely disconnect without reading any
further messages.

In the event of a GSS-API error on the server, the server MAY send
the following message before terminating the connection:

```
        byte        SSH_MSG_KEXGSS_ERROR
        uint32      major_status
        uint32      minor_status
        string      message
        string      language tag
```

The message text MUST be encoded in the UTF-8 encoding described in
[UTF8]. Language tags are those described in [LANGTAG]. Note that
the message text may contain multiple lines separated by carriage
return-line feed (CRLF) sequences. Application developers should
take this into account when displaying these messages.

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, the server's version string (CR, NL excluded)
        string      I_C, the payload of the client's SSH_MSG_KEXINIT
        string      I_S, the payload of the server's SSH_MSG_KEXINIT
        string      K_S, the host key
        mpint       e, exchange value sent by the client
        mpint       f, exchange value sent by the server
        mpint       K, the 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.

The GSS_GetMIC call MUST be applied over H, not the original data.

2.2. Group Exchange

This section describes a modification to the generic GSS-API-
authenticated Diffie-Hellman key exchange to allow the negotiation of
the group to be used, using a method based on that described in
[GROUP-EXCHANGE].

The server keeps a list of safe primes and corresponding generators
that it can select from. These are chosen as described in Section 3
of [GROUP-EXCHANGE]. The client requests a modulus from the server,
indicating the minimum, maximum, and preferred sizes; the server
responds with a suitable modulus and generator. The exchange then
proceeds as described in Section 2.1 above.

This description uses the following symbols, in addition to those
defined above:

o n is the size of the modulus p in bits that the client would like
   to receive from the server

o min and max are the minimal and maximal sizes of p in bits that
   are acceptable to the client

1. C sends "min || n || max" to S, indicating the minimal acceptable
    group size, the preferred size of the group, and the maximal
    group size in bits the client will accept.

2. S finds a group that best matches the client's request, and sends
    "p || g" to C.

3. The exchange proceeds as described in Section 2.1 above,
    beginning with step 1, except that the exchange hash is computed
    as described below.

Servers and clients SHOULD support groups with a modulus length of k
bits, where 1024 <= k <= 8192. The recommended values for min and
max are 1024 and 8192, respectively.

This is implemented using the following messages, in addition to
those described above:

First, the client sends:

```
        byte        SSH_MSG_KEXGSS_GROUPREQ
        uint32      min, minimal size in bits of an acceptable group
        uint32      n, preferred size in bits of the group the server
                    should send
        uint32      max, maximal size in bits of an acceptable group
```

The server responds with:

```
        byte        SSH_MSG_KEXGSS_GROUP
        mpint       p, safe prime
        mpint       g, generator for subgroup in GF(p)
```

This is followed by the message exchange described above in
Section 2.1, except that the exchange 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, the server's version string (CR, NL excluded)
        string      I_C, the payload of the client's SSH_MSG_KEXINIT
        string      I_S, the payload of the server's SSH_MSG_KEXINIT
        string      K_S, the host key
        uint32      min, minimal size in bits of an acceptable group
        uint32      n, preferred size in bits of the group the server
                    should send
        uint32      max, maximal size in bits of an acceptable group
        mpint       p, safe prime
        mpint       g, generator for subgroup in GF(p)
        mpint       e, exchange value sent by the client
        mpint       f, exchange value sent by the server
        mpint       K, the shared secret
```

2.3. gss-group1-sha1-*

Each of these methods specifies GSS-API-authenticated Diffie-Hellman
key exchange as described in Section 2.1 with SHA-1 as HASH, and the
group defined in Section 8.1 of [SSH-TRANSPORT]. The method name for
each method is the concatenation of the string "gss-group1-sha1-"
with the Base64 encoding of the MD5 hash [MD5] of the ASN.1
Distinguished Encoding Rules (DER) encoding [ASN1] of the underlying
GSS-API mechanism's Object Identifier (OID). Base64 encoding is
described in Section 6.8 of [MIME].

Each and every such key exchange method is implicitly registered by
this specification. The IESG is considered to be the owner of all
such key exchange methods; this does NOT imply that the IESG is
considered to be the owner of the underlying GSS-API mechanism.

2.4. gss-group14-sha1-*

   Each of these methods specifies GSS-API authenticated Diffie-Hellman
   key exchange as described in Section 2.1 with SHA-1 as HASH, and the
   group defined in Section 8.2 of [SSH-TRANSPORT]. The method name for
   each method is the concatenation of the string "gss-group14-sha1-"
   with the Base64 encoding of the MD5 hash [MD5] of the ASN.1 DER
   encoding [ASN1] of the underlying GSS-API mechanism's OID. Base64
   encoding is described in Section 6.8 of [MIME].

   Each and every such key exchange method is implicitly registered by
   this specification. The IESG is considered to be the owner of all
   such key exchange methods; this does NOT imply that the IESG is
   considered to be the owner of the underlying GSS-API mechanism.

2.5. gss-gex-sha1-*

   Each of these methods specifies GSS-API-authenticated Diffie-Hellman
   key exchange as described in Section 2.2 with SHA-1 as HASH. The
   method name for each method is the concatenation of the string "gss-
   gex-sha1-" with the Base64 encoding of the MD5 hash [MD5] of the
   ASN.1 DER encoding [ASN1] of the underlying GSS-API mechanism's OID.
   Base64 encoding is described in Section 6.8 of [MIME].

   Each and every such key exchange method is implicitly registered by
   this specification. The IESG is considered to be the owner of all
   such key exchange methods; this does NOT imply that the IESG is
   considered to be the owner of the underlying GSS-API mechanism.

2.6. Other GSS-API Key Exchange Methods

   Key exchange method names starting with "gss-" are reserved for key
   exchange methods that conform to this document; in particular, for
   those methods that use the GSS-API-authenticated Diffie-Hellman key
   exchange algorithm described in Section 2.1, including any future
   methods that use different groups and/or hash functions. The intent
   is that the names for any such future methods be defined in a similar
   manner to that used in Section 2.3.

3. GSS-API User Authentication

   This section describes a general-purpose user authentication method
   based on [GSSAPI]. It is intended to be run over the SSH user
   authentication protocol [SSH-USERAUTH].

   The authentication method name for this protocol is "gssapi-with-
   mic".

3.1. GSS-API Authentication Overview

   GSS-API authentication must maintain a context. Authentication
   begins when the client sends an SSH_MSG_USERAUTH_REQUEST, which
   specifies the mechanism OIDs the client supports.

   If the server supports any of the requested mechanism OIDs, the
   server sends an SSH_MSG_USERAUTH_GSSAPI_RESPONSE message containing
   the mechanism OID.

   After the client receives SSH_MSG_USERAUTH_GSSAPI_RESPONSE, the
   client and server exchange SSH_MSG_USERAUTH_GSSAPI_TOKEN packets
   until the authentication mechanism either succeeds or fails.

   If at any time during the exchange the client sends a new
   SSH_MSG_USERAUTH_REQUEST packet, the GSS-API context is completely
   discarded and destroyed, and any further GSS-API authentication MUST
   restart from the beginning.

   If the authentication succeeds and a non-empty user name is presented
   by the client, the SSH server implementation verifies that the user
   name is authorized based on the credentials exchanged in the GSS-API
   exchange. If the user name is not authorized, then the
   authentication MUST fail.

3.2. Initiating GSS-API Authentication

   The GSS-API authentication method is initiated when the client sends
   an SSH_MSG_USERAUTH_REQUEST:

          byte   SSH_MSG_USERAUTH_REQUEST
          string   user name (in ISO-10646 UTF-8 encoding)
          string   service name (in US-ASCII)
          string   "gssapi-with-mic" (US-ASCII method name)
          uint32   n, the number of mechanism OIDs client supports
          string[n] mechanism OIDs

   Mechanism OIDs are encoded according to the ASN.1 Distinguished
   Encoding Rules (DER), as described in [ASN1] and in Section 3.1 of

[GSSAPI]. The mechanism OIDs MUST be listed in order of preference, and the server must choose the first mechanism OID on the list that it supports.

The client SHOULD send GSS-API mechanism OIDs only for mechanisms that are of the same priority, compared to non-GSS-API authentication methods. Otherwise, authentication methods may be executed out of order. Thus, the client could first send an SSH_MSG_USERAUTH_REQUEST for one GSS-API mechanism, then try public key authentication, and then try another GSS-API mechanism.

If the server does not support any of the specified OIDs, the server MUST fail the request by sending an SSH_MSG_USERAUTH_FAILURE packet.

The user name may be an empty string if it can be deduced from the results of the GSS-API authentication. If the user name is not empty, and the requested user does not exist, the server MAY disconnect or MAY send a bogus list of acceptable authentications but never accept any. This makes it possible for the server to avoid disclosing information about which accounts exist. In any case, if the user does not exist, the authentication request MUST NOT be accepted.

Note that the 'user name' value is encoded in ISO-10646 UTF-8. It is up to the server how it interprets the user name and determines whether the client is authorized based on his GSS-API credentials. In particular, the encoding used by the system for user names is a matter for the ssh server implementation. However, if the client reads the user name in some other encoding (e.g., ISO 8859-1 - ISO Latin1), it MUST convert the user name to ISO-10646 UTF-8 before transmitting, and the server MUST convert the user name to the encoding used on that system for user names.

Any normalization or other preparation of names is done by the ssh server based on the requirements of the system, and is outside the scope of SSH. SSH implementations which maintain private user databases SHOULD prepare user names as described by [SASLPREP].

The client MAY at any time continue with a new SSH_MSG_USERAUTH_REQUEST message, in which case the server MUST abandon the previous authentication attempt and continue with the new one.

3.3. Initial Server Response

The server responds to the SSH_MSG_USERAUTH_REQUEST with either an SSH_MSG_USERAUTH_FAILURE if none of the mechanisms are supported or with an SSH_MSG_USERAUTH_GSSAPI_RESPONSE as follows:

```
                byte            SSH_MSG_USERAUTH_GSSAPI_RESPONSE
                string          selected mechanism OID
```

The mechanism OID must be one of the OIDs sent by the client in the
SSH_MSG_USERAUTH_REQUEST packet.

3.4. GSS-API Session

Once the mechanism OID has been selected, the client will then
initiate an exchange of one or more pairs of
SSH_MSG_USERAUTH_GSSAPI_TOKEN packets. These packets contain the
tokens produced from the 'GSS_Init_sec_context()' and
'GSS_Accept_sec_context()' calls. The actual number of packets
exchanged is determined by the underlying GSS-API mechanism.

```
                byte            SSH_MSG_USERAUTH_GSSAPI_TOKEN
                string          data returned from either GSS_Init_sec_context()
                                or GSS_Accept_sec_context()
```

If an error occurs during this exchange on server side, the server
can terminate the method by sending an SSH_MSG_USERAUTH_FAILURE
packet. If an error occurs on client side, the client can terminate
the method by sending a new SSH_MSG_USERAUTH_REQUEST packet.

When calling GSS_Init_sec_context(), the client MUST set
integ_req_flag to "true" to request that per-message integrity
protection be supported for this context. In addition,
deleg_req_flag MAY be set to "true" to request access delegation, if
requested by the user.

Since the user authentication process by its nature authenticates
only the client, the setting of mutual_req_flag is not needed for
this process. This flag SHOULD be set to "false".

Since the user authentication process will involve the exchange of
only a single token once the context has been established, it is not
necessary that the context support detection of replayed or out-of-
sequence tokens. Thus, the setting of replay_det_req_flag and
sequence_req_flag are not needed for this process. These flags
SHOULD be set to "false".

Additional SSH_MSG_USERAUTH_GSSAPI_TOKEN messages are sent if and
only if the calls to the GSS-API routines produce send tokens of non-
zero length.

Any major status code other than GSS_S_COMPLETE or
GSS_S_CONTINUE_NEEDED SHOULD be a failure.

3.5. Binding Encryption Keys

   In some cases, it is possible to obtain improved security by allowing
   access only if the client sends a valid message integrity code (MIC)
   binding the GSS-API context to the keys used for encryption and
   integrity protection of the SSH session. With this extra level of
   protection, a "man-in-the-middle" attacker who has convinced a client
   of his authenticity cannot then relay user authentication messages
   between the real client and server, thus gaining access to the real
   server. This additional protection is available when the negotiated
   GSS-API context supports per-message integrity protection, as
   indicated by the setting of the integ_avail flag on successful return
   from GSS_Init_sec_context() or GSS_Accept_sec_context().

   When the client's call to GSS_Init_sec_context() returns
   GSS_S_COMPLETE with the integ_avail flag set, the client MUST
   conclude the user authentication exchange by sending the following
   message:

```
        byte        SSH_MSG_USERAUTH_GSSAPI_MIC
        string      MIC
```

   This message MUST be sent only if GSS_Init_sec_context() returned
   GSS_S_COMPLETE. If a token is also returned, then the
   SSH_MSG_USERAUTH_GSSAPI_TOKEN message MUST be sent before this one.

   The contents of the MIC field are obtained by calling GSS_GetMIC()
   over the following, using the GSS-API context that was just
   established:

```
        string      session identifier
        byte        SSH_MSG_USERAUTH_REQUEST
        string      user name
        string      service
        string      "gssapi-with-mic"
```

   If this message is received by the server before the GSS-API context
   is fully established, the server MUST fail the authentication.

   If this message is received by the server when the negotiated GSS-API
   context does not support per-message integrity protection, the server
   MUST fail the authentication.

3.6. Client Acknowledgement

   Some servers may wish to permit user authentication to proceed even
   when the negotiated GSS-API context does not support per-message
   integrity protection. In such cases, it is possible for the server

to successfully complete the GSS-API method, while the client's last
call to GSS_Init_sec_context() fails. If the server simply assumed
success on the part of the client and completed the authentication
service, it is possible that the client would fail to complete the
authentication method, but not be able to retry other methods because
the server had already moved on. To protect against this, a final
message is sent by the client to indicate it has completed
authentication.

When the client's call to GSS_Init_sec_context() returns
GSS_S_COMPLETE with the integ_avail flag not set, the client MUST
conclude the user authentication exchange by sending the following
message:

        byte   SSH_MSG_USERAUTH_GSSAPI_EXCHANGE_COMPLETE

This message MUST be sent only if GSS_Init_sec_context() returned
GSS_S_COMPLETE. If a token is also returned, then the
SSH_MSG_USERAUTH_GSSAPI_TOKEN message MUST be sent before this one.

If this message is received by the server before the GSS-API context
is fully established, the server MUST fail the authentication.

If this message is received by the server when the negotiated GSS-API
context supports per-message integrity protection, the server MUST
fail the authentication.

It is a site policy decision for the server whether or not to permit
authentication using GSS-API mechanisms and/or contexts that do not
support per-message integrity protection. The server MAY fail the
otherwise valid gssapi-with-mic authentication if per-message
integrity protection is not supported.

3.7. Completion

As with all SSH authentication methods, successful completion is
indicated by an SSH_MSG_USERAUTH_SUCCESS if no other authentication
is required, or an SSH_MSG_USERAUTH_FAILURE with the partial success
flag set if the server requires further authentication. This packet
SHOULD be sent immediately following receipt of the
SSH_MSG_USERAUTH_GSSAPI_EXCHANGE_COMPLETE packet.

3.8. Error Status

In the event that a GSS-API error occurs on the server during context
establishment, the server MAY send the following message to inform
the client of the details of the error before sending an
SSH_MSG_USERAUTH_FAILURE message:

```
        byte        SSH_MSG_USERAUTH_GSSAPI_ERROR
        uint32      major_status
        uint32      minor_status
        string      message
        string      language tag
```

The message text MUST be encoded in the UTF-8 encoding described in
[UTF8]. Language tags are those described in [LANGTAG]. Note that
the message text may contain multiple lines separated by carriage
return-line feed (CRLF) sequences. Application developers should
take this into account when displaying these messages.

Clients receiving this message MAY log the error details and/or
report them to the user. Any server sending this message MUST ignore
any SSH_MSG_UNIMPLEMENTED sent by the client in response.

3.9. Error Token

In the event that, during context establishment, a client's call to
GSS_Init_sec_context() or a server's call to GSS_Accept_sec_context()
returns a token along with an error status, the resulting "error
token" SHOULD be sent to the peer using the following message:

```
        byte        SSH_MSG_USERAUTH_GSSAPI_ERRTOK
        string      error token
```

This message implies that the authentication is about to fail, and is
defined to allow the error token to be communicated without losing
synchronization.

When a server sends this message, it MUST be followed by an
SSH_MSG_USERAUTH_FAILURE message, which is to be interpreted as
applying to the same authentication request. A client receiving this
message SHOULD wait for the following SSH_MSG_USERAUTH_FAILURE
message before beginning another authentication attempt.

When a client sends this message, it MUST be followed by a new
authentication request or by terminating the connection. A server
receiving this message MUST NOT send an SSH_MSG_USERAUTH_FAILURE in
reply, since such a message might otherwise be interpreted by a
client as a response to the following authentication sequence.

Any server sending this message MUST ignore any SSH_MSG_UNIMPLEMENTED
sent by the client in response. If a server sends both this message
and an SSH_MSG_USERAUTH_GSSAPI_ERROR message, the
SSH_MSG_USERAUTH_GSSAPI_ERROR message MUST be sent first, to allow
the client to store and/or display the error status before processing
the error token.

4. Authentication Using GSS-API Key Exchange

   This section describes a user authentication method building on the
   framework described in [SSH-USERAUTH]. This method performs user
   authentication by making use of an existing GSS-API context
   established during key exchange.

   The authentication method name for this protocol is "gssapi-keyex".

   This method may be used only if the initial key exchange was
   performed using a GSS-API-based key exchange method defined in
   accordance with Section 2. The GSS-API context used with this method
   is always that established during an initial GSS-API-based key
   exchange. Any context established during key exchange for the
   purpose of rekeying MUST NOT be used with this method.

   The server SHOULD include this user authentication method in the list
   of methods that can continue (in an SSH_MSG_USERAUTH_FAILURE) if the
   initial key exchange was performed using a GSS-API-based key exchange
   method and provides information about the user's identity that is
   useful to the server. It MUST NOT include this method if the initial
   key exchange was not performed using a GSS-API-based key exchange
   method defined in accordance with Section 2.

   The client SHOULD attempt to use this method if it is advertised by
   the server, initial key exchange was performed using a GSS-API-based
   key exchange method, and this method has not already been tried. The
   client SHOULD NOT try this method more than once per session. It
   MUST NOT try this method if initial key exchange was not performed
   using a GSS-API-based key exchange method defined in accordance with
   Section 2.

   If a server receives a request for this method when initial key
   exchange was not performed using a GSS-API-based key exchange method
   defined in accordance with Section 2, it MUST return
   SSH_MSG_USERAUTH_FAILURE.

   This method is defined as a single message:

        byte   SSH_MSG_USERAUTH_REQUEST
        string   user name
        string   service
        string   "gssapi-keyex"
        string   MIC

   The contents of the MIC field are obtained by calling GSS_GetMIC over
   the following, using the GSS-API context that was established during
   initial key exchange:

```
            string          session identifier
            byte            SSH_MSG_USERAUTH_REQUEST
            string          user name
            string          service
            string          "gssapi-keyex"
```

Upon receiving this message when initial key exchange was performed
using a GSS-API-based key exchange method, the server uses
GSS_VerifyMIC() to verify that the MIC received is valid. If the MIC
is not valid, the user authentication fails, and the server MUST
return SSH_MSG_USERAUTH_FAILURE.

If the MIC is valid and the server is satisfied as to the user's
credentials, it MAY return either SSH_MSG_USERAUTH_SUCCESS or
SSH_MSG_USERAUTH_FAILURE with the partial success flag set, depending
on whether additional authentications are needed.

5. Null Host Key Algorithm

The "null" host key algorithm has no associated host key material and
provides neither signature nor encryption algorithms. Thus, it can
be used only with key exchange methods that do not require any
public-key operations and do not require the use of host public key
material. The key exchange methods described in Section 2 are
examples of such methods.

This algorithm is used when, as a matter of configuration, the host
does not have or does not wish to use a public key. For example, it
can be used when the administrator has decided as a matter of policy
to require that all key exchanges be authenticated using Kerberos
[KRB5], and thus the only permitted key exchange method is the
GSS-API-authenticated Diffie-Hellman exchange described above, with
Kerberos V5 as the underlying GSS-API mechanism. In such a
configuration, the server implementation supports the "ssh-dss" key
algorithm (as required by [SSH-TRANSPORT]), but could be prohibited
by configuration from using it. In this situation, the server needs
some key exchange algorithm to advertise; the "null" algorithm fills
this purpose.

Note that the use of the "null" algorithm in this way means that the
server will not be able to interoperate with clients that do not
support this algorithm. This is not a significant problem, since in
the configuration described, it will also be unable to interoperate
with implementations that do not support the GSS-API-authenticated
key exchange and Kerberos.

Any implementation supporting at least one key exchange method that
conforms to Section 2 MUST also support the "null" host key
algorithm. Servers MUST NOT advertise the "null" host key algorithm
unless it is the only algorithm advertised.

6. Summary of Message Numbers

The following message numbers have been defined for use with GSS-
API-based key exchange methods:

```
        #define SSH_MSG_KEXGSS_INIT                   30
        #define SSH_MSG_KEXGSS_CONTINUE               31
        #define SSH_MSG_KEXGSS_COMPLETE               32
        #define SSH_MSG_KEXGSS_HOSTKEY                33
        #define SSH_MSG_KEXGSS_ERROR                  34
        #define SSH_MSG_KEXGSS_GROUPREQ               40
        #define SSH_MSG_KEXGSS_GROUP                  41
```

The numbers 30-49 are specific to key exchange and may be redefined
by other kex methods.

The following message numbers have been defined for use with the
'gssapi-with-mic' user authentication method:

```
        #define SSH_MSG_USERAUTH_GSSAPI_RESPONSE          60
        #define SSH_MSG_USERAUTH_GSSAPI_TOKEN             61
        #define SSH_MSG_USERAUTH_GSSAPI_EXCHANGE_COMPLETE 63
        #define SSH_MSG_USERAUTH_GSSAPI_ERROR             64
        #define SSH_MSG_USERAUTH_GSSAPI_ERRTOK            65
        #define SSH_MSG_USERAUTH_GSSAPI_MIC               66
```

The numbers 60-79 are specific to user authentication and may be
redefined by other user auth methods. Note that in the method
described in this document, message number 62 is unused.

7. GSS-API Considerations

7.1. Naming Conventions

In order to establish a GSS-API security context, the SSH client
needs to determine the appropriate targ_name to use in identifying
the server when calling GSS_Init_sec_context(). For this purpose,
the GSS-API mechanism-independent name form for host-based services
is used, as described in Section 4.1 of [GSSAPI].

In particular, the targ_name to pass to GSS_Init_sec_context() is
obtained by calling GSS_Import_name() with an input_name_type of
GSS_C_NT_HOSTBASED_SERVICE, and an input_name_string consisting of
the string "host@" concatenated with the hostname of the SSH server.

Because the GSS-API mechanism uses the targ_name to authenticate the
server's identity, it is important that it be determined in a secure
fashion. One common way to do this is to construct the targ_name
from the hostname as typed by the user; unfortunately, because some
GSS-API mechanisms do not canonicalize hostnames, it is likely that
this technique will fail if the user has not typed a fully-qualified,
canonical hostname. Thus, implementers may wish to use other
methods, but should take care to ensure they are secure. For
example, one should not rely on an unprotected DNS record to map a
host alias to the primary name of a server, or an IP address to a
hostname, since an attacker can modify the mapping and impersonate
the server.

Implementations of mechanisms conforming to this document MUST NOT
use the results of insecure DNS queries to construct the targ_name.
Clients MAY make use of a mapping provided by local configuration or
use other secure means to determine the targ_name to be used. If a
client system is unable to securely determine which targ_name to use,
then it SHOULD NOT use this mechanism.

7.2. Channel Bindings

This document recommends that channel bindings SHOULD NOT be
specified in the calls during context establishment. This document
does not specify any standard data to be used as channel bindings,
and the use of network addresses as channel bindings may break SSH in
environments where it is most useful.

7.3. SPNEGO

   The use of the Simple and Protected GSS-API Negotiation Mechanism
   [SPNEGO] in conjunction with the authentication and key exchange
   methods described in this document is both unnecessary and
   undesirable. As a result, mechanisms conforming to this document
   MUST NOT use SPNEGO as the underlying GSS-API mechanism.

   Since SSH performs its own negotiation of authentication and key
   exchange methods, the negotiation capability of SPNEGO alone does not
   provide any added benefit. In fact, as described below, it has the
   potential to result in the use of a weaker method than desired.

   Normally, SPNEGO provides the added benefit of protecting the GSS-API
   mechanism negotiation. It does this by having the server compute a
   MIC of the list of mechanisms proposed by the client, and then
   checking that value at the client. In the case of key exchange, this
   protection is not needed because the key exchange methods described
   here already perform an equivalent operation; namely, they generate a
   MIC of the SSH exchange hash, which is a hash of several items
   including the lists of key exchange mechanisms supported by both
   sides. In the case of user authentication, the protection is not
   needed because the negotiation occurs over a secure channel, and the
   host's identity has already been proved to the user.

   The use of SPNEGO combined with GSS-API mechanisms used without
   SPNEGO can lead to interoperability problems. For example, a client
   that supports key exchange using the Kerberos V5 GSS-API mechanism
   [KRB5-GSS] only underneath SPNEGO will not interoperate with a server
   that supports key exchange only using the Kerberos V5 GSS-API
   mechanism directly. As a result, allowing GSS-API mechanisms to be
   used both with and without SPNEGO is undesirable.

   If a client's policy is to first prefer GSS-API-based key exchange
   method X, then non-GSS-API method Y, then GSS-API-based method Z, and
   if a server supports mechanisms Y and Z but not X, then an attempt to
   use SPNEGO to negotiate a GSS-API mechanism might result in the use
   of method Z when method Y would have been preferable. As a result,
   the use of SPNEGO could result in the subversion of the negotiation
   algorithm for key exchange methods as described in Section 7.1 of
   [SSH-TRANSPORT] and/or the negotiation algorithm for user
   authentication methods as described in [SSH-USERAUTH].

8. IANA Considerations

    Consistent with Section 8 of [SSH-ARCH] and Section 4.6 of
    [SSH-NUMBERS], this document makes the following registrations:

        The family of SSH key exchange method names beginning with "gss-
        group1-sha1-" and not containing the at-sign ('@'), to name the
        key exchange methods defined in Section 2.3.

        The family of SSH key exchange method names beginning with "gss-
        gex-sha1-" and not containing the at-sign ('@'), to name the key
        exchange methods defined in Section 2.5.

        All other SSH key exchange method names beginning with "gss-" and
        not containing the at-sign ('@'), to be reserved for future key
        exchange methods defined in conformance with this document, as
        noted in Section 2.6.

        The SSH host public key algorithm name "null", to name the NULL
        host key algorithm defined in Section 5.

        The SSH user authentication method name "gssapi-with-mic", to name
        the GSS-API user authentication method defined in Section 3.

        The SSH user authentication method name "gssapi-keyex", to name
        the GSS-API user authentication method defined in Section 4.

        The SSH user authentication method name "gssapi" is to be
        reserved, in order to avoid conflicts with implementations
        supporting an earlier version of this specification.

        The SSH user authentication method name "external-keyx" is to be
        reserved, in order to avoid conflicts with implementations
        supporting an earlier version of this specification.

    This document creates no new registries.

9. Security Considerations

    This document describes authentication and key-exchange protocols.
    As such, security considerations are discussed throughout.

    This protocol depends on the SSH protocol itself, the GSS-API, any
    underlying GSS-API mechanisms that are used, and any protocols on
    which such mechanisms might depend. Each of these components plays a
    part in the security of the resulting connection, and each will have
    its own security considerations.

The key exchange method described in Section 2 depends on the
underlying GSS-API mechanism to provide both mutual authentication
and per-message integrity services. If either of these features is
not supported by a particular GSS-API mechanism, or by a particular
implementation of a GSS-API mechanism, then the key exchange is not
secure and MUST fail.

In order for the "external-keyx" user authentication method to be
used, it MUST have access to user authentication information obtained
as a side-effect of the key exchange. If this information is
unavailable, the authentication MUST fail.

Revealing information about the reason for an authentication failure
may be considered by some sites to be an unacceptable security risk
for a production environment. However, having that information
available can be invaluable for debugging purposes. Thus, it is
RECOMMENDED that implementations provide a means for controlling, as
a matter of policy, whether to send SSH_MSG_USERAUTH_GSSAPI_ERROR,
SSH_MSG_USERAUTH_GSSAPI_ERRTOK, and SSH_MSG_KEXGSS_ERROR messages,
and SSH_MSG_KEXGSS_CONTINUE messages containing a GSS-API error
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[GROUP-EXCHANGE], by Markus Friedl, Niels Provos, and William A.
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