**Quantum-Safe Hybrid (QSH) Ciphersuite for**
**Transport Layer Security (TLS) version 1.2**
**draft-whyte-qsh-tls12-02.txt**


Abstract

   This document describes the Quantum-Safe Hybrid ciphersuite, a new
   cipher suite providing modular design for quantum-safe cryptography
   to be adopted in the handshake for the Transport Layer Security (TLS)
   protocol version 1.2.  In particular, it specifies the use of the
   NTRUEncrypt encryption scheme in a TLS handshake.

Status of This Memo

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## 1.  Introduction

Quantum computers pose a significant threat to modern cryptography.
Two most widely adopted public key cryptosystems, namely, RSA [PKCS1]
and Elliptic Curve Cryptography (ECC) [SECG], will be broken by
general purpose quantum computers.  RSA is adopted in TLS from
Version 1.0 and to TLS Version 1.2 [RFC2246], [RFC4346], [RFC5246],
[TLS1.3].  ECC is enabled in RFC 4492 [RFC4492] and adopted in TLS
version 1.2 [RFC5246].  On the other hand, there exist several
quantum-safe cryptosystems, such as the NTRUEncrypt cryptosystem
[EESS1], that deliver similar performance, yet are conjectured to be
robust against quantum computers.

This document describes a modular design that allows one or many
quantum-safe cryptosystems to be adopted in the handshake protocol,
applicable to TLS Version 1.0 to Version 1.3 [RFC2246], [RFC4346],
[RFC5246], [TLS1.3].  It uses a hybrid approach that combines a
classical handshake mechanism with key encapsulation mechanisms
instantiated with quantum-safe encryption schemes.  The modular
design provides quantum-safe features to TLS with an introduction of
only one new cipher suite.  Yet, it allows the flexibility to include
new and advanced quantum-safe encryption schemes at present and in
the future.

The remainder of this document is organized as follows.  Section 2
provides an overview of the modular design of quantum-safe handshake
for TLS.  Section 3 specifies various data structures needed for a
quantum safe handshake, their encoding in TLS messages, and the
processing of those messages.  Section 4 defines new TLS_QSH cipher
suites.  Section 5 provides specific information for quantum safe
encryption schemes.  Section 6 discusses security considerations.
Section 7 describes IANA considerations for the name spaces created
by this document.  Section 8 gives acknowledgements.

This is followed by the lists of normative and informative references
cited in this document, the authors' contact information, and
statements on intellectual property rights and copyrights.

Implementation of this specification requires familiarity with TLS
[RFC2246], [RFC4346], [RFC5246], [TLS1.3], TLS extensions [RFC4366],
and knowledge of the corresponding quantum-safe cryptosystem.

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 RFC 2119 [RFC2119].

Well-known abbreviations and acronyms can be found at RFC Editor
Abbreviations List [REAL].

## [2](#). Modular design for quantum-safe hybrid handshake

This document introduces a modular approach to including new quantum-safe key exchange algorithms within TLS, while maintaining the assurance that comes from the use of already established cipher suites.  It allows the TLS premaster secret to be agreed using both an established classical cipher suite and a quantum-safe key encapsulation mechanism.
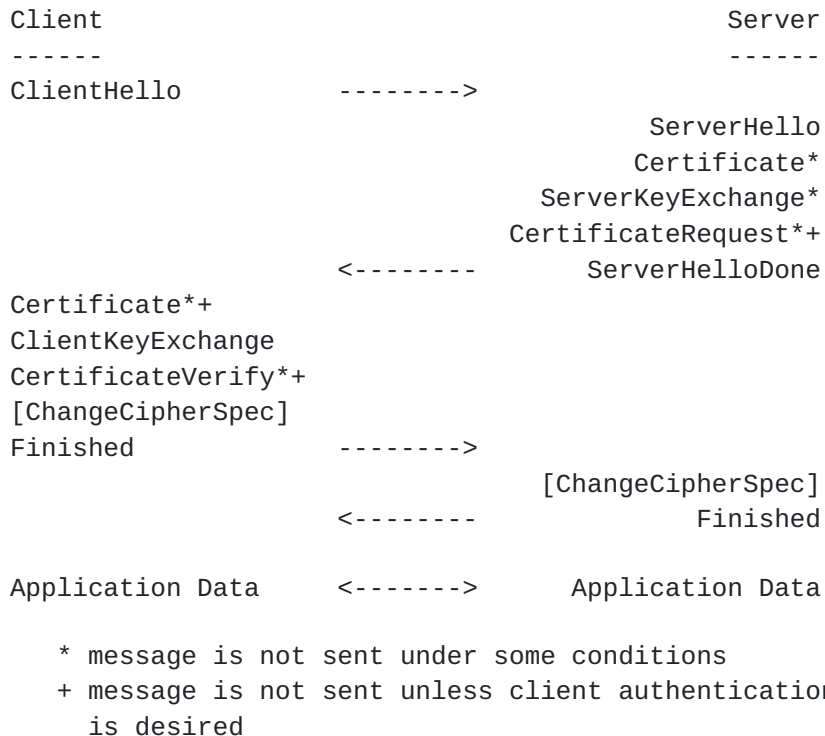
```
        Client                                      Server
        ------                                      ------
        ClientHello           -------->
                                                 ServerHello
                                                Certificate*
                                          ServerKeyExchange*
                                          CertificateRequest*+
                              <--------       ServerHelloDone
        Certificate*+
        ClientKeyExchange
        CertificateVerify*+
        [ChangeCipherSpec]
        Finished              -------->
                                          [ChangeCipherSpec]
                              <--------            Finished

        Application Data      <------->     Application Data

           * message is not sent under some conditions
           + message is not sent unless client authentication
             is desired

        Figure 1: Message flow in a full TLS 1.2 handshake
```

Figure 1 shows all messages involved in the TLS key establishment protocol (aka full handshake).  The addition of quantum-safe cryptography has direct impact only on the ClientHello, the ServerHello, the ServerKeyExchange, and the ClientKeyExchange.  In the rest of this document, we describe each quantum-safe key exchange data structure in greater detail in terms of the content and processing of these messages.

The authentication is provided by classical cryptography.  The introduction of quantum-safe encryption schemes delivers forward secrecy against quantum attackers.  The additional cryptographic data exchanged between the client and the server is shown in Figure 2.

```
         Client                                         Server
         ------                                         ------
         ClientHelloExtension
         (SerPKReq|
         QSHSchemeIDList|
         [CliPKList])        -------->
                                           ServerHelloExtension
                                                 ([SerPKList])
                                             ServerKeyExchange
                                 <--------     ([SerCipherList])
         ClientKeyExchange
         ([CliCipherList])   -------->

         ClassicS|SerS|CliS  <------->    ClassicS|SerS|CliS

             [struct]: struct is optional


         Figure 2: Additional cryptographic data in handshake
```

As usual, the ClientHello message includes the list of classical cipher suites the client wishes to negotiate (e.g., TLS_ECDH_ECDSA_WITH_NULL_SHA), as well as a new cipher suite identifier TLS_QSH (short for TLS with Quantum Safe Hybrid handshake).  This new identifier SHOULD appear first in the list of cipher suites.

The ClientHelloExtension field MAY have three additional fields:
o    SerPKReq:  a request for server's public key; also indicates the number of server's public keys the client wishes to receive
o    QSHSchemeIDList:
              a list of distinct QSHSchemeIDs from the client, each ID represents a quantum safe encryption scheme/parameter set supported by the client
o    CliPKList: a list of client's public keys [CPK1]|[CPK2]|... each corresponding to a distinct QSHScheme in QSHSchemeIDList

Note: The client does not need to provide public keys for all QSSchemes from the list. The client indicates that it does not wish to contribute a public key for certain QSScheme by omitting the corresponding public key field.

The ServerHelloExtension field MAY have one additional field:
o    SerPKList: a list of Server's public keys [SPK1]|[SPK2]|... each corresponding to a QSHScheme in QSHSchemeIDList

Note: SerPKList is a list of public key structures QSHPK.  For each
structure, there is a QSHSchemeID field identifying the corresponding
encryption scheme.  This QSHSchemeID MUST exist in QSHSchemeIDList.

The ServerKeyExchange message MAY contain an additional list of
ciphertexts:
o    SerCipherList:
                a list of ciphertexts
                [Encrypt_CPK1(SerS1)]|[Encrypt_CPK2(SerS2)]|...
                where the server-contributed secret keying material
                is SerS = SerS1|SerS2|..., and CPKi is selected from
                CliPKList.
At least one of SerPKList and SerCipherList MUST have at least one
entry.

Additionally, the ServerKeyExchange contains an indication of the
classical cipher suite selected, and the ServerKeyExchange material
appropriate to that cipher suite.

If SerPKList was provided, the ClientKeyExchange message MUST contain
an additional list of ciphertexts:
o    CliCipherList:
                a list of ciphertexts
                [Encrypt_SPK1(CliS1)]|[Encrypt_SPK2(CliS2)]|...
                where the client-contributed secret keying material
                is CliS = CliS1|CliS2|... , and SPKi is from
                SerPKList.

The client MUST use all public keys from SerPKList.

Additionally, the ClientKeyExchange contains the ServerKeyExchange
material appropriate to the selected classical cipher suite.

SerS and CliS cannot be both NULL.

The final premaster secret negotiated by the client and the server is
the concatenation of the classical premaster secret, SerS, and CliS
in that order.
A 48 bytes fixed length master secret is derived from the premaster
secret at the end of the handshake, using a pseudo random function
specified by the classical cipher suite (see Section 8.1. RFC 5246
[RFC5246]).

## 3.  Data Structures and Computations

This section specifies the data structures and computations used by
TLS_QSH cipher suite specified in Sections 2.  The presentation
language used here is the same as that used in TLS [RFC2246],

[RFC4346], [RFC5246].  Since this specification extends TLS, these
descriptions should be merged with those in the TLS specification and
any others that extend TLS.  This means that enum types may not
specify all possible values, and structures with multiple formats
chosen with a select() clause may not indicate all possible cases.

## 3.1.  Data structures for Quantum-safe Crypto Schemes

```
    enum {
        ntru_eess439 (0x0101),
        ntru_eess593 (0x0102),
        ntru_eess743 (0x0103),
        reserved     (0x0102..0x01FF),
        lwe_XXX      (0x0201),
        reserved     (0x0202..0x02FF),
        hfe_XXX      (0x0301),
        reserved     (0x0302..0x03FF),
        reserved     (0x0400..0xFEFF),
        (0xFFFF)
    } QSHSchemeID;
```

ntru_eess439, etc:   Indicates parameter set to be used for the
   NTRUEncrypt encryption scheme.  The name of the parameter sets
   defined here are those specified in [EESS1].

lwe_XXX, etc:   Indicates parameters for Learning With Error (LWE)
   encryption scheme.  The name of the parameters defined here are
   not specified in this document.

hfe_XXX, etc:   Indicates parameters for Hidden Field Equotion (HFE)
   encryption scheme.  The name of the parameters defined here are
   not specified in this document.

The QSHSchemes name space is maintained by IANA [IANA].  See Section
6 for information on how new schemes are added.

The server implementation SHOULD support all of the above QSHSchemes,
and client implementation SHALL support at least one of them.

```
    struct {
        QSHSchemeID   id,
        opaque        pubKey<1..2^16-1>
    } QSHPK;

    struct {
        QSHPK         keys<1..2^24-1>
    } QSHPKList;
```

The structure of public keys exchanged by the client and the server,
namely, QSHPK, has two fields: QSHSchemeID specifies the
corresponding quantum safe encryption scheme, and an opaque encodes
the actual public key data following the specification of the
corresponding quantum safe encryption scheme.  Any entity that
reserves a new quantum safe encryption scheme identifier MUST specify
how the keys and ciphertexts for that scheme are encoded.  See
Section 5 for definitions of the encodings of the schemes specified
in this document.

The QSHPKList is a list of QSHPKs.

```
    struct {
        QSHSchemeID   id,
        opaque        encryptedKey<1..2^16-1>
    } QSHCipher;

    struct {
        QSHCipher     encryptedKeys<1..2^24-1>
    } QSHCipherList;
```

The structure of ciphertext exchanged by the client and the server,
namely QSHCipher, has two fields: QSHSchemeID specifies the
corresponding quantum safe encryption scheme, and an opaque encodes
the actual ciphertext following the specification of the
corresponding quantum safe encryption scheme.

The QSHCipherList is a list of ciphertexts.


**3.2.  Client Hello Extensions**

This section specifies a TLS extension that can be included with the
ClientHello message as described in RFC 4366 [RFC4366].

When these extensions are sent:

The extensions MUST be sent along with any ClientHello message that
proposes TLS_QSH cipher suites.

Meaning of these extensions:

These extensions allow a client to send a request for server's public
key, a list that enumerates QSHSchemeIDs for supported quantum safe
cryptosystems, and/or public keys corresponding to QSHSchemeIDs.

Note: QSHSchemeID MUST be distinct in QSHSchemeIDList.  For each
QSHSchemeID there MUST be at most one public key CPKi.

Structure of the extension:

The general structure of TLS extensions is described in [RFC4366],
and this specification adds a new type to ExtensionType.

```
 enum { quantum-safe-hybrid(0x18)} ExtensionType;
```

quantum-safe-hybrid (Supported TLS_QSH Extension): Indicates the list
   of QSHSchemeIDs supported by the client.  For this extension, the
   opaque extension_data field may contain SrvPkReq, QSHSchemeIDList
   and CliPKList.

```
   struct {
       select (CipherSuite) {
           case TLS_QSH:
               QSHSchemeIDList qshSchemeIDList,
               QSHPKList       cliPKList,
               SerPkReqType    serPkReq,
   } ClientHelloExtension;
```

SerPKReqType is defined as follows:

```
   struct {
       int    min,
       int    max
   } SerPkReqType;
```

serPKReq.min MUST not be greater than serPKReq.max.  Either field
MUST not be greater than the maximum number that is supported by the
protocol (this may due to the size of the extensions and size of the
encoded public keys, etc).  If the serPKReq.min equal serPKReq.max,
the client requires specifically serPKReq.min number of public keys.
When both field are zero, the client do not wish to receive any
public keys. When 0 <= serPKReq.min < serPKReq.max, the client lets
the server to decide the number of public keys (between serPKReq.min
and serPKReq.max).

Items in qshSchemeIDList are ordered according to the client's
preferences (favorite choice first).

As an example, a client that only supports ntru_eess439 (0x0101) and
ntru_eess593 (0x0102) and prefers to use ntru_eess439 would encode
its qshSchemeIDList as follows:

```
    04 01 01 01 02
```

The client MAY append a list of public keys corresponding to each
crypto system. If serPKReq is (0,0), the client MUST list all public

keys corresponding to each qshSchemeID form qshSchemeIDList.

        00 18 | extension length | 00 04 01 01 01 02 | CliPKList length
        | CPK1 | CPK2 | CPK3 | ... | 00 |

Note: the extension type value appearing in these examples is
tentative.

Actions of the sender:

A client that proposes TLS_QSH cipher suites in its ClientHello
message appends these extensions (along with any others), indicating
whether the client wishes the server to contribute its quantum-safe
public key, enumerating the supported quantum-safe crypto systems,
and/or the public key corresponding to each crypto system.

Actions of the receiver:

A server that receives a ClientHello with a TLS_QSH cipher suite MUST
check the extension field to use the client's enumerated capabilities
to guide its selection of an appropriate cipher suite.  The TLS_QSH
cipher suite must be negotiated only if the server can successfully
complete the handshake while using the listed quantum-safe
cryptosystems from the client.

The server will carry out a classic handshake with the client using a
classical cipher suite (other than TLS_QSH) indicated by the client.
The server will also select a (list of) supported QSHScheme(s),
indexed by QSHSchemeID(s).  If server's public key(s) is required,
the server will generate public/private keys corresponding to these
QSHSchemeIDs.

If a server does not understand the Extension, does not understand
the list of quantum-safe encryption schemes, or is unable to complete
the TLS_QSH handshake while restricting itself to the enumerated
cryptosystems, it MUST NOT negotiate the use of a TLS_QSH cipher
suite.  Depending on what other cipher suites are proposed by the
client and supported by the server, this may result in a fatal
handshake failure alert due to the lack of common cipher suites.

## 3.3.  Server Hello Extension

This section specifies a TLS extension that can be included with the
ServerHello message as described in RFC 4366 [RFC4366].

When this extension is sent:

The extensions MUST be sent along with any ServerHello message that

accepts TLS_QSH cipher suites.

Meaning of this extension:

This extension allows a server to notify the client the ID(s) and
public key(s) for the quantum-safe encryption scheme(s) it chooses
from the QSHSchemeIDList.

Structure of this extension:

```
    struct {
        select (CipherSuite) {
            case TLS_QSH:
                QSHPKList       serPKList
    } ServerHelloExtension;
```

Actions of the sender:

The server selects a number of QSHSchemeIDs in response to a
ClientHelloExtension message.  The selection is based on client's
preference and ReqSerPK field.  The QSHSchemeIDs selected MUST exist
in the received QSHSchemeIDList.  For each scheme, the server sets
QSHPK.id to the QSHSchemeID that it selects.  If the server is
willing/requested to contribute its public key, the server will
generate a pair of public/private keys, and set QSHPK.pubKey to this
the public key; otherwise this field will be empty.  The server form
the SerPKList with the list of QSHPK.

Note: if the server sends no public keys in the Server Hello
Extension, it MUST send at least one ciphertext in the EncryptedSerS
at the Server Key Exchange message.

Actions of the receiver:

A client that receives a ServerHello message containing an extension
will extract the agreed QSHSchemeIDs and the server's public keys
from serPKList.  The client-generated secrets will be encrypted with
server's ephemeral public keys as described in Section 3.5.

## 3.4.  Server Key Exchange

When this message is sent:

This message is sent in all implementations of this cipher suite.

Meaning of this message:

This message is used to send classical key exchange information to

the client.  It MAY also be used to send key material (encrypted by
one or many of the client's public keys) to the client.

Structure of this message:

The TLS ServerKeyExchange message is extended as follows.

```
struct {
    select (KeyExchangeAlgorithm) {
        case TLS_QSH:
            QSHCipherList      encryptedSerS,
            CipherSuite        classical_ciphersuite,
            ServerKeyExchange classical_exchange
    } exchange_keys;
} ServerKeyExchange;
```

Actions of the sender:

The server sets the CipherSuite field to the classical cipher suite.
This MUST be one of the next preferable cipher suites other than
TLS_QSH that was received in the ClientHello.

The server sets classical_exchange to have the contents appropriate
for the indicated classical cipher suite.

If a number of client's public keys CPK1,...CPKn were received in the
Client Hello Extension, the server:

    1. Selects k<=n of these public keys.

    2. For each of the public keys CPKi, generates a secret SerSi.
    The length in bytes of SerSi MUST be the lesser of (a) 48, the
    length of the classical master secret, and (b) the maximum
    plaintext input length for the corresponding encryption scheme
    (see Section 5).

    3. Encrypts the SerSi with PKi.

    4. Creates a QSHCipherList structure containing the encrypted
    secrets.

Note: since it is required that each of the public keys in the
ClientHelloExtension is for a distinct quantum-safe encryption
scheme, the QSHCipherList unambiguously identifies which client
public key corresponds to which server-generated ciphertext.

The server-contributed keying material is:
    SerS = SerS1|SerS2|...|SerSk

Actions of the receiver:

The client processes the ServerKeyExchange with KeyExchangeAlgorithm
as in a classical handshake.  If EncryptedSerS is not NULL, the
client decrypts each ciphertext in encryptedSerS using the client's
secret key identified by QSHIDs from SerPKList (received from
ServerHelloExtension) and obtains SerS. Otherwise, the client sets
SerS to NULL.

## 3.5.  Client Key Exchange

When this message is sent:

This message is sent in all key exchange algorithms.

Meaning of the message:

This message is used to convey ephemeral data relating to the key
exchange belonging to the client (such as its ephemeral ECDH public
key).  It is also used to send client's quantum-safe keying material
to the server.

Structure of this message:

The TLS ClientKeyExchange message is extended as follows.

```
    struct {
        select (KeyExchangeAlgorithm) {
            case QSH:
                QSHcipher        encryptedCliS,
                ClientKeyExchange classical_exchange
        } exchange_keys;
    } ClientKeyExchange;
```

Actions of the sender:

The client sets classical_exchange to have the contents appropriate
for the indicated classical cipher suite.

If a number of server's public keys SPK1,...SPKk were received in the
Server Hello Extension, the client:

> 1. For each of the public keys SPKi, generates a secret CliSi.
> The length in bytes of CliSi should be the lesser of (a) 48, the
> length of the classical master secret, and (b) the maximum
> plaintext input length for the corresponding encryption scheme
> (see Section 5).

2. Encrypts the CliSi with SPKi.

3. Creates a QSHCipherList structure containing the encrypted
secrets.

Note: since it is required that each of the public keys in the Client
Hello Extension is for a distinct quantum-safe encryption scheme, the
QSHCipherList unambiguously identifies which server public key
corresponds to which client-generated ciphertext.

The client-contributed keying material is:
CliS = CliS1|CliS2|...|CliSk.

The final premaster secret negotiated by the client and the server is
the concatenation of the classical premaster secret, SerS, and CliS
in that order. A 48 bytes fixed length master secret is derived from
the premaster secret at the end of the handshake, using a pseudo
random function specified by the classical cipher suite (see Section
8.1. RFC 5246 [RFC5246]).

Actions of the receiver:

The server processes the ClientKeyExchange with KeyExchangeAlgorithm
as in a classical handshake.  If EncryptedCliS is received, the
server decrypts the ciphertext(s) with the appropriate private secret
key(s) and obtains CliS.  Otherwise, the server sets CliS to NULL.

The final premaster secret negotiated by the client and the server is
the concatenation of the classical premaster secret, SerS, and CliS
in that order. A 48 bytes fixed length master secret is derived from
the premaster secret at the end of the handshake, using a pseudo
random function specified by the classical cipher suite (see Section
8.1. RFC 5246 [RFC5246]).

## 4.  Cipher Suites

CipherSuite TLS_QSH  = { 0x66 0x26 }

Implementations that support this cipher suite MUST support at least
one classical cipher suite.

## 5.  Specific information for Quantum Safe Scheme

### 5.1   NTRUEncrypt

NTRUEncrypt parameter sets are identified by the values ntru_eess439

(0x0101), ntru_eess593 (0x0102), ntru_eess743 (0x0103) assigned in
this document.

For each of these parameter sets, the public key and ciphertext are
Ring Elements as defined in [EESS1].  The encoded public key and
ciphertext are the result of encoding the relevant Ring Element with
RE2BSP as defined in [EESS1].

For each parameter set the the maximum plaintext input length in
bytes is as follows. This is used when determining the length of the
client/server-generated secrets CliSi and SerSi as specified in
sections 3.4 and 3.5.

```
eess439  65
eess593  86
eess743  106
```

## 5.2.  LWE
**Encoding not defined in this document.**

## 5.3.  HFE
**Encoding not defined in this document.**

## 6.  Security Considerations

## 6.1.  Security, Authenticity and Forward Secrecy

Security, authenticity and forward secrecy against classical
computers are inherent from classical handshake mechanism.

## 6.2.  Quantum Security and Quantum Forward Secrecy

The proposed handshake mechanism provides quantum security and
quantum forward secrecy.

Quantum resistant feature of QSHSchemes ensures a quantum attacker
will not learn SerS and/or CliS.  A quantum attacker may learn
classic handshake information.  Given an input X, the leftover hash
lemma [LHL] ensures that one can extract Y bits that are almost
uniformly distributed, where Y is asymptotic to the min-entropy of X.
An adversary who has some partial knowledge about X, will have almost
no knowledge about Y.  This guarantees the attacker will not learn
the final premaster secret so long as SerS and/or CliS have enough
entropy and remain secret.  This also guarantees the premaster secret
is secure even if the client's and/or the server's long term keys are
compromised.

## 6.3.  Quantum Authenticity

The proposed approach relies on the classical cipher suite for
authenticity.  Thus, an attacker with quantum computing capability
will be able to break the authenticity.

## 7.  IANA Considerations

This document describes a new name spaces for use with the TLS
protocol:

o  QSHSchemeID

Any additional assignments require IETF Consensus action [RFC2434].

## 8.  Acknowledgements

Funding for the RFC Editor function is provided by the IETF
Administrative Support Activity (IASA).


## 9.  References

### 9.1.  Normative References

[EESS1]      Consortium for Efficient Embedded Security, "Efficient
             Embedded Security Standard #1: Implementation Aspects of
             NTRUEncrypt", March 2015.
             <https://github.com/NTRUOpenSourceProject/ntru-
             crypto/raw/master/doc/EESS1-2015v3.0.pdf>

[FIPS180]  NIST, "Secure Hash Standard", FIPS 180-2, 2002.

[FIPS186]  NIST, "Digital Signature Standard", FIPS 186-2, 2000.

[LHL]        Impagliazzo, R., Levin, L., and Luby, M., "Pseudo-random
             generation from one-way functions", 1989.

[PKCS1]      RSA Laboratories, "PKCS#1: RSA Encryption Standard version
             1.5", PKCS 1, November 1993

[REAL]       "RFC Editor Abbreviations List", September 2013,
             <https://www.rfc-editor.org/rfc-style-
             guide/abbrev.expansion.txt/>.

[RFC2119]  Bradner, S., "Key Words for Use in RFCs to Indicate
             Requirement Levels", RFC 2119, March 1997.

[RFC2246]  Dierks, T. and C. Allen, "The TLS Protocol Version 1.0",
             RFC 2246, January 1999.

   [RFC2434]   Narten, T. and H. Alvestrand, "Guidelines for Writing an
               IANA Considerations Section in RFCs", RFC 2434, October
               1998.

   [RFC4346]   Dierks, T. and E. Rescorla, "The Transport Layer Security
               (TLS) Protocol Version 1.1", RFC 4346, April 2006.

   [RFC4366]   Blake-Wilson, S., Nysrom, M., Hopwood, D., Mikkelsen, J.,
               and T. Wright, "Transport Layer Security (TLS)
               Extensions", RFC 4366, April 2006.

   [RFC4492]   Blake-Wilson, S., Bolyard, N., Gupta, V., Hawk, C., and B.
               Moeller, "Elliptic Curve Cryptography (ECC) Cipher Suites
               for Transport Layer Security (TLS)", RFC 4492, May 2006.

   [RFC5246]   Dierks, T. and E. Rescorla, "The Transport Layer Security
               (TLS) Protocol Version 1.2", RFC 5246, August 2008.

   [TLS1.3]    E. Rescorla, "The Transport Layer Security (TLS) Protocol
               Version 1.3", draft-ietf-tls-tls13-05, March 2015.

## 8.2.  Informative References

   [RFC5990]   Randall, J., Kaliski, B., Brainard, J. and Turner S., "Use
               of the RSA-KEM Key Transport Algorithm in the
               Cryptographic Message Syntax (CMS)", RFC 5990, September
               2010.

   [RFC5859]   Krawczyk, H., Eronen, P., "HMAC-based Extract-and-Expand
               Key Derivation Function (HKDF)", RFC 5859, May 2010.

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