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The Transport Layer Security (TLS) Protocol Version 1.3 draft-ietf-tls-tls13-18

Abstract

This document specifies version 1.3 of the Transport Layer Security (TLS) protocol. TLS allows client/server applications to communicate over the Internet in a way that is designed to prevent eavesdropping, tampering, and message forgery.

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[1.](#) Introduction

DISCLAIMER: This is a WIP draft of TLS 1.3 and has not yet seen significant security analysis.

RFC EDITOR: PLEASE REMOVE THE FOLLOWING PARAGRAPH The source for this draft is maintained in GitHub. Suggested changes should be submitted as pull requests at <https://github.com/tlswg/tls13-spec>.

Instructions are on that page as well. Editorial changes can be managed in GitHub, but any substantive change should be discussed on the TLS mailing list.

The primary goal of TLS is to provide a secure channel between two communicating peers. Specifically, the channel should provide the following properties:

- Authentication: The server side of the channel is always authenticated; the client side is optionally authenticated. Authentication can happen via asymmetric cryptography (e.g., RSA [[RSA](#)], ECDSA [[ECDSA](#)]) or a pre-shared symmetric key.
- Confidentiality: Data sent over the channel is not visible to attackers.
- Integrity: Data sent over the channel cannot be modified by attackers.

These properties should be true even in the face of an attacker who has complete control of the network, as described in [[RFC3552](#)]. See [Appendix D](#) for a more complete statement of the relevant security properties.

TLS consists of two primary components:

- A handshake protocol ([Section 4](#)) that authenticates the communicating parties, negotiates cryptographic modes and parameters, and establishes shared keying material. The handshake protocol is designed to resist tampering; an active attacker should not be able to force the peers to negotiate different parameters than they would if the connection were not under attack.
- A record protocol ([Section 5](#)) that uses the parameters established by the handshake protocol to protect traffic between the communicating peers. The record protocol divides traffic up into a series of records, each of which is independently protected using the traffic keys.

TLS is application protocol independent; higher-level protocols can layer on top of TLS transparently. The TLS standard, however, does not specify how protocols add security with TLS; how to initiate TLS handshaking and how to interpret the authentication certificates exchanged are left to the judgment of the designers and implementors of protocols that run on top of TLS.

This document defines TLS version 1.3. While TLS 1.3 is not directly compatible with previous versions, all versions of TLS incorporate a versioning mechanism which allows clients and servers to interoperably negotiate a common version if one is supported.

[1.1](#). Conventions and Terminology

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 [RFC 2119](#) [[RFC2119](#)].

The following terms are used:

client: The endpoint initiating the TLS connection.

connection: A transport-layer connection between two endpoints.

endpoint: Either the client or server of the connection.

handshake: An initial negotiation between client and server that establishes the parameters of their transactions.

peer: An endpoint. When discussing a particular endpoint, "peer" refers to the endpoint that is remote to the primary subject of discussion.

receiver: An endpoint that is receiving records.

sender: An endpoint that is transmitting records.

session: An association between a client and a server resulting from a handshake.

server: The endpoint which did not initiate the TLS connection.

1.2. Major Differences from TLS 1.2

(*) indicates changes to the wire protocol which may require implementations to update.

draft-18

- Remove unnecessary `resumption_psk` which is the only thing expanded from the resumption master secret. (*).
- Fix `signature_algorithms` entry in extensions table.
- Restate rule from [RFC 6066](#) that you can't resume unless SNI is the same.

draft-17

- Remove the 0-RTT Finished, `resumption_context`, and replace with a `psk_binder` field in the PSK itself (*)
- Restructure PSK key exchange negotiation modes (*)
- Add `max_early_data_size` field to `TicketEarlyDataInfo` (*)
- Add a 0-RTT exporter and change the transcript for the regular exporter (*)
- Merge `TicketExtensions` and `Extensions` registry. Changes `ticket_early_data_info` code point (*)
- Replace `Client.key_shares` in response to HRR (*)

- Remove redundant labels for traffic key derivation (*)
- Harmonize requirements about cipher suite matching: for resumption you need to match KDF but for 0-RTT you need whole cipher suite. This allows PSKs to actually negotiate cipher suites. (*)
- Move SCT and OCSP into Certificate.extensions (*)
- Explicitly allow non-offered extensions in NewSessionTicket
- Explicitly allow predicting ClientFinished for NST
- Clarify conditions for allowing 0-RTT with PSK

[draft-16](#)

- Revise version negotiation (*)
- Change RSASSA-PSS and EdDSA SignatureScheme codepoints for better backwards compatibility (*)
- Move HelloRetryRequest.selected_group to an extension (*)
- Clarify the behavior of no exporter context and make it the same as an empty context. (*)
- New KeyUpdate format that allows for requesting/not-requesting an answer. This also means changes to the key schedule to support independent updates (*)
- New certificate_required alert (*)
- Forbid CertificateRequest with 0-RTT and PSK.
- Relax requirement to check SNI for 0-RTT.

[draft-15](#)

- New negotiation syntax as discussed in Berlin (*)
- Require CertificateRequest.context to be empty during handshake (*)
- Forbid empty tickets (*)
- Forbid application data messages in between post-handshake messages from the same flight (*)

- Clean up alert guidance (*)
- Clearer guidance on what is needed for TLS 1.2.
- Guidance on 0-RTT time windows.
- Rename a bunch of fields.
- Remove old PRNG text.
- Explicitly require checking that handshake records not span key changes.

[draft-14](#)

- Allow cookies to be longer (*)
- Remove the "context" from EarlyDataIndication as it was undefined and nobody used it (*)
- Remove 0-RTT EncryptedExtensions and replace the ticket_age extension with an obfuscated version. Also necessitates a change to NewSessionTicket (*).
- Move the downgrade sentinel to the end of ServerHello.Random to accommodate tlsdate (*).
- Define ecdsa_sha1 (*).
- Allow resumption even after fatal alerts. This matches current practice.
- Remove non-closure warning alerts. Require treating unknown alerts as fatal.
- Make the rules for accepting 0-RTT less restrictive.
- Clarify 0-RTT backward-compatibility rules.
- Clarify how 0-RTT and PSK identities interact.
- Add a section describing the data limits for each cipher.
- Major editorial restructuring.
- Replace the Security Analysis section with a WIP draft.

[draft-13](#)

- Allow server to send SupportedGroups.
- Remove 0-RTT client authentication
- Remove (EC)DHE 0-RTT.
- Flesh out 0-RTT PSK mode and shrink EarlyDataIndication
- Turn PSK-resumption response into an index to save room
- Move CertificateStatus to an extension
- Extra fields in NewSessionTicket.
- Restructure key schedule and add a resumption_context value.
- Require DH public keys and secrets to be zero-padded to the size of the group.
- Remove the redundant length fields in KeyShareEntry.
- Define a cookie field for HRR.

[draft-12](#)

- Provide a list of the PSK cipher suites.
- Remove the ability for the ServerHello to have no extensions (this aligns the syntax with the text).
- Clarify that the server can send application data after its first flight (0.5 RTT data)
- Revise signature algorithm negotiation to group hash, signature algorithm, and curve together. This is backwards compatible.
- Make ticket lifetime mandatory and limit it to a week.
- Make the purpose strings lower-case. This matches how people are implementing for interop.
- Define exporters.
- Editorial cleanup

[draft-11](#)

- Port the CFRG curves & signatures work from RFC4492bis.

- Remove sequence number and version from `additional_data`, which is now empty.
- Reorder values in `HkdfLabel`.
- Add support for version anti-downgrade mechanism.
- Update IANA considerations section and relax some of the policies.
- Unify authentication modes. Add post-handshake client authentication.
- Remove `early_handshake` content type. Terminate 0-RTT data with an alert.
- Reset sequence number upon key change (as proposed by Fournet et al.)

[draft-10](#)

- Remove `ClientCertificateTypes` field from `CertificateRequest` and add extensions.
- Merge client and server key shares into a single extension.

[draft-09](#)

- Change to RSA-PSS signatures for handshake messages.
- Remove support for DSA.
- Update key schedule per suggestions by Hugo, Hoeteck, and Bjoern Tackmann.
- Add support for per-record padding.
- Switch to encrypted record `ContentType`.
- Change HKDF labeling to include protocol version and value lengths.
- Shift the final decision to abort a handshake due to incompatible certificates to the client rather than having servers abort early.
- Deprecate SHA-1 with signatures.
- Add MTI algorithms.

[draft-08](#)

- Remove support for weak and lesser used named curves.
- Remove support for MD5 and SHA-224 hashes with signatures.
- Update lists of available AEAD cipher suites and error alerts.
- Reduce maximum permitted record expansion for AEAD from 2048 to 256 octets.
- Require digital signatures even when a previous configuration is used.
- Merge EarlyDataIndication and KnownConfiguration.
- Change code point for server_configuration to avoid collision with server_hello_done.
- Relax certificate_list ordering requirement to match current practice.

[draft-07](#)

- Integration of semi-ephemeral DH proposal.
- Add initial 0-RTT support.
- Remove resumption and replace with PSK + tickets.
- Move ClientKeyShare into an extension.
- Move to HKDF.

[draft-06](#)

- Prohibit RC4 negotiation for backwards compatibility.
- Freeze & deprecate record layer version field.
- Update format of signatures with context.
- Remove explicit IV.

[draft-05](#)

- Prohibit SSL negotiation for backwards compatibility.

- Fix which MS is used for exporters.

[draft-04](#)

- Modify key computations to include session hash.
- Remove ChangeCipherSpec.
- Renumber the new handshake messages to be somewhat more consistent with existing convention and to remove a duplicate registration.
- Remove renegotiation.
- Remove point format negotiation.

[draft-03](#)

- Remove GMT time.
- Merge in support for ECC from [RFC 4492](#) but without explicit curves.
- Remove the unnecessary length field from the AD input to AEAD ciphers.
- Rename {Client,Server}KeyExchange to {Client,Server}KeyShare.
- Add an explicit HelloRetryRequest to reject the client's.

[draft-02](#)

- Increment version number.
- Rework handshake to provide 1-RTT mode.
- Remove custom DHE groups.
- Remove support for compression.
- Remove support for static RSA and DH key exchange.
- Remove support for non-AEAD ciphers.

[1.3.](#) Updates Affecting TLS 1.2

This document defines several changes that optionally affect implementations of TLS 1.2:

- A version downgrade protection mechanism is described in [Section 4.1.3](#).
- RSASSA-PSS signature schemes are defined in [Section 4.2.3](#).

An implementation of TLS 1.3 that also supports TLS 1.2 might need to include changes to support these changes even when TLS 1.3 is not in use. See the referenced sections for more details.

2. Protocol Overview

The cryptographic parameters of the session state are produced by the TLS handshake protocol, which a TLS client and server use when first communicating to agree on a protocol version, select cryptographic algorithms, optionally authenticate each other, and establish shared secret keying material. Once the handshake is complete, the peers use the established keys to protect application layer traffic.

A failure of the handshake or other protocol error triggers the termination of the connection, optionally preceded by an alert message ([Section 6](#)).

TLS supports three basic key exchange modes:

- Diffie-Hellman (both the finite field and elliptic curve varieties),
- A pre-shared symmetric key (PSK), and
- A combination of PSK and Diffie-Hellman.

Figure 1 below shows the basic full TLS handshake:

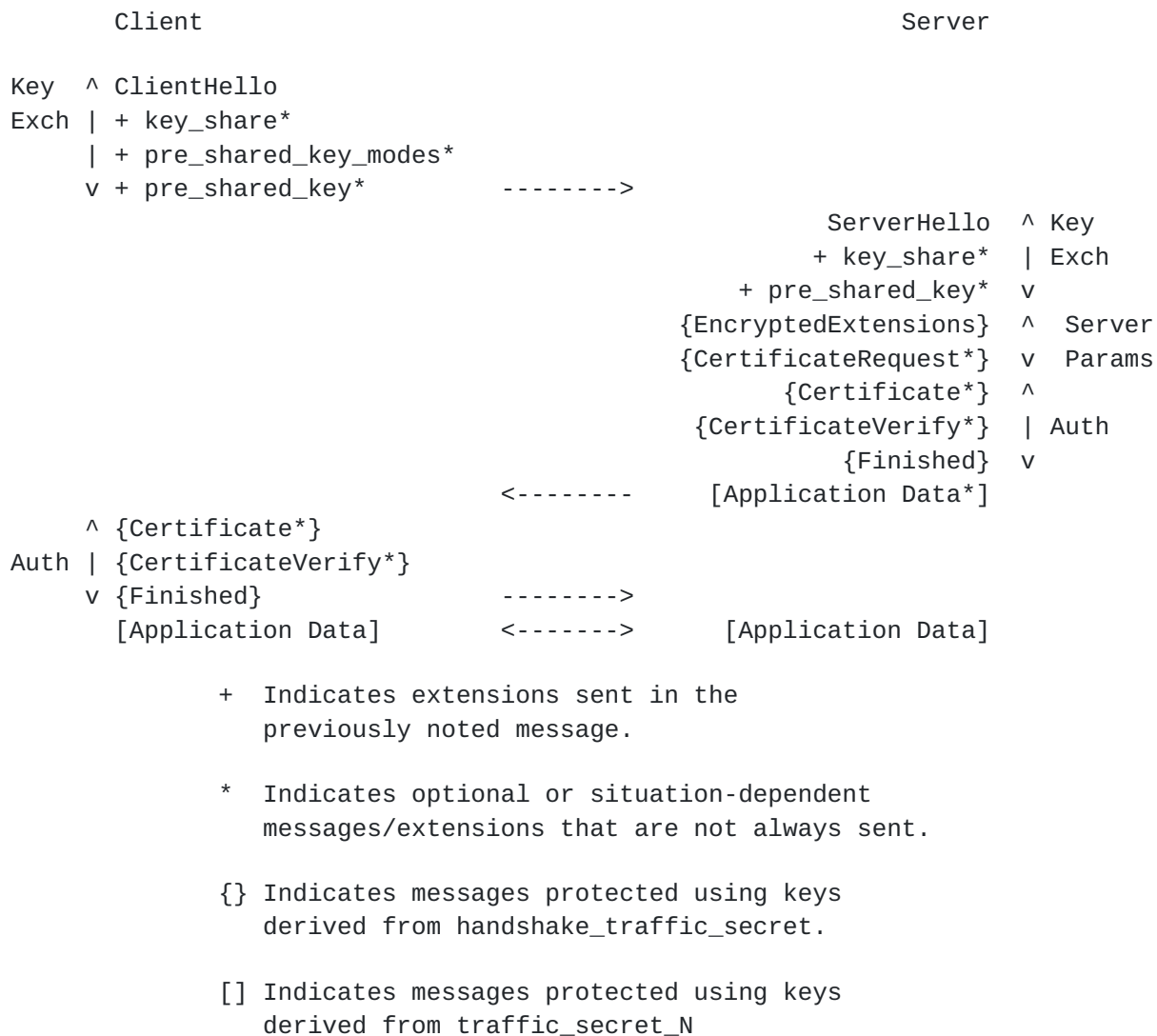


Figure 1: Message flow for full TLS Handshake

The handshake can be thought of as having three phases (indicated in the diagram above):

- Key Exchange: Establish shared keying material and select the cryptographic parameters. Everything after this phase is encrypted.
- Server Parameters: Establish other handshake parameters (whether the client is authenticated, application layer protocol support, etc.).
- Authentication: Authenticate the server (and optionally the client) and provide key confirmation and handshake integrity.

In the Key Exchange phase, the client sends the ClientHello ([Section 4.1.2](#)) message, which contains a random nonce (ClientHello.random); its offered protocol versions; a list of symmetric cipher/HKDF hash pairs; some set of Diffie-Hellman key shares (in the "key_share" extension [Section 4.2.5](#)), a set of pre-shared key labels (in the "pre_shared_key" extension [Section 4.2.6](#)) or both; and potentially some other extensions.

The server processes the ClientHello and determines the appropriate cryptographic parameters for the connection. It then responds with its own ServerHello, which indicates the negotiated connection parameters. [[Section 4.1.3](#)]. The combination of the ClientHello and the ServerHello determines the shared keys. If (EC)DHE key establishment is in use, then the ServerHello contains a "key_share" extension with the server's ephemeral Diffie-Hellman share which MUST be in the same group as one of the client's shares. If PSK key establishment is in use, then the ServerHello contains a "pre_shared_key" extension indicating which of the client's offered PSKs was selected. Note that implementations can use (EC)DHE and PSK together, in which case both extensions will be supplied.

The server then sends two messages to establish the Server Parameters:

EncryptedExtensions: responses to any extensions that are not required to determine the cryptographic parameters, other than those that are specific to individual certificates.
[[Section 4.3.1](#)]

CertificateRequest: if certificate-based client authentication is desired, the desired parameters for that certificate. This message is omitted if client authentication is not desired.
[[Section 4.3.2](#)]

Finally, the client and server exchange Authentication messages. TLS uses the same set of messages every time that authentication is needed. Specifically:

Certificate: the certificate of the endpoint and any per-certificate extensions. This message is omitted by the server if not authenticating with a certificate and by the client if the server did not send CertificateRequest (thus indicating that the client should not authenticate with a certificate). Note that if raw public keys [[RFC7250](#)] or the cached information extension [[RFC7924](#)] are in use, then this message will not contain a certificate but rather some other value corresponding to the server's long-term key. [[Section 4.4.1](#)]

CertificateVerify: a signature over the entire handshake using the public key in the Certificate message. This message is omitted if the endpoint is not authenticating via a certificate.
[[Section 4.4.2](#)]

Finished: a MAC (Message Authentication Code) over the entire handshake. This message provides key confirmation, binds the endpoint's identity to the exchanged keys, and in PSK mode also authenticates the handshake. [[Section 4.4.3](#)]

Upon receiving the server's messages, the client responds with its Authentication messages, namely Certificate and CertificateVerify (if requested), and Finished.

At this point, the handshake is complete, and the client and server may exchange application layer data. Application data MUST NOT be sent prior to sending the Finished message. Note that while the server may send application data prior to receiving the client's Authentication messages, any data sent at that point is, of course, being sent to an unauthenticated peer.

[2.1.](#) Incorrect DHE Share

If the client has not provided a sufficient "key_share" extension (e.g., it includes only DHE or ECDHE groups unacceptable or unsupported by the server), the server corrects the mismatch with a HelloRetryRequest and the client needs to restart the handshake with an appropriate "key_share" extension, as shown in Figure 2. If no common cryptographic parameters can be negotiated, the server MUST abort the handshake with an appropriate alert.



Figure 2: Message flow for a full handshake with mismatched parameters

Note: The handshake transcript includes the initial ClientHello/HelloRetryRequest exchange; it is not reset with the new ClientHello.

TLS also allows several optimized variants of the basic handshake, as described in the following sections.

2.2. Resumption and Pre-Shared Key (PSK)

Although TLS PSKs can be established out of band, PSKs can also be established in a previous session and then reused ("session resumption"). Once a handshake has completed, the server can send the client a PSK identity that corresponds to a key derived from the initial handshake (see [Section 4.5.1](#)). The client can then use that PSK identity in future handshakes to negotiate use of the PSK. If the server accepts it, then the security context of the new connection is tied to the original connection. In TLS 1.2 and below, this functionality was provided by "session IDs" and "session tickets" [[RFC5077](#)]. Both mechanisms are obsoleted in TLS 1.3.

PSKs can be used with (EC)DHE exchange in order to provide forward secrecy in combination with shared keys, or can be used alone, at the cost of losing forward secrecy.

Figure 3 shows a pair of handshakes in which the first establishes a PSK and the second uses it:

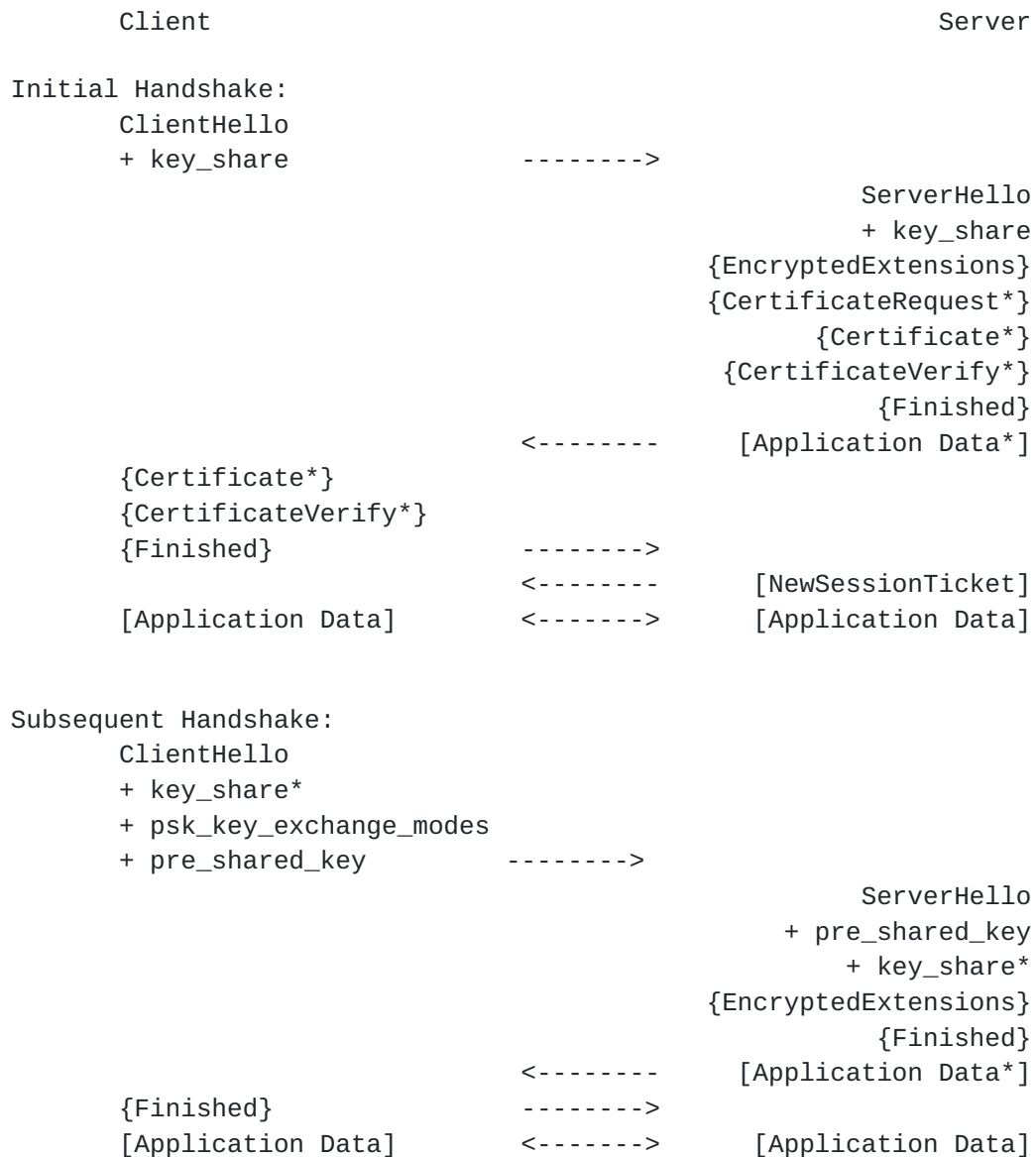


Figure 3: Message flow for resumption and PSK

As the server is authenticating via a PSK, it does not send a Certificate or a CertificateVerify message. When a client offers resumption via PSK, it SHOULD also supply a "key_share" extension to the server as well to allow the server to decline resumption and fall back to a full handshake, if needed. The server responds with a "pre_shared_key" extension to negotiate use of PSK key establishment and can (as shown here) respond with a "key_share" extension to do (EC)DHE key establishment, thus providing forward secrecy.

When PSKs are provisioned out of band, the PSK identity and the KDF to be used with the PSK MUST also be provisioned.

2.3. Zero-RTT Data

When clients and servers share a PSK (either obtained out-of-band or via a previous handshake), TLS 1.3 allows clients to send data on the first flight ("early data"). The client uses the PSK to authenticate the server and to encrypt the early data.

When clients use a PSK obtained out-of-band then the following additional information MUST be provisioned to both parties:

- The cipher suite for use with this PSK
- The Application-Layer Protocol Negotiation (ALPN) protocol, if any is to be used
- The Server Name Indication (SNI), if any is to be used

As shown in Figure 4, the Zero-RTT data is just added to the 1-RTT handshake in the first flight. The rest of the handshake uses the same messages as with a 1-RTT handshake with PSK resumption.

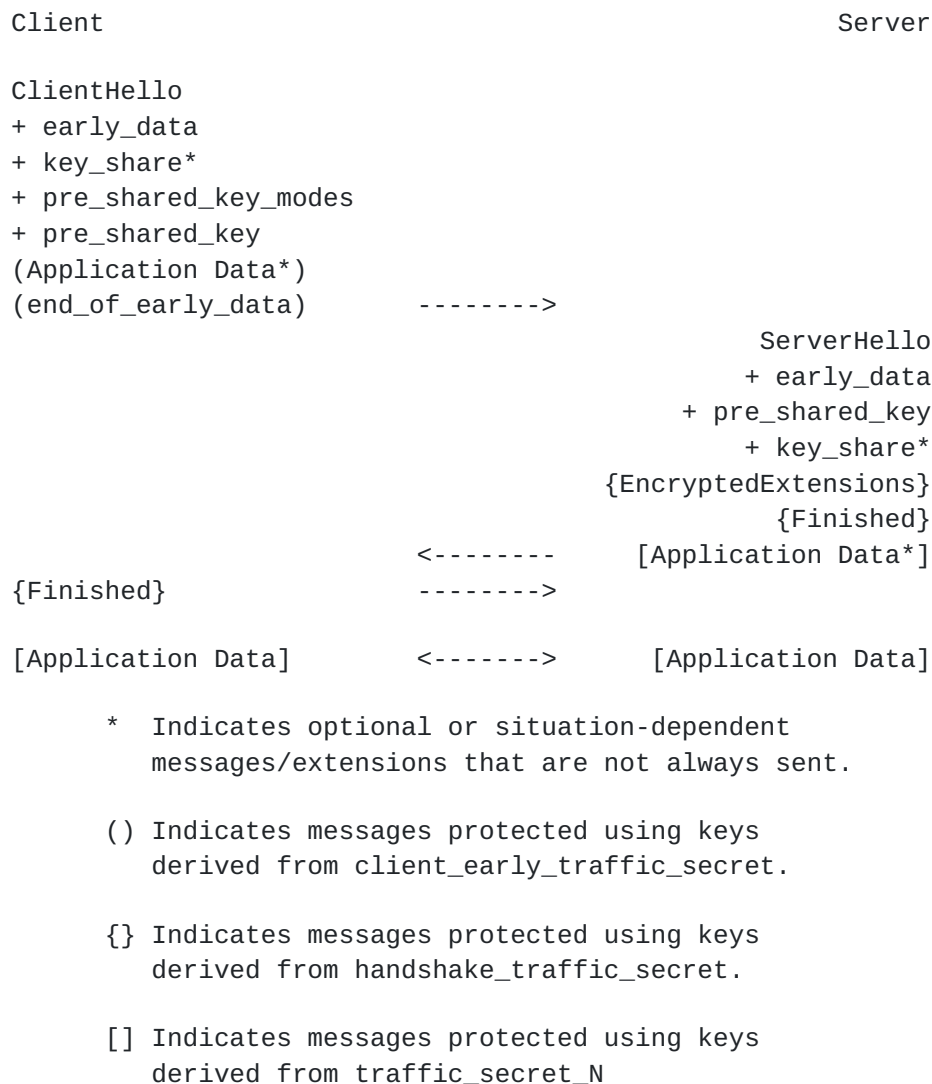


Figure 4: Message flow for a zero round trip handshake

IMPORTANT NOTE: The security properties for 0-RTT data are weaker than those for other kinds of TLS data. Specifically:

1. This data is not forward secret, as it is encrypted solely under keys derived using the offered PSK.
2. There are no guarantees of non-replay between connections. Unless the server takes special measures outside those provided by TLS, the server has no guarantee that the same 0-RTT data was not transmitted on multiple 0-RTT connections (See [Section 4.2.8.2](#) for more details). This is especially relevant if the data is authenticated either with TLS client authentication or inside the application layer protocol. However, 0-RTT data cannot be duplicated within a connection

(i.e., the server will not process the same data twice for the same connection) and an attacker will not be able to make 0-RTT data appear to be 1-RTT data (because it is protected with different keys.)

Protocols MUST NOT use 0-RTT data without a profile that defines its use. That profile needs to identify which messages or interactions are safe to use with 0-RTT. In addition, to avoid accidental misuse, implementations SHOULD NOT enable 0-RTT unless specifically requested. Special functions for 0-RTT data are RECOMMENDED to ensure that an application is always aware that it is sending or receiving data that might be replayed.

The same warnings apply to any use of the early exporter secret.

The remainder of this document provides a detailed description of TLS.

3. Presentation Language

This document deals with the formatting of data in an external representation. The following very basic and somewhat casually defined presentation syntax will be used.

3.1. Basic Block Size

The representation of all data items is explicitly specified. The basic data block size is one byte (i.e., 8 bits). Multiple byte data items are concatenations of bytes, from left to right, from top to bottom. From the byte stream, a multi-byte item (a numeric in the example) is formed (using C notation) by:

```
value = (byte[0] << 8*(n-1)) | (byte[1] << 8*(n-2)) |  
        ... | byte[n-1];
```

This byte ordering for multi-byte values is the commonplace network byte order or big-endian format.

3.2. Miscellaneous

Comments begin with "/*" and end with "*/".

Optional components are denoted by enclosing them in "[[]]" double brackets.

Single-byte entities containing uninterpreted data are of type opaque.

3.3. Vectors

A vector (single-dimensioned array) is a stream of homogeneous data elements. The size of the vector may be specified at documentation time or left unspecified until runtime. In either case, the length declares the number of bytes, not the number of elements, in the vector. The syntax for specifying a new type, *T'*, that is a fixed-length vector of type *T* is

```
T T'[n];
```

Here, *T'* occupies *n* bytes in the data stream, where *n* is a multiple of the size of *T*. The length of the vector is not included in the encoded stream.

In the following example, *Datum* is defined to be three consecutive bytes that the protocol does not interpret, while *Data* is three consecutive *Datum*, consuming a total of nine bytes.

```
opaque Datum[3];      /* three uninterpreted bytes */
Datum Data[9];        /* 3 consecutive 3 byte vectors */
```

Variable-length vectors are defined by specifying a subrange of legal lengths, inclusively, using the notation *<floor..ceiling>*. When these are encoded, the actual length precedes the vector's contents in the byte stream. The length will be in the form of a number consuming as many bytes as required to hold the vector's specified maximum (ceiling) length. A variable-length vector with an actual length field of zero is referred to as an empty vector.

```
T T'<floor..ceiling>;
```

In the following example, *mandatory* is a vector that must contain between 300 and 400 bytes of type opaque. It can never be empty. The actual length field consumes two bytes, a *uint16*, which is sufficient to represent the value 400 (see [Section 3.4](#)). On the other hand, *longer* can represent up to 800 bytes of data, or 400 *uint16* elements, and it may be empty. Its encoding will include a two-byte actual length field prepended to the vector. The length of an encoded vector must be an exact multiple of the length of a single element (e.g., a 17-byte vector of *uint16* would be illegal).

```
opaque mandatory<300..400>;
    /* length field is 2 bytes, cannot be empty */
uint16 longer<0..800>;
    /* zero to 400 16-bit unsigned integers */
```


3.4. Numbers

The basic numeric data type is an unsigned byte (uint8). All larger numeric data types are formed from fixed-length series of bytes concatenated as described in [Section 3.1](#) and are also unsigned. The following numeric types are predefined.

```
uint8 uint16[2];
uint8 uint24[3];
uint8 uint32[4];
uint8 uint64[8];
```

All values, here and elsewhere in the specification, are stored in network byte (big-endian) order; the uint32 represented by the hex bytes 01 02 03 04 is equivalent to the decimal value 16909060.

3.5. Enumerateds

An additional sparse data type is available called enum. Each definition is a different type. Only enumerateds of the same type may be assigned or compared. Every element of an enumerated must be assigned a value, as demonstrated in the following example. Since the elements of the enumerated are not ordered, they can be assigned any unique value, in any order.

```
enum { e1(v1), e2(v2), ... , en(vn) [, (n)] } Te;
```

Future extension or additions to the protocol may define new values. Implementations need to be able to parse and ignore unknown values unless the definition of the field states otherwise.

An enumerated occupies as much space in the byte stream as would its maximal defined ordinal value. The following definition would cause one byte to be used to carry fields of type Color.

```
enum { red(3), blue(5), white(7) } Color;
```

One may optionally specify a value without its associated tag to force the width definition without defining a superfluous element.

In the following example, Taste will consume two bytes in the data stream but can only assume the values 1, 2, or 4 in current version of protocol.

```
enum { sweet(1), sour(2), bitter(4), (32000) } Taste;
```

The names of the elements of an enumeration are scoped within the defined type. In the first example, a fully qualified reference to

the second element of the enumeration would be `Color.blue`. Such qualification is not required if the target of the assignment is well specified.

```
Color color = Color.blue;    /* overspecified, legal */
Color color = blue;          /* correct, type implicit */
```

The names assigned to enumerations do not need to be unique. The numerical value can describe a range over which the same name applies. The value includes the minimum and maximum inclusive values in that range, separated by two period characters. This is principally useful for reserving regions of the space.

```
enum { sad(0), meh(1..254), happy(255) } Mood;
```

3.6. Constructed Types

Structure types may be constructed from primitive types for convenience. Each specification declares a new, unique type. The syntax for definition is much like that of C.

```
struct {
    T1 f1;
    T2 f2;
    ...
    Tn fn;
} [[T]];
```

The fields within a structure may be qualified using the type's name, with a syntax much like that available for enumerations. For example, `T.f2` refers to the second field of the previous declaration. Structure definitions may be embedded. Anonymous structs may also be defined inside other structures.

3.7. Constants

Fields and variables may be assigned a fixed value using "=", as in:

```
struct {
    T1 f1 = 8; /* T.f1 must always be 8 */
    T2 f2;
} T;
```

3.8. Variants

Defined structures may have variants based on some knowledge that is available within the environment. The selector must be an enumerated type that defines the possible variants the structure defines. There

must be a case arm for every element of the enumeration declared in the select. Case arms have limited fall-through: if two case arms follow in immediate succession with no fields in between, then they both contain the same fields. Thus, in the example below, "orange" and "banana" both contain V2. Note that this piece of syntax was added in TLS 1.2 [[RFC5246](#)]. Each case arm can have one or more fields.

The body of the variant structure may be given a label for reference. The mechanism by which the variant is selected at runtime is not prescribed by the presentation language.

```
struct {  
    T1 f1;  
    T2 f2;  
    ....  
    Tn fn;  
    select (E) {  
        case e1: Te1;  
        case e2: Te21;  
                Te22;  
        case e3: case e4: Te3;  
        ....  
        case en: Ten;  
    } [[fv]];  
} [[Tv]];
```

For example:


```
enum { apple(0), orange(1), banana(2) } VariantTag;

struct {
    uint16 number;
    opaque string<0..10>; /* variable length */
} V1;

struct {
    uint32 number;
    opaque string[10];    /* fixed length */
} V2;

struct {
    select (VariantTag) {
        case apple:
            V1; /* VariantBody, tag = apple */
        case orange:
        case banana:
            V2; /* VariantBody, tag = orange or banana */
    } variant_body;      /* optional label on variant */
} VariantRecord;
```

3.9. Decoding Errors

TLS defines two generic alerts (see [Section 6](#)) to use upon failure to parse a message. Peers which receive a message which cannot be parsed according to the syntax (e.g., have a length extending beyond the message boundary or contain an out-of-range length) MUST terminate the connection with a "decode_error" alert. Peers which receive a message which is syntactically correct but semantically invalid (e.g., a DHE share of $p - 1$, or an invalid enum) MUST terminate the connection with an "illegal_parameter" alert.

4. Handshake Protocol

The handshake protocol is used to negotiate the secure attributes of a session. Handshake messages are supplied to the TLS record layer, where they are encapsulated within one or more TLSPlaintext or TLSCiphertext structures, which are processed and transmitted as specified by the current active session state.


```
enum {
    client_hello(1),
    server_hello(2),
    new_session_ticket(4),
    hello_retry_request(6),
    encrypted_extensions(8),
    certificate(11),
    certificate_request(13),
    certificate_verify(15),
    finished(20),
    key_update(24),
    (255)
} HandshakeType;

struct {
    HandshakeType msg_type;      /* handshake type */
    uint24 length;              /* bytes in message */
    select (Handshake.msg_type) {
        case client_hello:      ClientHello;
        case server_hello:      ServerHello;
        case hello_retry_request: HelloRetryRequest;
        case encrypted_extensions: EncryptedExtensions;
        case certificate_request: CertificateRequest;
        case certificate:        Certificate;
        case certificate_verify: CertificateVerify;
        case finished:           Finished;
        case new_session_ticket: NewSessionTicket;
        case key_update:         KeyUpdate;
    } body;
} Handshake;
```

Protocol messages MUST be sent in the order defined below (and shown in the diagrams in [Section 2](#)). A peer which receives a handshake message in an unexpected order MUST abort the handshake with an "unexpected_message" alert. Unneeded handshake messages are omitted, however.

New handshake message types are assigned by IANA as described in [Section 10](#).

4.1. Key Exchange Messages

The key exchange messages are used to exchange security capabilities between the client and server and to establish the traffic keys used to protect the handshake and data.

4.1.1.1. Cryptographic Negotiation

TLS cryptographic negotiation proceeds by the client offering the following four sets of options in its ClientHello:

- A list of cipher suites which indicates the AEAD algorithm/HKDF hash pairs which the client supports.
- A "supported_groups" ([Section 4.2.4](#)) extension which indicates the (EC)DHE groups which the client supports and a "key_share" ([Section 4.2.5](#)) extension which contains (EC)DHE shares for some or all of these groups.
- A "signature_algorithms" ([Section 4.2.3](#)) extension which indicates the signature algorithms which the client can accept.
- A "pre_shared_key" ([Section 4.2.6](#)) extension which contains a list of symmetric key identities known to the client and a "psk_key_exchange_modes" ([Section 4.2.7](#)) extension which indicates the key exchange modes that may be used with PSKs.

If the server does not select a PSK, then the first three of these options are entirely orthogonal: the server independently selects a cipher suite, an (EC)DHE group and key share for key establishment, and a signature algorithm/certificate pair to authenticate itself to the client. If there is overlap in the "supported_groups" extension but the client did not offer a compatible "key_share" extension, then the server will respond with a HelloRetryRequest ([Section 4.1.4](#)) message. If there is no overlap in "supported_groups" then the server MUST abort the handshake.

If the server selects a PSK, then it MUST also select a key establishment mode from the set indicated by client's "psk_key_exchange_modes" extension (PSK alone or with (EC)DHE). Note that if the PSK can be used without (EC)DHE then non-overlap in the "supported_groups" parameters need not be fatal.

The server indicates its selected parameters in the ServerHello as follows:

- If PSK is being used then the server will send a "pre_shared_key" extension indicating the selected key.
- If PSK is not being used, then (EC)DHE and certificate-based authentication are always used.
- When (EC)DHE is in use, the server will also provide a "key_share" extension.

- When authenticating via a certificate (i.e., when a PSK is not in use), the server will send the Certificate ([Section 4.4.1](#)) and CertificateVerify ([Section 4.4.2](#)) messages.

If the server is unable to negotiate a supported set of parameters (i.e., there is no overlap between the client and server parameters), it MUST abort the handshake with either a "handshake_failure" or "insufficient_security" fatal alert (see [Section 6](#)).

[4.1.2](#). Client Hello

When a client first connects to a server, it is REQUIRED to send the ClientHello as its first message. The client will also send a ClientHello when the server has responded to its ClientHello with a HelloRetryRequest. In that case, the client MUST send the same ClientHello (without modification) except:

- If a "key_share" extension was supplied in the HelloRetryRequest, replacing the list of shares with a list containing a single KeyShareEntry from the indicated group.
- Removing the "early_data" extension ([Section 4.2.8](#)) if one was present. Early data is not permitted after HelloRetryRequest.
- Including a "cookie" extension if one was provided in the HelloRetryRequest.

Because TLS 1.3 forbids renegotiation, if a server receives a ClientHello at any other time, it MUST terminate the connection.

If a server established a TLS connection with a previous version of TLS and receives a TLS 1.3 ClientHello in a renegotiation, it MUST retain the previous protocol version. In particular, it MUST NOT negotiate TLS 1.3. A client that receives a TLS 1.3 ServerHello during renegotiation MUST abort the handshake with a "protocol_version" alert.

Structure of this message:


```
uint16 ProtocolVersion;
opaque Random[32];

uint8 CipherSuite[2];    /* Cryptographic suite selector */

struct {
    ProtocolVersion legacy_version = 0x0303;    /* TLS v1.2 */
    Random random;
    opaque legacy_session_id<0..32>;
    CipherSuite cipher_suites<2..2^16-2>;
    opaque legacy_compression_methods<1..2^8-1>;
    Extension extensions<0..2^16-1>;
} ClientHello;
```

TLS allows extensions to follow the `compression_methods` field in an extensions block. The presence of extensions can be detected by determining whether there are bytes following the `compression_methods` at the end of the `ClientHello`. Note that this method of detecting optional data differs from the normal TLS method of having a variable-length field, but it is used for compatibility with TLS before extensions were defined. As of TLS 1.3, all clients and servers will send at least one extension (at least "key_share" or "pre_shared_key").

legacy_version In previous versions of TLS, this field was used for version negotiation and represented the highest version number supported by the client. Experience has shown that many servers do not properly implement version negotiation, leading to "version intolerance" in which the server rejects an otherwise acceptable `ClientHello` with a version number higher than it supports. In TLS 1.3, the client indicates its version preferences in the "supported_versions" extension ([Section 4.2.1](#)) and this field **MUST** be set to 0x0303, which was the version number for TLS 1.2. (See [Appendix C](#) for details about backward compatibility.)

random 32 bytes generated by a secure random number generator. See [Appendix B](#) for additional information.

legacy_session_id Versions of TLS before TLS 1.3 supported a session resumption feature which has been merged with Pre-Shared Keys in this version (see [Section 2.2](#)). This field **MUST** be ignored by a server negotiating TLS 1.3 and **MUST** be set as a zero length vector (i.e., a single zero byte length field) by clients which do not have a cached session ID set by a pre-TLS 1.3 server.

cipher_suites This is a list of the symmetric cipher options supported by the client, specifically the record protection algorithm (including secret key length) and a hash to be used with

HKDF, in descending order of client preference. If the list contains cipher suites the server does not recognize, support, or wish to use, the server MUST ignore those cipher suites, and process the remaining ones as usual. Values are defined in [Appendix A.4](#).

legacy_compression_methods Versions of TLS before 1.3 supported compression with the list of supported compression methods being sent in this field. For every TLS 1.3 ClientHello, this vector MUST contain exactly one byte set to zero, which corresponds to the "null" compression method in prior versions of TLS. If a TLS 1.3 ClientHello is received with any other value in this field, the server MUST abort the handshake with an "illegal_parameter" alert. Note that TLS 1.3 servers might receive TLS 1.2 or prior ClientHellos which contain other compression methods and MUST follow the procedures for the appropriate prior version of TLS.

extensions Clients request extended functionality from servers by sending data in the extensions field. The actual "Extension" format is defined in [Section 4.2](#).

In the event that a client requests additional functionality using extensions, and this functionality is not supplied by the server, the client MAY abort the handshake. Note that TLS 1.3 ClientHello messages always contain extensions (minimally they must contain "supported_versions" or they will be interpreted as TLS 1.2 ClientHello messages). TLS 1.3 servers may receive TLS 1.2 ClientHello messages without extensions. If negotiating TLS 1.2, a server MUST check that the message either contains no data after legacy_compression_methods or that it contains a valid extensions block with no data following. If not, then it MUST abort the handshake with a "decode_error" alert.

After sending the ClientHello message, the client waits for a ServerHello or HelloRetryRequest message.

[4.1.3](#). Server Hello

The server will send this message in response to a ClientHello message when it was able to find an acceptable set of algorithms and the client's "key_share" extension was acceptable. If it is not able to find an acceptable set of parameters, the server will respond with a "handshake_failure" fatal alert.

Structure of this message:


```
struct {  
    ProtocolVersion version;  
    Random random;  
    CipherSuite cipher_suite;  
    Extension extensions<0..2^16-1>;  
} ServerHello;
```

version This field contains the version of TLS negotiated for this session. Servers MUST select a version from the list in ClientHello.supported_versions extension. A client which receives a version that was not offered MUST abort the handshake. For this version of the specification, the version is 0x0304. (See [Appendix C](#) for details about backward compatibility.)

random This structure is generated by the server and MUST be generated independently of the ClientHello.random.

cipher_suite The single cipher suite selected by the server from the list in ClientHello.cipher_suites. A client which receives a cipher suite that was not offered MUST abort the handshake.

extensions A list of extensions. The ServerHello MUST only include extensions which are required to establish the cryptographic context. Currently the only such extensions are "key_share" and "pre_shared_key".

TLS 1.3 has a downgrade protection mechanism embedded in the server's random value. TLS 1.3 server implementations which respond to a ClientHello indicating only support for TLS 1.2 or below MUST set the last eight bytes of their Random value to the bytes:

```
44 4F 57 4E 47 52 44 01
```

TLS 1.3 server implementations which respond to a ClientHello indicating only support for TLS 1.1 or below SHOULD set the last eight bytes of their Random value to the bytes:

```
44 4F 57 4E 47 52 44 00
```

TLS 1.3 clients receiving a TLS 1.2 or below ServerHello MUST check that the last eight octets are not equal to either of these values. TLS 1.2 clients SHOULD also perform this check if the ServerHello indicates TLS 1.1 or below. If a match is found, the client MUST abort the handshake with an "illegal_parameter" alert. This mechanism provides limited protection against downgrade attacks over and above that provided by the Finished exchange: because the ServerKeyExchange includes a signature over both random values, it is not possible for an active attacker to modify the randoms without

detection as long as ephemeral ciphers are used. It does not provide downgrade protection when static RSA is used.

Note: This is an update to TLS 1.2 so in practice many TLS 1.2 clients and servers will not behave as specified above.

RFC EDITOR: PLEASE REMOVE THE FOLLOWING PARAGRAPH Implementations of draft versions (see [Section 4.2.1.1](#)) of this specification SHOULD NOT implement this mechanism on either client and server. A pre-RFC client connecting to RFC servers, or vice versa, will appear to downgrade to TLS 1.2. With the mechanism enabled, this will cause an interoperability failure.

[4.1.4.](#) Hello Retry Request

Servers send this message in response to a ClientHello message if they were able to find an acceptable set of algorithms and groups that are mutually supported, but the client's ClientHello did not contain sufficient information to proceed with the handshake. If a server cannot successfully select algorithms, it MUST abort the handshake with a "handshake_failure" alert.

Structure of this message:

```
struct {  
    ProtocolVersion server_version;  
    Extension extensions<2..2^16-1>;  
} HelloRetryRequest;
```

The version and extensions fields have the same meanings as their corresponding values in the ServerHello. The server SHOULD send only the extensions necessary for the client to generate a correct ClientHello pair. As with ServerHello, a HelloRetryRequest MUST NOT contain any extensions that were not first offered by the client in its ClientHello, with the exception of optionally the "cookie" (see [Section 4.2.2](#)) extension.

Upon receipt of a HelloRetryRequest, the client MUST verify that the extensions block is not empty and otherwise MUST abort the handshake with a "decode_error" alert. Clients MUST abort the handshake with an "illegal_parameter" alert if the HelloRetryRequest would not result in any change in the ClientHello. If a client receives a second HelloRetryRequest in the same connection (i.e., where the ClientHello was itself in response to a HelloRetryRequest), it MUST abort the handshake with an "unexpected_message" alert.

Otherwise, the client MUST process all extensions in the HelloRetryRequest and send a second updated ClientHello. The HelloRetryRequest extensions defined in this specification are:

- cookie (see [Section 4.2.2](#))
- key_share (see [Section 4.2.5](#))

[4.2.](#) Extensions

A number of TLS messages contain tag-length-value encoded extensions structures.

```
struct {
    ExtensionType extension_type;
    opaque extension_data<0..2^16-1>;
} Extension;

enum {
    supported_groups(10),
    signature_algorithms(13),
    key_share(40),
    pre_shared_key(41),
    early_data(42),
    supported_versions(43),
    cookie(44),
    psk_key_exchange_modes(45),
    ticket_early_data_info(46),
    (65535)
} ExtensionType;
```

Here:

- "extension_type" identifies the particular extension type.
- "extension_data" contains information specific to the particular extension type.

The list of extension types is maintained by IANA as described in [Section 10](#).

The client sends its extensions in the ClientHello. The server MAY send extensions in the ServerHello, EncryptedExtensions, Certificate, and HelloRetryRequest messages. The NewSessionTicket also allows the server to send extensions to the client though these are not directly associated with the extensions in the ClientHello. The table in [Section 10](#) indicates where a given extension may appear. If the client receives an extension which is not specified for a given

message it MUST abort the handshake with an "illegal_parameter" alert.

The server MUST NOT send any extensions which did not appear in the corresponding ClientHello, with the exception of the NewSessionTicket message and the "cookie" extension in the HelloRetryRequest message. Upon receiving an unexpected extension, it MUST abort the handshake with an "unsupported_extension" alert. Server-oriented extensions are supported by having the client send an extension with zero-length extension_data indicating support for that extension type.

When multiple extensions of different types are present, the extensions MAY appear in any order, with the exception of "pre_shared_key" [Section 4.2.6](#) which MUST be the last extension in the ClientHello. There MUST NOT be more than one extension of the same type.

In TLS 1.3, unlike TLS 1.2, extensions are renegotiated with each handshake even when in resumption-PSK mode. However, 0-RTT parameters are those negotiated in the previous handshake; mismatches may require rejecting 0-RTT (see [Section 4.2.8](#)).

There are subtle (and not so subtle) interactions that may occur in this protocol between new features and existing features which may result in a significant reduction in overall security. The following considerations should be taken into account when designing new extensions:

- Some cases where a server does not agree to an extension are error conditions, and some are simply refusals to support particular features. In general, error alerts should be used for the former, and a field in the server extension response for the latter.
- Extensions should, as far as possible, be designed to prevent any attack that forces use (or non-use) of a particular feature by manipulation of handshake messages. This principle should be followed regardless of whether the feature is believed to cause a security problem. Often the fact that the extension fields are included in the inputs to the Finished message hashes will be sufficient, but extreme care is needed when the extension changes the meaning of messages sent in the handshake phase. Designers and implementors should be aware of the fact that until the handshake has been authenticated, active attackers can modify messages and insert, remove, or replace extensions.

[4.2.1.](#) Supported Versions

```
struct {  
    ProtocolVersion versions<2..254>;  
} SupportedVersions;
```

The "supported_versions" extension is used by the client to indicate which versions of TLS it supports. The extension contains a list of supported versions in preference order, with the most preferred version first. Implementations of this specification MUST send this extension containing all versions of TLS which they are prepared to negotiate (for this specification, that means minimally 0x0304, but if previous versions of TLS are supported, they MUST be present as well).

Servers which are compliant with this specification MUST use only the "supported_versions" extension, if present, to determine client preferences and MUST only select a version of TLS present in that extension. They MUST ignore any unknown versions. If the extension is not present, they MUST negotiate TLS 1.2 or prior as specified in [\[RFC5246\]](#), even if ClientHello.legacy_version is 0x0304 or later.

The server MUST NOT send the "supported_versions" extension. The server's selected version is contained in the ServerHello.version field as in previous versions of TLS.

[4.2.1.1.](#) Draft Version Indicator

RFC EDITOR: PLEASE REMOVE THIS SECTION

While the eventual version indicator for the RFC version of TLS 1.3 will be 0x0304, implementations of draft versions of this specification SHOULD instead advertise 0x7f00 | draft_version in ServerHello.version, and HelloRetryRequest.server_version. For instance, [draft-17](#) would be encoded as the 0x7f11. This allows pre-RFC implementations to safely negotiate with each other, even if they would otherwise be incompatible.

[4.2.2.](#) Cookie

```
struct {  
    opaque cookie<1..2^16-1>;  
} Cookie;
```

Cookies serve two primary purposes:

- Allowing the server to force the client to demonstrate reachability at their apparent network address (thus providing a

measure of DoS protection). This is primarily useful for non-connection-oriented transports (see [[RFC6347](#)] for an example of this).

- Allowing the server to offload state to the client, thus allowing it to send a HelloRetryRequest without storing any state. The server does this by pickling that post-ClientHello hash state into the cookie (protected with some suitable integrity algorithm).

When sending a HelloRetryRequest, the server MAY provide a "cookie" extension to the client (this is an exception to the usual rule that the only extensions that may be sent are those that appear in the ClientHello). When sending the new ClientHello, the client MUST echo the value of the extension. Clients MUST NOT use cookies in subsequent connections.

4.2.3. Signature Algorithms

The client uses the "signature_algorithms" extension to indicate to the server which signature algorithms may be used in digital signatures. Clients which desire the server to authenticate itself via a certificate MUST send this extension. If a server is authenticating via a certificate and the client has not sent a "signature_algorithms" extension then the server MUST abort the handshake with a "missing_extension" alert (see [Section 8.2](#)).

The "extension_data" field of this extension in a ClientHello contains a SignatureSchemeList value:


```
enum {
    /* RSASSA-PKCS1-v1_5 algorithms */
    rsa_pkcs1_sha1 (0x0201),
    rsa_pkcs1_sha256 (0x0401),
    rsa_pkcs1_sha384 (0x0501),
    rsa_pkcs1_sha512 (0x0601),

    /* ECDSA algorithms */
    ecdsa_secp256r1_sha256 (0x0403),
    ecdsa_secp384r1_sha384 (0x0503),
    ecdsa_secp521r1_sha512 (0x0603),

    /* RSASSA-PSS algorithms */
    rsa_pss_sha256 (0x0804),
    rsa_pss_sha384 (0x0805),
    rsa_pss_sha512 (0x0806),

    /* EdDSA algorithms */
    ed25519 (0x0807),
    ed448 (0x0808),

    /* Reserved Code Points */
    private_use (0xFE00..0xFFFF),
    (0xFFFF)
} SignatureScheme;

struct {
    SignatureScheme supported_signature_algorithms<2..2^16-2>;
} SignatureSchemeList;
```

Note: This enum is named "SignatureScheme" because there is already a "SignatureAlgorithm" type in TLS 1.2, which this replaces. We use the term "signature algorithm" throughout the text.

Each SignatureScheme value lists a single signature algorithm that the client is willing to verify. The values are indicated in descending order of preference. Note that a signature algorithm takes as input an arbitrary-length message, rather than a digest. Algorithms which traditionally act on a digest should be defined in TLS to first hash the input with a specified hash algorithm and then proceed as usual. The code point groups listed above have the following meanings:

RSASSA-PKCS1-v1_5 algorithms Indicates a signature algorithm using RSASSA-PKCS1-v1_5 [RFC3447] with the corresponding hash algorithm as defined in [SHS]. These values refer solely to signatures which appear in certificates (see [Section 4.4.1.2](#)) and are not defined for use in signed TLS handshake messages.

ECDSA algorithms Indicates a signature algorithm using ECDSA [[ECDSA](#)], the corresponding curve as defined in ANSI X9.62 [[X962](#)] and FIPS 186-4 [[DSS](#)], and the corresponding hash algorithm as defined in [[SHS](#)]. The signature is represented as a DER-encoded [[X690](#)] ECDSA-Sig-Value structure.

RSASSA-PSS algorithms Indicates a signature algorithm using RSASSA-PSS [[RFC3447](#)] with MGF1. The digest used in the mask generation function and the digest being signed are both the corresponding hash algorithm as defined in [[SHS](#)]. When used in signed TLS handshake messages, the length of the salt MUST be equal to the length of the digest output. This codepoint is defined for use with TLS 1.2 as well as TLS 1.3.

EdDSA algorithms Indicates a signature algorithm using EdDSA as defined in [[I-D.irtf-cfrg-eddsa](#)] or its successors. Note that these correspond to the "PureEdDSA" algorithms and not the "prehash" variants.

rsa_pkcs1_sha1, dsa_sha1, and ecdsa_sha1 SHOULD NOT be offered. Clients offering these values for backwards compatibility MUST list them as the lowest priority (listed after all other algorithms in SignatureSchemeList). TLS 1.3 servers MUST NOT offer a SHA-1 signed certificate unless no valid certificate chain can be produced without it (see [Section 4.4.1.2](#)).

The signatures on certificates that are self-signed or certificates that are trust anchors are not validated since they begin a certification path (see [[RFC5280](#)], [Section 3.2](#)). A certificate that begins a certification path MAY use a signature algorithm that is not advertised as being supported in the "signature_algorithms" extension.

Note that TLS 1.2 defines this extension differently. TLS 1.3 implementations willing to negotiate TLS 1.2 MUST behave in accordance with the requirements of [[RFC5246](#)] when negotiating that version. In particular:

- TLS 1.2 ClientHellos MAY omit this extension.
- In TLS 1.2, the extension contained hash/signature pairs. The pairs are encoded in two octets, so SignatureScheme values have been allocated to align with TLS 1.2's encoding. Some legacy pairs are left unallocated. These algorithms are deprecated as of TLS 1.3. They MUST NOT be offered or negotiated by any implementation. In particular, MD5 [[SLOTH](#)] and SHA-224 MUST NOT be used.

- ECDSA signature schemes align with TLS 1.2's ECDSA hash/signature pairs. However, the old semantics did not constrain the signing curve. If TLS 1.2 is negotiated, implementations MUST be prepared to accept a signature that uses any curve that they advertised in the "supported_groups" extension.
- Implementations that advertise support for RSASSA-PSS (which is mandatory in TLS 1.3), MUST be prepared to accept a signature using that scheme even when TLS 1.2 is negotiated. In TLS 1.2, RSASSA-PSS is used with RSA cipher suites.

4.2.4. Negotiated Groups

When sent by the client, the "supported_groups" extension indicates the named groups which the client supports for key exchange, ordered from most preferred to least preferred.

Note: In versions of TLS prior to TLS 1.3, this extension was named "elliptic_curves" and only contained elliptic curve groups. See [\[RFC4492\]](#) and [\[RFC7919\]](#). This extension was also used to negotiate ECDSA curves. Signature algorithms are now negotiated independently (see [Section 4.2.3](#)).

The "extension_data" field of this extension contains a "NamedGroupList" value:

```
enum {  
    /* Elliptic Curve Groups (ECDHE) */  
    secp256r1 (23), secp384r1 (24), secp521r1 (25),  
    x25519 (29), x448 (30),  
  
    /* Finite Field Groups (DHE) */  
    ffdhe2048 (256), ffdhe3072 (257), ffdhe4096 (258),  
    ffdhe6144 (259), ffdhe8192 (260),  
  
    /* Reserved Code Points */  
    ffdhe_private_use (0x01FC..0x01FF),  
    ecdhe_private_use (0xFE00..0xFEFF),  
    (0xFFFF)  
} NamedGroup;  
  
struct {  
    NamedGroup named_group_list<2..2^16-1>;  
} NamedGroupList;
```

Elliptic Curve Groups (ECDHE) Indicates support of the corresponding named curve, defined either in FIPS 186-4 [\[DSS\]](#) or in [\[RFC7748\]](#). Values 0xFE00 through 0xFEFF are reserved for private use.

Finite Field Groups (DHE) Indicates support of the corresponding finite field group, defined in [[RFC7919](#)]. Values 0x01FC through 0x01FF are reserved for private use.

Items in `named_group_list` are ordered according to the client's preferences (most preferred choice first).

As of TLS 1.3, servers are permitted to send the "supported_groups" extension to the client. If the server has a group it prefers to the ones in the "key_share" extension but is still willing to accept the ClientHello, it SHOULD send "supported_groups" to update the client's view of its preferences; this extension SHOULD contain all groups the server supports, regardless of whether they are currently supported by the client. Clients MUST NOT act upon any information found in "supported_groups" prior to successful completion of the handshake, but MAY use the information learned from a successfully completed handshake to change what groups they use in their "key_share" extension in subsequent connections.

[4.2.5](#). Key Share

The "key_share" extension contains the endpoint's cryptographic parameters.

Clients MAY send an empty `client_shares` vector in order to request group selection from the server at the cost of an additional round trip. (see [Section 4.1.4](#))

```
struct {  
    NamedGroup group;  
    opaque key_exchange<1..2^16-1>;  
} KeyShareEntry;
```

`group` The named group for the key being exchanged. Finite Field Diffie-Hellman [[DH](#)] parameters are described in [Section 4.2.5.1](#); Elliptic Curve Diffie-Hellman parameters are described in [Section 4.2.5.2](#).

`key_exchange` Key exchange information. The contents of this field are determined by the specified group and its corresponding definition. Endpoints MUST NOT send empty or otherwise invalid `key_exchange` values for any reason.

The "extension_data" field of this extension contains a "KeyShare" value:


```
struct {  
    select (Handshake.msg_type) {  
        case client_hello:  
            KeyShareEntry client_shares<0..2^16-1>;  
  
        case hello_retry_request:  
            NamedGroup selected_group;  
  
        case server_hello:  
            KeyShareEntry server_share;  
    };  
} KeyShare;
```

client_shares A list of offered KeyShareEntry values in descending order of client preference. This vector MAY be empty if the client is requesting a HelloRetryRequest. The ordering of values here SHOULD match that of the ordering of offered support in the "supported_groups" extension.

selected_group The mutually supported group the server intends to negotiate and is requesting a retried ClientHello/KeyShare for.

server_share A single KeyShareEntry value that is in the same group as one of the client's shares.

Clients offer an arbitrary number of KeyShareEntry values, each representing a single set of key exchange parameters. For instance, a client might offer shares for several elliptic curves or multiple FFDHE groups. The key_exchange values for each KeyShareEntry MUST be generated independently. Clients MUST NOT offer multiple KeyShareEntry values for the same group. Clients MUST NOT offer any KeyShareEntry values for groups not listed in the client's "supported_groups" extension. Servers MAY check for violations of these rules and abort the handshake with an "illegal_parameter" alert if one is violated.

Upon receipt of this extension in a HelloRetryRequest, the client MUST verify that (1) the selected_group field corresponds to a group which was provided in the "supported_groups" extension in the original ClientHello; and (2) the selected_group field does not correspond to a group which was provided in the "key_share" extension in the original ClientHello. If either of these checks fails, then the client MUST abort the handshake with an "illegal_parameter" alert. Otherwise, when sending the new ClientHello, the client MUST replace the original "key_share" extension with one containing only a new KeyShareEntry for the group indicated in the selected_group field.

If using (EC)DHE key establishment, servers offer exactly one KeyShareEntry in the ServerHello. This value MUST correspond to the KeyShareEntry value offered by the client that the server has selected for the negotiated key exchange. Servers MUST NOT send a KeyShareEntry for any group not indicated in the "supported_groups" extension. If a HelloRetryRequest was received, the client MUST verify that the selected NamedGroup matches that supplied in the selected_group field and MUST abort the handshake with an "illegal_parameter" alert if it does not.

4.2.5.1. Diffie-Hellman Parameters

Diffie-Hellman [DH] parameters for both clients and servers are encoded in the opaque key_exchange field of a KeyShareEntry in a KeyShare structure. The opaque value contains the Diffie-Hellman public value ($Y = g^X \bmod p$) for the specified group (see [RFC7919] for group definitions) encoded as a big-endian integer, padded with zeros to the size of p in bytes.

Note: For a given Diffie-Hellman group, the padding results in all public keys having the same length.

Peers SHOULD validate each other's public key Y by ensuring that $1 < Y < p-1$. This check ensures that the remote peer is properly behaved and isn't forcing the local system into a small subgroup.

4.2.5.2. ECDHE Parameters

ECDHE parameters for both clients and servers are encoded in the the opaque key_exchange field of a KeyShareEntry in a KeyShare structure.

For secp256r1, secp384r1 and secp521r1, the contents are the byte string representation of an elliptic curve public value following the conversion routine in [Section 4.3.6](#) of ANSI X9.62 [X962].

Although X9.62 supports multiple point formats, any given curve MUST specify only a single point format. All curves currently specified in this document MUST only be used with the uncompressed point format (the format for all ECDH functions is considered uncompressed).

For x25519 and x448, the contents are the byte string inputs and outputs of the corresponding functions defined in [RFC7748], 32 bytes for x25519 and 56 bytes for x448.

Note: Versions of TLS prior to 1.3 permitted point format negotiation; TLS 1.3 removes this feature in favor of a single point format for each curve.

[4.2.6.](#) Pre-Shared Key Extension

The "pre_shared_key" extension is used to indicate the identity of the pre-shared key to be used with a given handshake in association with PSK key establishment.

The "extension_data" field of this extension contains a "PreSharedKeyExtension" value:

```
struct {
    opaque identity<0..2^16-1>;
    uint32 obfuscated_ticket_age;
} PskIdentity;

opaque PskBinderEntry<32..255>;

struct {
    select (Handshake.msg_type) {
        case client_hello:
            PskIdentity identities<6..2^16-1>;
            PskBinderEntry binders<33..2^16-1>;

        case server_hello:
            uint16 selected_identity;
    };
} PreSharedKeyExtension;
```

identities A list of the identities (labels for keys) that the client is willing to negotiate with the server. If sent alongside the "early_data" extension (see [Section 4.2.8](#)), the first identity is the one used for 0-RTT data.

obfuscated_ticket_age For each ticket, the time since the client learned about the server configuration that it is using, in milliseconds. This value is added modulo 2^{32} to with the "ticket_age_add" value that was included with the ticket, see [Section 4.5.1](#). This addition prevents passive observers from correlating sessions unless tickets are reused. Note: because ticket lifetimes are restricted to a week, 32 bits is enough to represent any plausible age, even in milliseconds. External tickets SHOULD use an obfuscated_ticket_age of 0; servers MUST ignore this value for external tickets.

binders A series of HMAC values, one for each PSK offered in the "pre_shared_keys" extension and in the same order, computed as described below.

`selected_identity` The server's chosen identity expressed as a (0-based) index into the identities in the client's list.

Each PSK is associated with a single Hash algorithm. For PSKs established via the ticket mechanism ([Section 4.5.1](#)), this is the Hash used for the KDF. For externally established PSKs, the Hash algorithm **MUST** be set when the PSK is established.

Prior to accepting PSK key establishment, the server **MUST** validate the corresponding binder value (see [Section 4.2.6.1](#) below). If this value is not present or does not validate, the server **MUST** abort the handshake. Servers **SHOULD NOT** attempt to validate multiple binders; rather they **SHOULD** select a single PSK and validate solely the binder that corresponds to that PSK. In order to accept PSK key establishment, the server sends a "pre_shared_key" extension indicating the selected identity.

Clients **MUST** verify that the server's `selected_identity` is within the range supplied by the client, that the server selected the cipher suite associated with the PSK, and that the "key_share", and "signature_algorithms" extensions are consistent with the indicated `key_modes` and `auth_modes` values. If these values are not consistent, the client **MUST** abort the handshake with an "illegal_parameter" alert.

If the server supplies an "early_data" extension, the client **MUST** verify that the server's `selected_identity` is 0. If any other value is returned, the client **MUST** abort the handshake with an "illegal_parameter" alert.

This extension **MUST** be the last extension in the ClientHello (this facilitates implementation as described below). Servers **MUST** check that it is the last extension and otherwise fail the handshake with an "illegal_parameter" alert.

[4.2.6.1](#). PSK Binder

The PSK binder value forms a binding between a PSK and the current handshake, as well as between the session where the PSK was established (if via a NewSessionTicket message) and the session where it was used. Each entry in the binders list is computed as an HMAC over the portion of the ClientHello up to and including the PreSharedKeyExtension.identities field. That is, it includes all of the ClientHello but not the binder list itself. The length fields for the message (including the overall length, the length of the extensions block, and the length of the "pre_shared_key" extension) are all set as if the binder were present.

The `binding_value` is computed in the same way as the `Finished` message ([Section 4.4.3](#)) but with the `BaseKey` being the `binder_key` (see [Section 7.1](#)).

If the handshake includes a `HelloRetryRequest`, the initial `ClientHello` and `HelloRetryRequest` are included in the transcript along with the new `ClientHello`. For instance, if the client sends `ClientHello1`, its binder will be computed over:

```
ClientHello1[truncated]
```

If the server responds with `HelloRetryRequest`, and the client then sends `ClientHello2`, its binder will be computed over:

```
ClientHello1 + HelloRetryRequest + ClientHello2[truncated]
```

The full `ClientHello` is included in all other handshake hash computations.

[4.2.7](#). Pre-Shared Key Exchange Modes

In order to use PSKs, clients MUST also send a "psk_key_exchange_modes" extension. The semantics of this extension are that the client only supports the use of PSKs with these modes, which restricts both the use of PSKs offered in this `ClientHello` and those which the server might supply via `NewSessionTicket`.

A clients MUST provide a "psk_key_exchange_modes" extension if it offers a "pre_shared_key" extension. If clients offer "pre_shared_key" without a "psk_key_exchange_modes" extension, servers MUST abort the handshake. Servers MUST NOT select a key exchange mode that is not listed by the client. This extension also restricts the modes for use with PSK resumption; servers SHOULD NOT send `NewSessionTicket` with tickets that are not compatible with the advertised modes; however if it does so, the impact will just be that the client's attempts at resumption fail.

The server MUST NOT send a "psk_key_exchange_modes" extension.

```
enum { psk_ke(0), psk_dhe_ke(1), (255) } PskKeyExchangeMode;

struct {
    PskKeyExchangeMode ke_modes<1..255>;
} PskKeyExchangeModes;
```

`psk_ke` PSK-only key establishment. In this mode, the server MUST NOT supply a "key_share" value.

psk_dhe_ke PSK key establishment with (EC)DHE key establishment. In this mode, the client and servers MUST supply "key_share" values as described in [Section 4.2.5](#).

[4.2.8](#). Early Data Indication

When a PSK is used, the client can send application data in its first flight of messages. If the client opts to do so, it MUST supply an "early_data" extension as well as the "pre_shared_key" extension.

The "extension_data" field of this extension contains an "EarlyDataIndication" value:

```
struct {  
    } EarlyDataIndication;
```

For PSKs provisioned via NewSessionTicket, a server MUST validate that the ticket age for the selected PSK identity (computed by unmasking PskIdentity.obfuscated_ticket_age) is within a small tolerance of the time since the ticket was issued (see [Section 4.2.8.2](#)). If it is not, the server SHOULD proceed with the handshake but reject 0-RTT, and SHOULD NOT take any other action that assumes that this ClientHello is fresh.

The parameters for the 0-RTT data (symmetric cipher suite, ALPN protocol, etc.) are the same as those which were negotiated in the connection which established the PSK. The PSK used to encrypt the early data MUST be the first PSK listed in the client's "pre_shared_key" extension.

0-RTT messages sent in the first flight have the same content types as their corresponding messages sent in other flights (handshake, application_data, and alert respectively) but are protected under different keys. After all the 0-RTT application data messages (if any) have been sent, an "end_of_early_data" alert of type "warning" is sent to indicate the end of the flight. 0-RTT MUST always be followed by an "end_of_early_data" alert, which will be encrypted with the 0-RTT traffic keys.

A server which receives an "early_data" extension can behave in one of two ways:

- Ignore the extension and return no response. This indicates that the server has ignored any early data and an ordinary 1-RTT handshake is required.

- Return its own extension, indicating that it intends to process the early data. It is not possible for the server to accept only a subset of the early data messages.
- Request that the client send another ClientHello by responding with a HelloRetryRequest. A client MUST NOT include the "early_data" extension in its followup ClientHello.

In order to accept early data, the server MUST have accepted a PSK cipher suite and selected the first key offered in the client's "pre_shared_key" extension. In addition, it MUST verify that the following values are consistent with those negotiated in the connection during which the ticket was established.

- The TLS version number and cipher suite.
- The selected ALPN [[RFC7301](#)] protocol, if any.

Future extensions MUST define their interaction with 0-RTT.

If any of these checks fail, the server MUST NOT respond with the extension and must discard all the remaining first flight data (thus falling back to 1-RTT). If the client attempts a 0-RTT handshake but the server rejects it, it will generally not have the 0-RTT record protection keys and must instead trial decrypt each record with the 1-RTT handshake keys until it finds one that decrypts properly, and then pick up the handshake from that point.

If the server chooses to accept the "early_data" extension, then it MUST comply with the same error handling requirements specified for all records when processing early data records. Specifically, if the server fails to decrypt any 0-RTT record following an accepted "early_data" extension it MUST terminate the connection with a "bad_record_mac" alert as per [Section 5.2](#).

If the server rejects the "early_data" extension, the client application MAY opt to retransmit the data once the handshake has been completed. TLS stacks SHOULD not do this automatically and client applications MUST take care that the negotiated parameters are consistent with those it expected. For example, if the selected ALPN protocol has changed, it is likely unsafe to retransmit the original application layer data.

[4.2.8.1](#). Processing Order

Clients are permitted to "stream" 0-RTT data until they receive the server's Finished, only then sending the "end_of_early_data" alert. In order to avoid deadlock, when accepting "early_data", servers MUST

process the client's ClientHello and then immediately send the ServerHello, rather than waiting for the client's "end_of_early_data" alert.

4.2.8.2. Replay Properties

As noted in [Section 2.3](#), TLS provides a limited mechanism for replay protection for data sent by the client in the first flight.

The "obfuscated_ticket_age" parameter in the client's "pre_shared_key" extension SHOULD be used by servers to limit the time over which the first flight might be replayed. A server can store the time at which it sends a session ticket to the client, or encode the time in the ticket. Then, each time it receives an "pre_shared_key" extension, it can subtract the base value and check to see if the value used by the client matches its expectations.

The ticket age (the value with "ticket_age_add" subtracted) provided by the client will be shorter than the actual time elapsed on the server by a single round trip time. This difference is comprised of the delay in sending the NewSessionTicket message to the client, plus the time taken to send the ClientHello to the server. For this reason, a server SHOULD measure the round trip time prior to sending the NewSessionTicket message and account for that in the value it saves.

To properly validate the ticket age, a server needs to save at least two items:

- The time that the server generated the session ticket and the estimated round trip time can be added together to form a baseline time.
- The "ticket_age_add" parameter from the NewSessionTicket is needed to recover the ticket age from the "obfuscated_ticket_age" parameter.

There are several potential sources of error that make an exact measurement of time difficult. Variations in client and server clocks are likely to be minimal, outside of gross time corrections. Network propagation delays are most likely causes of a mismatch in legitimate values for elapsed time. Both the NewSessionTicket and ClientHello messages might be retransmitted and therefore delayed, which might be hidden by TCP.

A small allowance for errors in clocks and variations in measurements is advisable. However, any allowance also increases the opportunity for replay. In this case, it is better to reject early data and fall

back to a full 1-RTT handshake than to risk greater exposure to replay attacks. In common network topologies for browser clients, small allowances on the order of ten seconds are reasonable. Clock skew distributions are not symmetric, so the optimal tradeoff may involve an asymmetric replay window.

4.3. Server Parameters

The next two messages from the server, EncryptedExtensions and CertificateRequest, contain encrypted information from the server that determines the rest of the handshake.

4.3.1. Encrypted Extensions

In all handshakes, the server MUST send the EncryptedExtensions message immediately after the ServerHello message. This is the first message that is encrypted under keys derived from handshake_traffic_secret.

The EncryptedExtensions message contains extensions which should be protected, i.e., any which are not needed to establish the cryptographic context, but which are not associated with individual certificates. The client MUST check EncryptedExtensions for the presence of any forbidden extensions and if any are found MUST abort the handshake with an "illegal_parameter" alert.

Structure of this message:

```
struct {  
    Extension extensions<0..2^16-1>;  
} EncryptedExtensions;
```

extensions A list of extensions.

4.3.2. Certificate Request

A server which is authenticating with a certificate can optionally request a certificate from the client. This message, if sent, will follow EncryptedExtensions.

Structure of this message:


```
opaque DistinguishedName<1..2^16-1>;

struct {
    opaque certificate_extension_oid<1..2^8-1>;
    opaque certificate_extension_values<0..2^16-1>;
} CertificateExtension;

struct {
    opaque certificate_request_context<0..2^8-1>;
    SignatureScheme
        supported_signature_algorithms<2..2^16-2>;
    DistinguishedName certificate_authorities<0..2^16-1>;
    CertificateExtension certificate_extensions<0..2^16-1>;
} CertificateRequest;
```

certificate_request_context An opaque string which identifies the certificate request and which will be echoed in the client's Certificate message. The `certificate_request_context` MUST be unique within the scope of this connection (thus preventing replay of client CertificateVerify messages). This field SHALL be zero length unless used for the post-handshake authentication exchanges described in [Section 4.5.2](#).

supported_signature_algorithms A list of the signature algorithms that the server is able to verify, listed in descending order of preference. Any certificates provided by the client MUST be signed using a signature algorithm found in `supported_signature_algorithms`.

certificate_authorities A list of the distinguished names [[X501](#)] of acceptable certificate authorities, represented in DER-encoded [[X690](#)] format. These distinguished names may specify a desired distinguished name for a root CA or for a subordinate CA; thus, this message can be used to describe known roots as well as a desired authorization space. If the `certificate_authorities` list is empty, then the client MAY send any certificate that meets the rest of the selection criteria in the CertificateRequest, unless there is some external arrangement to the contrary.

certificate_extensions A list of certificate extension OIDs [[RFC5280](#)] with their allowed values, represented in DER-encoded [[X690](#)] format. Some certificate extension OIDs allow multiple values (e.g. Extended Key Usage). If the server has included a non-empty `certificate_extensions` list, the client certificate MUST contain all of the specified extension OIDs that the client recognizes. For each extension OID recognized by the client, all of the specified values MUST be present in the client certificate (but the certificate MAY have other values as well). However, the

client MUST ignore and skip any unrecognized certificate extension OIDs. If the client has ignored some of the required certificate extension OIDs, and supplied a certificate that does not satisfy the request, the server MAY at its discretion either continue the session without client authentication, or abort the handshake with an "unsupported_certificate" alert. PKIX RFCs define a variety of certificate extension OIDs and their corresponding value types. Depending on the type, matching certificate extension values are not necessarily bitwise-equal. It is expected that TLS implementations will rely on their PKI libraries to perform certificate selection using certificate extension OIDs. This document defines matching rules for two standard certificate extensions defined in [\[RFC5280\]](#):

- o The Key Usage extension in a certificate matches the request when all key usage bits asserted in the request are also asserted in the Key Usage certificate extension.
- o The Extended Key Usage extension in a certificate matches the request when all key purpose OIDs present in the request are also found in the Extended Key Usage certificate extension. The special anyExtendedKeyUsage OID MUST NOT be used in the request.

Separate specifications may define matching rules for other certificate extensions.

Servers which are authenticating with a PSK MUST NOT send the CertificateRequest message.

4.4. Authentication Messages

As discussed in [Section 2](#), TLS uses a common set of messages for authentication, key confirmation, and handshake integrity: Certificate, CertificateVerify, and Finished. These messages are always sent as the last messages in their handshake flight. The Certificate and CertificateVerify messages are only sent under certain circumstances, as defined below. The Finished message is always sent as part of the Authentication block.

The computations for the Authentication messages all uniformly take the following inputs:

- The certificate and signing key to be used.
- A Handshake Context based on the hash of the handshake messages
- A base key to be used to compute a MAC key.

Based on these inputs, the messages then contain:

Certificate The certificate to be used for authentication and any supporting certificates in the chain. Note that certificate-based client authentication is not available in the 0-RTT case.

CertificateVerify A signature over the value Hash(Handshake Context + Certificate)

Finished A MAC over the value Hash(Handshake Context + Certificate + CertificateVerify) using a MAC key derived from the base key.

Because the CertificateVerify signs the Handshake Context + Certificate and the Finished MACs the Handshake Context + Certificate + CertificateVerify, this is mostly equivalent to keeping a running hash of the handshake messages (exactly so in the pure 1-RTT cases). Note, however, that subsequent post-handshake authentications do not include each other, just the messages through the end of the main handshake.

The following table defines the Handshake Context and MAC Base Key for each scenario:

Mode	Handshake Context	Base Key
Server	ClientHello ... later of EncryptedExtensions/CertificateRequest	server_handshake_traffic_secret
Client	ClientHello ... ServerFinished	client_handshake_traffic_secret
Post-Handshake	ClientHello ... ClientFinished + CertificateRequest	client_traffic_secret_N

In all cases, the handshake context is formed by concatenating the indicated handshake messages, including the handshake message type and length fields.

[4.4.1. Certificate](#)

The server MUST send a Certificate message whenever the agreed-upon key exchange method uses certificates for authentication (this includes all key exchange methods defined in this document except

PSK). This message conveys the endpoint's certificate chain to the peer.

The client MUST send a Certificate message if and only if the server has requested client authentication via a CertificateRequest message ([Section 4.3.2](#)). If the server requests client authentication but no suitable certificate is available, the client MUST send a Certificate message containing no certificates (i.e., with the "certificate_list" field having length 0).

Structure of this message:

```
opaque ASN1Cert<1..224-1>;

struct {
    ASN1Cert cert_data;
    Extension extensions<0..216-1>;
} CertificateEntry;

struct {
    opaque certificate_request_context<0..28-1>;
    CertificateEntry certificate_list<0..224-1>;
} Certificate;
```

certificate_request_context If this message is in response to a CertificateRequest, the value of certificate_request_context in that message. Otherwise, in the case of server authentication this field SHALL be zero length.

certificate_list This is a sequence (chain) of CertificateEntry structures, each containing a single certificate and set of extensions. The sender's certificate MUST come in the first CertificateEntry in the list. Each following certificate SHOULD directly certify one preceding it. Because certificate validation requires that trust anchors be distributed independently, a certificate that specifies a trust anchor MAY be omitted from the chain, provided that supported peers are known to possess any omitted certificates.

extensions: A set of extension values for the CertificateEntry. The "Extension" format is defined in [Section 4.2](#). Valid extensions include OSCP Status extensions ([[RFC6066](#)] and [[RFC6961](#)]) and SignedCertificateTimestamps ([[RFC6962](#)]). Any extension presented in a Certificate message must only be presented if the corresponding ClientHello extension was presented in the initial handshake. If an extension applies the the entire chain, it SHOULD be included in the first CertificateEntry.

Note: Prior to TLS 1.3, "certificate_list" ordering required each certificate to certify the one immediately preceding it, however some implementations allowed some flexibility. Servers sometimes send both a current and deprecated intermediate for transitional purposes, and others are simply configured incorrectly, but these cases can nonetheless be validated properly. For maximum compatibility, all implementations SHOULD be prepared to handle potentially extraneous certificates and arbitrary orderings from any TLS version, with the exception of the end-entity certificate which MUST be first.

The server's certificate list MUST always be non-empty. A client will send an empty certificate list if it does not have an appropriate certificate to send in response to the server's authentication request.

4.4.1.1. OCSP Status and SCT Extensions

[RFC6066] and [[RFC6961](#)] provide extensions to negotiate the server sending OCSP responses to the client. In TLS 1.2 and below, the server sends an empty extension to indicate negotiation of this extension and the OCSP information is carried in a CertificateStatus message. In TLS 1.3, the server's OCSP information is carried in an extension in the CertificateEntry containing the associated certificate. Specifically: The body of the "status_request" or "status_request_v2" extension from the server MUST be a CertificateStatus structure as defined in [[RFC6066](#)] and [[RFC6961](#)] respectively.

Similarly, [[RFC6962](#)] provides a mechanism for a server to send a Signed Certificate Timestamp (SCT) as an extension in the ServerHello. In TLS 1.3, the server's SCT information is carried in an extension in CertificateEntry.

4.4.1.2. Server Certificate Selection

The following rules apply to the certificates sent by the server:

- The certificate type MUST be X.509v3 [[RFC5280](#)], unless explicitly negotiated otherwise (e.g., [[RFC5081](#)]).
- The server's end-entity certificate's public key (and associated restrictions) MUST be compatible with the selected authentication algorithm (currently RSA or ECDSA).
- The certificate MUST allow the key to be used for signing (i.e., the digitalSignature bit MUST be set if the Key Usage extension is present) with a signature scheme indicated in the client's "signature_algorithms" extension.

- The "server_name" and "trusted_ca_keys" extensions [[RFC6066](#)] are used to guide certificate selection. As servers MAY require the presence of the "server_name" extension, clients SHOULD send this extension, when applicable.

All certificates provided by the server MUST be signed by a signature algorithm that appears in the "signature_algorithms" extension provided by the client, if they are able to provide such a chain (see [Section 4.2.3](#)). Certificates that are self-signed or certificates that are expected to be trust anchors are not validated as part of the chain and therefore MAY be signed with any algorithm.

If the server cannot produce a certificate chain that is signed only via the indicated supported algorithms, then it SHOULD continue the handshake by sending the client a certificate chain of its choice that may include algorithms that are not known to be supported by the client. This fallback chain MAY use the deprecated SHA-1 hash algorithm only if the "signature_algorithms" extension provided by the client permits it. If the client cannot construct an acceptable chain using the provided certificates and decides to abort the handshake, then it MUST abort the handshake with an "unsupported_certificate" alert.

If the server has multiple certificates, it chooses one of them based on the above-mentioned criteria (in addition to other criteria, such as transport layer endpoint, local configuration and preferences).

[4.4.1.3](#). Client Certificate Selection

The following rules apply to certificates sent by the client:

- The certificate type MUST be X.509v3 [[RFC5280](#)], unless explicitly negotiated otherwise (e.g., [[RFC5081](#)]).
- If the certificate_authorities list in the certificate request message was non-empty, one of the certificates in the certificate chain SHOULD be issued by one of the listed CAs.
- The certificates MUST be signed using an acceptable signature algorithm, as described in [Section 4.3.2](#). Note that this relaxes the constraints on certificate-signing algorithms found in prior versions of TLS.
- If the certificate_extensions list in the certificate request message was non-empty, the end-entity certificate MUST match the extension OIDs recognized by the client, as described in [Section 4.3.2](#).

Note that, as with the server certificate, there are certificates that use algorithm combinations that cannot be currently used with TLS.

4.4.1.4. Receiving a Certificate Message

In general, detailed certificate validation procedures are out of scope for TLS (see [[RFC5280](#)]). This section provides TLS-specific requirements.

If the server supplies an empty Certificate message, the client **MUST** abort the handshake with a "decode_error" alert.

If the client does not send any certificates, the server **MAY** at its discretion either continue the handshake without client authentication, or abort the handshake with a "certificate_required" alert. Also, if some aspect of the certificate chain was unacceptable (e.g., it was not signed by a known, trusted CA), the server **MAY** at its discretion either continue the handshake (considering the client unauthenticated) or abort the handshake.

Any endpoint receiving any certificate signed using any signature algorithm using an MD5 hash **MUST** abort the handshake with a "bad_certificate" alert. SHA-1 is deprecated and it is **RECOMMENDED** that any endpoint receiving any certificate signed using any signature algorithm using a SHA-1 hash abort the handshake with a "bad_certificate" alert. All endpoints are **RECOMMENDED** to transition to SHA-256 or better as soon as possible to maintain interoperability with implementations currently in the process of phasing out SHA-1 support.

Note that a certificate containing a key for one signature algorithm **MAY** be signed using a different signature algorithm (for instance, an RSA key signed with an ECDSA key).

4.4.2. Certificate Verify

This message is used to provide explicit proof that an endpoint possesses the private key corresponding to its certificate and also provides integrity for the handshake up to this point. Servers **MUST** send this message when authenticating via a certificate. Clients **MUST** send this message whenever authenticating via a Certificate (i.e., when the Certificate message is non-empty). When sent, this message **MUST** appear immediately after the Certificate Message and immediately prior to the Finished message.

Structure of this message:


```
struct {  
    SignatureScheme algorithm;  
    opaque signature<0..2^16-1>;  
} CertificateVerify;
```

The algorithm field specifies the signature algorithm used (see [Section 4.2.3](#) for the definition of this field). The signature is a digital signature using that algorithm that covers the hash output described in [Section 4.4](#) namely:

Hash(Handshake Context + Certificate)

In TLS 1.3, the digital signature process takes as input:

- A signing key
- A context string
- The actual content to be signed

The digital signature is then computed using the signing key over the concatenation of:

- 64 bytes of octet 32
- The context string
- A single 0 byte which serves as the separator
- The content to be signed

This structure is intended to prevent an attack on previous versions of previous versions of TLS in which the ServerKeyExchange format meant that attackers could obtain a signature of a message with a chosen, 32-byte prefix. The initial 64 byte pad clears that prefix.

The context string for a server signature is "TLS 1.3, server CertificateVerify" and for a client signature is "TLS 1.3, client CertificateVerify".

For example, if Hash(Handshake Context + Certificate) was 32 bytes of 01 (this length would make sense for SHA-256), the input to the final signing process for a server CertificateVerify would be:

[illegible]

If sent by a server, the signature algorithm MUST be one offered in the client's "signature_algorithms" extension unless no valid certificate chain can be produced without unsupported algorithms (see [Section 4.2.3](#)).

If sent by a client, the signature algorithm used in the signature MUST be one of those present in the `supported_signature_algorithms` field of the `CertificateRequest` message.

In addition, the signature algorithm MUST be compatible with the key in the sender's end-entity certificate. RSA signatures MUST use an RSASSA-PSS algorithm, regardless of whether RSASSA-PKCS1-v1_5 algorithms appear in "signature_algorithms". SHA-1 MUST NOT be used in any signatures in CertificateVerify. All SHA-1 signature algorithms in this specification are defined solely for use in legacy certificates, and are not valid for CertificateVerify signatures.

Note: When used with non-certificate-based handshakes (e.g., PSK), the client's signature does not cover the server's certificate directly. When the PSK was established through a NewSessionTicket, the client's signature transitively covers the server's certificate through the PSK binder. [\[PSK-FINISHED\]](#) describes a concrete attack on constructions that do not bind to the server's certificate. It is unsafe to use certificate-based client authentication when the client might potentially share the same PSK/key-id pair with two different endpoints and implementations MUST NOT combine external PSKs with certificate-based authentication.

4.4.3. Finished

The Finished message is the final message in the authentication block. It is essential for providing authentication of the handshake and of the computed keys.

Recipients of Finished messages MUST verify that the contents are correct. Once a side has sent its Finished message and received and validated the Finished message from its peer, it may begin to send and receive application data over the connection.

The key used to compute the finished message is computed from the Base key defined in [Section 4.4](#) using HKDF (see [Section 7.1](#)). Specifically:

```
finished_key =  
    HKDF-Expand-Label(BaseKey, "finished", "", Hash.length)
```

Structure of this message:

```
struct {  
    opaque verify_data[Hash.length];  
} Finished;
```

The verify_data value is computed as follows:

```
verify_data =  
    HMAC(finished_key, Hash(  
        Handshake Context +  
        Certificate* +  
        CertificateVerify*  
    ))
```

* Only included if present.

Where HMAC [[RFC2104](#)] uses the Hash algorithm for the handshake. As noted above, the HMAC input can generally be implemented by a running hash, i.e., just the handshake hash at this point.

In previous versions of TLS, the verify_data was always 12 octets long. In the current version of TLS, it is the size of the HMAC output for the Hash used for the handshake.

Note: Alerts and any other record types are not handshake messages and are not included in the hash computations.

Any records following a 1-RTT Finished message MUST be encrypted under the application traffic key. In particular, this includes any alerts sent by the server in response to client Certificate and CertificateVerify messages.

[4.5.](#) Post-Handshake Messages

TLS also allows other messages to be sent after the main handshake. These messages use a handshake content type and are encrypted under the application traffic key.

Handshake messages sent after the handshake MUST NOT be interleaved with other record types. That is, if a message is split over two or more handshake records, there MUST NOT be any other records between them.

4.5.1. New Session Ticket Message

At any time after the server has received the client Finished message, it MAY send a NewSessionTicket message. This message creates a pre-shared key (PSK) binding between the ticket value and the resumption master secret.

The client MAY use this PSK for future handshakes by including the ticket value in the "pre_shared_key" extension in its ClientHello ([Section 4.2.6](#)). Servers MAY send multiple tickets on a single connection, either immediately after each other or after specific events. For instance, the server might send a new ticket after post-handshake authentication in order to encapsulate the additional client authentication state. Clients SHOULD attempt to use each ticket no more than once, with more recent tickets being used first.

Any ticket MUST only be resumed with a cipher suite that has the same KDF hash as that used to establish the original connection, and if the client provides the same SNI value as described in [Section 3 of \[RFC6066\]](#).

Note: Although the resumption master secret depends on the client's second flight, servers which do not request client authentication MAY compute the remainder of the transcript independently and then send a NewSessionTicket immediately upon sending its Finished rather than waiting for the client Finished.

```
struct {
    uint32 ticket_lifetime;
    uint32 ticket_age_add;
    opaque ticket<1..2^16-1>;
    Extension extensions<0..2^16-2>;
} NewSessionTicket;
```

`ticket_lifetime` Indicates the lifetime in seconds as a 32-bit unsigned integer in network byte order from the time of ticket issuance. Servers MUST NOT use any value more than 604800 seconds (7 days). The value of zero indicates that the ticket should be discarded immediately. Clients MUST NOT cache session tickets for longer than 7 days, regardless of the `ticket_lifetime`. It MAY delete the ticket earlier based on local policy. A server MAY treat a ticket as valid for a shorter period of time than what is stated in the `ticket_lifetime`.

ticket_age_add A randomly generated 32-bit value that is used to obscure the age of the ticket that the client includes in the "early_data" extension. The client-side ticket age is added to this value modulo 2^{32} to obtain the value that is transmitted by the client.

ticket The value of the ticket to be used as the PSK identifier. The ticket itself is an opaque label. It MAY either be a database lookup key or a self-encrypted and self-authenticated value. [Section 4 of \[RFC5077\]](#) describes a recommended ticket construction mechanism.

extensions A set of extension values for the ticket. The "Extension" format is defined in [Section 4.2](#). Clients MUST ignore unrecognized extensions.

This document defines one ticket extension, "ticket_early_data_info"

```
struct {  
    uint32 max_early_data_size;  
} TicketEarlyDataInfo;
```

This extension indicates that the ticket may be used to send 0-RTT data ([Section 4.2.8](#)). It contains the following value:

max_early_data_size The maximum amount of 0-RTT data that the client is allowed to send when using this ticket, in bytes. Only Application Data payload is counted. A server receiving more than max_early_data_size bytes of 0-RTT data SHOULD terminate the connection with an "unexpected_message" alert.

[4.5.2](#). Post-Handshake Authentication

The server is permitted to request client authentication at any time after the handshake has completed by sending a CertificateRequest message. The client SHOULD respond with the appropriate Authentication messages. If the client chooses to authenticate, it MUST send Certificate, CertificateVerify, and Finished. If it declines, it MUST send a Certificate message containing no certificates followed by Finished.

Note: Because client authentication may require prompting the user, servers MUST be prepared for some delay, including receiving an arbitrary number of other messages between sending the CertificateRequest and receiving a response. In addition, clients which receive multiple CertificateRequests in close succession MAY respond to them in a different order than they were received (the

certificate_request_context value allows the server to disambiguate the responses).

4.5.3. Key and IV Update

```
enum {  
    update_not_requested(0), update_requested(1), (255)  
} KeyUpdateRequest;  
  
struct {  
    KeyUpdateRequest request_update;  
} KeyUpdate;
```

request_update Indicates that the recipient of the KeyUpdate should respond with its own KeyUpdate. If an implementation receives any other value, it MUST terminate the connection with an "illegal_parameter" alert.

The KeyUpdate handshake message is used to indicate that the sender is updating its sending cryptographic keys. This message can be sent by the server after sending its first flight and the client after sending its second flight. Implementations that receive a KeyUpdate message prior to receiving a Finished message as part of the 1-RTT handshake MUST terminate the connection with an "unexpected_message" alert. After sending a KeyUpdate message, the sender SHALL send all its traffic using the next generation of keys, computed as described in [Section 7.2](#). Upon receiving a KeyUpdate, the receiver MUST update its receiving keys.

If the request_update field is set to "update_requested" then the receiver MUST send a KeyUpdate of its own with request_update set to "update_not_requested" prior to sending its next application data record. This mechanism allows either side to force an update to the entire connection, but causes an implementation which receives multiple KeyUpdates while it is silent to respond with a single update. Note that implementations may receive an arbitrary number of messages between sending a KeyUpdate and receiving the peer's KeyUpdate because those messages may already be in flight. However, because send and receive keys are derived from independent traffic secrets, retaining the receive traffic secret does not threaten the forward secrecy of data sent before the sender changed keys.

If implementations independently send their own KeyUpdates with request_update set to "update_requested", and they cross in flight, then each side will also send a response, with the result that each side increments by two generations.

Both sender and receiver MUST encrypt their KeyUpdate messages with the old keys. Additionally, both sides MUST enforce that a KeyUpdate with the old key is received before accepting any messages encrypted with the new key. Failure to do so may allow message truncation attacks.

[4.6.](#) Handshake Layer and Key Changes

Handshake messages MUST NOT span key changes. Because the ServerHello, Finished, and KeyUpdate messages signal a key change, upon receiving these messages a receiver MUST verify that the end of these messages aligns with a record boundary; if not, then it MUST terminate the connection with an "unexpected_message" alert.

[5.](#) Record Protocol

The TLS record protocol takes messages to be transmitted, fragments the data into manageable blocks, protects the records, and transmits the result. Received data is decrypted and verified, reassembled, and then delivered to higher-level clients.

TLS records are typed, which allows multiple higher level protocols to be multiplexed over the same record layer. This document specifies three content types: handshake, application data, and alert. Implementations MUST NOT send record types not defined in this document unless negotiated by some extension. If a TLS implementation receives an unexpected record type, it MUST terminate the connection with an "unexpected_message" alert. New record content type values are assigned by IANA in the TLS Content Type Registry as described in [Section 10](#).

Application Data messages are carried by the record layer and are fragmented and encrypted as described below. The messages are treated as transparent data to the record layer.

[5.1.](#) Record Layer

The TLS record layer receives uninterpreted data from higher layers in non-empty blocks of arbitrary size.

The record layer fragments information blocks into TLSPlaintext records carrying data in chunks of 2^{14} bytes or less. Message boundaries are not preserved in the record layer (i.e., multiple messages of the same ContentType MAY be coalesced into a single TLSPlaintext record, or a single message MAY be fragmented across several records). Alert messages ([Section 6](#)) MUST NOT be fragmented across records.


```
enum {
    alert(21),
    handshake(22),
    application_data(23),
    (255)
} ContentType;

struct {
    ContentType type;
    ProtocolVersion legacy_record_version = 0x0301;    /* TLS v1.x */
    uint16 length;
    opaque fragment[TLSPplaintext.length];
} TLSPplaintext;
```

type The higher-level protocol used to process the enclosed fragment.

legacy_record_version This value MUST be set to 0x0301 for all records. This field is deprecated and MUST be ignored for all purposes.

length The length (in bytes) of the following TLSPplaintext.fragment. The length MUST NOT exceed 2^{14} . An endpoint that receives a record that exceeds this length MUST terminate the connection with a "record_overflow" alert.

fragment The data being transmitted. This value transparent and treated as an independent block to be dealt with by the higher-level protocol specified by the type field.

This document describes TLS Version 1.3, which uses the version 0x0304. This version value is historical, deriving from the use of 0x0301 for TLS 1.0 and 0x0300 for SSL 3.0. In order to maximize backwards compatibility, the record layer version identifies as simply TLS 1.0. Endpoints supporting other versions negotiate the version to use by following the procedure and requirements in [Appendix C](#).

Implementations MUST NOT send zero-length fragments of Handshake or Alert types, even if those fragments contain padding. Zero-length fragments of Application Data MAY be sent as they are potentially useful as a traffic analysis countermeasure.

When record protection has not yet been engaged, TLSPplaintext structures are written directly onto the wire. Once record protection has started, TLSPplaintext records are protected and sent as described in the following section.

5.2. Record Payload Protection

The record protection functions translate a `TLSP Plaintext` structure into a `TLSCiphertext`. The deprotection functions reverse the process. In TLS 1.3 as opposed to previous versions of TLS, all ciphers are modeled as "Authenticated Encryption with Additional Data" (AEAD) [RFC5116]. AEAD functions provide a unified encryption and authentication operation which turns plaintext into authenticated ciphertext and back again. Each encrypted record consists of a plaintext header followed by an encrypted body, which itself contains a type and optional padding.

```
struct {
    opaque content[TLSP Plaintext.length];
    ContentType type;
    uint8 zeros[length_of_padding];
} TLSInnerPlaintext;

struct {
    ContentType opaque_type = 23; /* application_data */
    ProtocolVersion legacy_record_version = 0x0301; /* TLS v1.x */
    uint16 length;
    opaque encrypted_record[length];
} TLSCiphertext;
```

`content` The cleartext of `TLSP Plaintext.fragment`.

`type` The content type of the record.

`zeros` An arbitrary-length run of zero-valued bytes may appear in the cleartext after the type field. This provides an opportunity for senders to pad any TLS record by a chosen amount as long as the total stays within record size limits. See [Section 5.4](#) for more details.

`opaque_type` The outer `opaque_type` field of a `TLSCiphertext` record is always set to the value 23 (`application_data`) for outward compatibility with middleboxes accustomed to parsing previous versions of TLS. The actual content type of the record is found in `TLSInnerPlaintext.type` after decryption.

`legacy_record_version` The `legacy_record_version` field is identical to `TLSP Plaintext.legacy_record_version` and is always 0x0301. Note that the handshake protocol including the `ClientHello` and `ServerHello` messages authenticates the protocol version, so this value is redundant.

`length` The length (in bytes) of the following `TLSCiphertext.fragment`, which is the sum of the lengths of the content and the padding, plus one for the inner content type. The length MUST NOT exceed $2^{14} + 256$. An endpoint that receives a record that exceeds this length MUST terminate the connection with a "record_overflow" alert.

`encrypted_record` The AEAD encrypted form of the serialized `TLSPayload` structure.

AEAD algorithms take as input a single key, a nonce, a plaintext, and "additional data" to be included in the authentication check, as described in [Section 2.1 of \[RFC5116\]](#). The key is either the `client_write_key` or the `server_write_key`, the nonce is derived from the sequence number (see [Section 5.3](#)) and the `client_write_iv` or `server_write_iv`, and the additional data input is empty (zero length). Derivation of traffic keys is defined in [Section 7.3](#).

The plaintext is the concatenation of `TLSPayload.fragment`, `TLSPayload.type`, and any padding bytes (zeros).

The AEAD output consists of the ciphertext output by the AEAD encryption operation. The length of the plaintext is greater than `TLSPayload.length` due to the inclusion of `TLSPayload.type` and however much padding is supplied by the sender. The length of the AEAD output will generally be larger than the plaintext, but by an amount that varies with the AEAD algorithm. Since the ciphers might incorporate padding, the amount of overhead could vary with different lengths of plaintext. Symbolically,

```
AEADEncrypted =  
    AEAD-Encrypt(write_key, nonce, plaintext of fragment)
```

In order to decrypt and verify, the cipher takes as input the key, nonce, and the AEADEncrypted value. The output is either the plaintext or an error indicating that the decryption failed. There is no separate integrity check. That is:

```
plaintext of fragment =  
    AEAD-Decrypt(write_key, nonce, AEADEncrypted)
```

If the decryption fails, the receiver MUST terminate the connection with a "bad_record_mac" alert.

An AEAD algorithm used in TLS 1.3 MUST NOT produce an expansion of greater than 255 bytes. An endpoint that receives a record from its peer with `TLSCiphertext.length` larger than $2^{14} + 256$ octets MUST terminate the connection with a "record_overflow" alert. This limit

is derived from the maximum TLSPlaintext length of 2^{14} octets + 1 octet for ContentType + the maximum AEAD expansion of 255 octets.

5.3. Per-Record Nonce

A 64-bit sequence number is maintained separately for reading and writing records. Each sequence number is set to zero at the beginning of a connection and whenever the key is changed.

The sequence number is incremented after reading or writing each record. The first record transmitted under a particular set of traffic keys record key MUST use sequence number 0.

Sequence numbers do not wrap. If a TLS implementation would need to wrap a sequence number, it MUST either rekey ([Section 4.5.3](#)) or terminate the connection.

The length of the per-record nonce (iv_length) is set to max(8 bytes, N_MIN) for the AEAD algorithm (see [\[RFC5116\] Section 4](#)). An AEAD algorithm where N_MAX is less than 8 bytes MUST NOT be used with TLS. The per-record nonce for the AEAD construction is formed as follows:

1. The 64-bit record sequence number is padded to the left with zeroes to iv_length.
2. The padded sequence number is XORed with the static client_write_iv or server_write_iv, depending on the role.

The resulting quantity (of length iv_length) is used as the per-record nonce.

Note: This is a different construction from that in TLS 1.2, which specified a partially explicit nonce.

5.4. Record Padding

All encrypted TLS records can be padded to inflate the size of the TLSCipherText. This allows the sender to hide the size of the traffic from an observer.

When generating a TLSCiphertext record, implementations MAY choose to pad. An unpadded record is just a record with a padding length of zero. Padding is a string of zero-valued bytes appended to the ContentType field before encryption. Implementations MUST set the padding octets to all zeros before encrypting.

Application Data records may contain a zero-length TLSInnerPlaintext.content if the sender desires. This permits

generation of plausibly-sized cover traffic in contexts where the presence or absence of activity may be sensitive. Implementations MUST NOT send Handshake or Alert records that have a zero-length `TLSInnerPlaintext.content`.

The padding sent is automatically verified by the record protection mechanism: Upon successful decryption of a `TLSCiphertext.fragment`, the receiving implementation scans the field from the end toward the beginning until it finds a non-zero octet. This non-zero octet is the content type of the message. This padding scheme was selected because it allows padding of any encrypted TLS record by an arbitrary size (from zero up to TLS record size limits) without introducing new content types. The design also enforces all-zero padding octets, which allows for quick detection of padding errors.

Implementations MUST limit their scanning to the cleartext returned from the AEAD decryption. If a receiving implementation does not find a non-zero octet in the cleartext, it MUST terminate the connection with an "unexpected_message" alert.

The presence of padding does not change the overall record size limitations - the full fragment plaintext may not exceed 2^{14} octets.

Selecting a padding policy that suggests when and how much to pad is a complex topic, and is beyond the scope of this specification. If the application layer protocol atop TLS has its own padding, it may be preferable to pad application_data TLS records within the application layer. Padding for encrypted handshake and alert TLS records must still be handled at the TLS layer, though. Later documents may define padding selection algorithms, or define a padding policy request mechanism through TLS extensions or some other means.

5.5. Limits on Key Usage

There are cryptographic limits on the amount of plaintext which can be safely encrypted under a given set of keys. [\[AEAD-LIMITS\]](#) provides an analysis of these limits under the assumption that the underlying primitive (AES or ChaCha20) has no weaknesses. Implementations SHOULD do a key update [Section 4.5.3](#) prior to reaching these limits.

For AES-GCM, up to $2^{24.5}$ full-size records (about 24 million) may be encrypted on a given connection while keeping a safety margin of approximately 2^{-57} for Authenticated Encryption (AE) security. For ChaCha20/Poly1305, the record sequence number would wrap before the safety limit is reached.

6. Alert Protocol

One of the content types supported by the TLS record layer is the alert type. Like other messages, alert messages are encrypted as specified by the current connection state.

Alert messages convey the severity of the message (warning or fatal) and a description of the alert. Warning-level messages are used to indicate orderly closure of the connection or the end of early data (see [Section 6.1](#)). Upon receiving a warning-level alert, the TLS implementation SHOULD indicate end-of-data to the application and, if appropriate for the alert type, send a closure alert in response.

Fatal-level messages are used to indicate abortive closure of the connection (See [Section 6.2](#)). Upon receiving a fatal-level alert, the TLS implementation SHOULD indicate an error to the application and MUST NOT allow any further data to be sent or received on the connection. Servers and clients MUST forget keys and secrets associated with a failed connection. Stateful implementations of session tickets (as in many clients) SHOULD discard tickets associated with failed connections.

All the alerts listed in [Section 6.2](#) MUST be sent as fatal and MUST be treated as fatal regardless of the AlertLevel in the message. Unknown alert types MUST be treated as fatal.


```
enum { warning(1), fatal(2), (255) } AlertLevel;
```

```
enum {  
    close_notify(0),  
    end_of_early_data(1),  
    unexpected_message(10),  
    bad_record_mac(20),  
    record_overflow(22),  
    handshake_failure(40),  
    bad_certificate(42),  
    unsupported_certificate(43),  
    certificate_revoked(44),  
    certificate_expired(45),  
    certificate_unknown(46),  
    illegal_parameter(47),  
    unknown_ca(48),  
    access_denied(49),  
    decode_error(50),  
    decrypt_error(51),  
    protocol_version(70),  
    insufficient_security(71),  
    internal_error(80),  
    inappropriate_fallback(86),  
    user_canceled(90),  
    missing_extension(109),  
    unsupported_extension(110),  
    certificate_unobtainable(111),  
    unrecognized_name(112),  
    bad_certificate_status_response(113),  
    bad_certificate_hash_value(114),  
    unknown_psk_identity(115),  
    certificate_required(116),  
    (255)  
} AlertDescription;  
  
struct {  
    AlertLevel level;  
    AlertDescription description;  
} Alert;
```

6.1. Closure Alerts

The client and the server must share knowledge that the connection is ending in order to avoid a truncation attack. Failure to properly close a connection does not prohibit a session from being resumed.

`close_notify` This alert notifies the recipient that the sender will not send any more messages on this connection. Any data received after a closure **MUST** be ignored.

`end_of_early_data` This alert is sent by the client to indicate that all 0-RTT `application_data` messages have been transmitted (or none will be sent at all) and that this is the end of the flight. This alert **MUST** be at the warning level. Servers **MUST NOT** send this alert and clients receiving it **MUST** terminate the connection with an "unexpected_message" alert.

`user_canceled` This alert notifies the recipient that the sender is canceling the handshake for some reason unrelated to a protocol failure. If a user cancels an operation after the handshake is complete, just closing the connection by sending a "close_notify" is more appropriate. This alert **SHOULD** be followed by a "close_notify". This alert is generally a warning.

Either party **MAY** initiate a close by sending a "close_notify" alert. Any data received after a closure alert is ignored. If a transport-level close is received prior to a "close_notify", the receiver cannot know that all the data that was sent has been received.

Each party **MUST** send a "close_notify" alert before closing the write side of the connection, unless some other fatal alert has been transmitted. The other party **MUST** respond with a "close_notify" alert of its own and close down the connection immediately, discarding any pending writes. The initiator of the close need not wait for the responding "close_notify" alert before closing the read side of the connection.

If the application protocol using TLS provides that any data may be carried over the underlying transport after the TLS connection is closed, the TLS implementation must receive the responding "close_notify" alert before indicating to the application layer that the TLS connection has ended. If the application protocol will not transfer any additional data, but will only close the underlying transport connection, then the implementation **MAY** choose to close the transport without waiting for the responding "close_notify". No part of this standard should be taken to dictate the manner in which a usage profile for TLS manages its data transport, including when connections are opened or closed.

Note: It is assumed that closing a connection reliably delivers pending data before destroying the transport.

6.2. Error Alerts

Error handling in the TLS Handshake Protocol is very simple. When an error is detected, the detecting party sends a message to its peer. Upon transmission or receipt of a fatal alert message, both parties immediately close the connection.

Whenever an implementation encounters a fatal error condition, it SHOULD send an appropriate fatal alert and MUST close the connection without sending or receiving any additional data. In the rest of this specification, the phrase "{terminate the connection, abort the handshake}" is used without a specific alert means that the implementation SHOULD send the alert indicated by the descriptions below. The phrase "{terminate the connection, abort the handshake} with a X alert" MUST send alert X if it sends any alert. All alerts defined in this section below, as well as all unknown alerts are universally considered fatal as of TLS 1.3 (see [Section 6](#)).

The following error alerts are defined:

`unexpected_message` An inappropriate message (e.g., the wrong handshake message, premature application data, etc.) was received. This alert should never be observed in communication between proper implementations.

`bad_record_mac` This alert is returned if a record is received which cannot be deprotected. Because AEAD algorithms combine decryption and verification, this alert is used for all deprotection failures. This alert should never be observed in communication between proper implementations, except when messages were corrupted in the network.

`record_overflow` A `TLSCiphertext` record was received that had a length more than $2^{14} + 256$ bytes, or a record decrypted to a `TLSPlaintext` record with more than 2^{14} bytes. This alert should never be observed in communication between proper implementations, except when messages were corrupted in the network.

`handshake_failure` Reception of a "handshake_failure" alert message indicates that the sender was unable to negotiate an acceptable set of security parameters given the options available.

`bad_certificate` A certificate was corrupt, contained signatures that did not verify correctly, etc.

`unsupported_certificate` A certificate was of an unsupported type.

`certificate_revoked` A certificate was revoked by its signer.

certificate_expired A certificate has expired or is not currently valid.

certificate_unknown Some other (unspecified) issue arose in processing the certificate, rendering it unacceptable.

illegal_parameter A field in the handshake was incorrect or inconsistent with other fields. This alert is used for errors which conform to the formal protocol syntax but are otherwise incorrect.

unknown_ca A valid certificate chain or partial chain was received, but the certificate was not accepted because the CA certificate could not be located or couldn't be matched with a known, trusted CA.

access_denied A valid certificate or PSK was received, but when access control was applied, the sender decided not to proceed with negotiation.

decode_error A message could not be decoded because some field was out of the specified range or the length of the message was incorrect. This alert is used for errors where the message does not conform to the formal protocol syntax. This alert should never be observed in communication between proper implementations, except when messages were corrupted in the network.

decrypt_error A handshake cryptographic operation failed, including being unable to correctly verify a signature or validate a Finished message or a PSK binder.

protocol_version The protocol version the peer has attempted to negotiate is recognized but not supported. (see [Appendix C](#))

insufficient_security Returned instead of "handshake_failure" when a negotiation has failed specifically because the server requires parameters more secure than those supported by the client.

internal_error An internal error unrelated to the peer or the correctness of the protocol (such as a memory allocation failure) makes it impossible to continue.

inappropriate_fallback Sent by a server in response to an invalid connection retry attempt from a client. (see [\[RFC7507\]](#))

missing_extension Sent by endpoints that receive a hello message not containing an extension that is mandatory to send for the offered TLS version or other negotiated parameters.

`unsupported_extension` Sent by endpoints receiving any hello message containing an extension known to be prohibited for inclusion in the given hello message, including any extensions in a `ServerHello` or `Certificate` not first offered in the corresponding `ClientHello`.

`certificate_unobtainable` Sent by servers when unable to obtain a certificate from a URL provided by the client via the `"client_certificate_url"` extension [[RFC6066](#)].

`unrecognized_name` Sent by servers when no server exists identified by the name provided by the client via the `"server_name"` extension [[RFC6066](#)].

`bad_certificate_status_response` Sent by clients when an invalid or unacceptable OCSP response is provided by the server via the `"status_request"` extension [[RFC6066](#)].

`bad_certificate_hash_value` Sent by servers when a retrieved object does not have the correct hash provided by the client via the `"client_certificate_url"` extension [[RFC6066](#)].

`unknown_psk_identity` Sent by servers when PSK key establishment is desired but no acceptable PSK identity is provided by the client. Sending this alert is OPTIONAL; servers MAY instead choose to send a `"decrypt_error"` alert to merely indicate an invalid PSK identity.

`certificate_required` Sent by servers when a client certificate is desired but none was provided by the client.

New Alert values are assigned by IANA as described in [Section 10](#).

7. Cryptographic Computations

In order to begin connection protection, the TLS Record Protocol requires specification of a suite of algorithms, a master secret, and the client and server random values.

7.1. Key Schedule

The TLS handshake establishes one or more input secrets which are combined to create the actual working keying material, as detailed below. The key derivation process makes use of the HKDF-Extract and HKDF-Expand functions as defined for HKDF [[RFC5869](#)], as well as the functions defined below:


```
HKDF-Expand-Label(Secret, Label, HashValue, Length) =
    HKDF-Expand(Secret, HkdfLabel, Length)
```

Where HkdfLabel is specified as:

```
struct {
    uint16 length = Length;
    opaque label<9..255> = "TLS 1.3, " + Label;
    opaque hash_value<0..255> = HashValue;
} HkdfLabel;
```

```
Derive-Secret(Secret, Label, Messages) =
    HKDF-Expand-Label(Secret, Label,
        Hash(Messages), Hash.Length)
```

The Hash function and the HKDF hash are the cipher suite hash algorithm. Hash.length is its output length.

Given a set of n InputSecrets, the final "master secret" is computed by iteratively invoking HKDF-Extract with InputSecret_1, InputSecret_2, etc. The initial secret is simply a string of zeroes as long as the size of the Hash that is the basis for the HKDF. Concretely, for the present version of TLS 1.3, secrets are added in the following order:

- PSK
- (EC)DHE shared secret

This produces a full key derivation schedule shown in the diagram below. In this diagram, the following formatting conventions apply:

- HKDF-Extract is drawn as taking the Salt argument from the top and the IKM argument from the left.
- Derive-Secret's Secret argument is indicated by the arrow coming in from the left. For instance, the Early Secret is the Secret for generating the client_early_traffic_secret.

```

      0
      |
      v
PSK -> HKDF-Extract
      |
      v
    Early Secret
      |
      +-----> Derive-Secret(.,
```



```

|                                     "external psk binder key" |
|                                     "resumption psk binder key",
|                                     "")
|                                     = binder_key
|
+-----> Derive-Secret(., "client early traffic secret",
|                               ClientHello)
|                               = client_early_traffic_secret
|
+-----> Derive-Secret(., "early exporter master secret",
|                               ClientHello)
|                               = early_exporter_secret
v
(EC)DHE -> HKDF-Extract
|
v
Handshake Secret
|
+-----> Derive-Secret(., "client handshake traffic secret",
|                               ClientHello...ServerHello)
|                               = client_handshake_traffic_secret
|
+-----> Derive-Secret(., "server handshake traffic secret",
|                               ClientHello...ServerHello)
|                               = server_handshake_traffic_secret
|
v
0 -> HKDF-Extract
|
v
Master Secret
|
+-----> Derive-Secret(., "client application traffic secret",
|                               ClientHello...Server Finished)
|                               = client_traffic_secret_0
|
+-----> Derive-Secret(., "server application traffic secret",
|                               ClientHello...Server Finished)
|                               = server_traffic_secret_0
|
+-----> Derive-Secret(., "exporter master secret",
|                               ClientHello...Server Finished)
|                               = exporter_secret
|
+-----> Derive-Secret(., "resumption master secret",
|                               ClientHello...Client Finished)
|                               = resumption_secret

```


The general pattern here is that the secrets shown down the left side of the diagram are just raw entropy without context, whereas the secrets down the right side include handshake context and therefore can be used to derive working keys without additional context. Note that the different calls to Derive-Secret may take different Messages arguments, even with the same secret. In a 0-RTT exchange, Derive-Secret is called with four distinct transcripts; in a 1-RTT only exchange with three distinct transcripts.

If a given secret is not available, then the 0-value consisting of a string of Hash.length zeroes is used. Note that this does not mean skipping rounds, so if PSK is not in use Early Secret will still be HKDF-Extract(0, 0). For the computation of the binder_secret, the label is "external psk binder key" for external PSKs and "resumption psk binder key" for resumption PSKs. The different labels prevents the substitution of one type of PSK for the other.

There are multiple potential Early Secret values depending on which PSK the server ultimately selects. The client will need to compute one for each potential PSK; if no PSK is selected, it will then need to compute the early secret corresponding to the zero PSK.

7.2. Updating Traffic Keys and IVs

Once the handshake is complete, it is possible for either side to update its sending traffic keys using the KeyUpdate handshake message defined in [Section 4.5.3](#). The next generation of traffic keys is computed by generating client_/server_traffic_secret_N+1 from client_/server_traffic_secret_N as described in this section then re-deriving the traffic keys as described in [Section 7.3](#).

The next-generation traffic_secret is computed as:

```
traffic_secret_N+1 = HKDF-Expand-Label(  
    traffic_secret_N,  
    "application traffic secret", "", Hash.length)
```

Once client/server_traffic_secret_N+1 and its associated traffic keys have been computed, implementations SHOULD delete client_/server_traffic_secret_N and its associated traffic keys.

7.3. Traffic Key Calculation

The traffic keying material is generated from the following input values:

- A secret value

- A purpose value indicating the specific value being generated
- The length of the key

The traffic keying material is generated from an input traffic secret value using:

```
[sender]_write_key = HKDF-Expand-Label(Secret, "key", "", key_length)
[sender]_write_iv = HKDF-Expand-Label(Secret, "iv", "", iv_length)
```

[sender] denotes the sending side. The Secret value for each record type is shown in the table below.

Record Type	Secret
0-RTT Application	client_early_traffic_secret
Handshake	[sender]_handshake_traffic_secret
Application Data	[sender]_traffic_secret_N

All the traffic keying material is recomputed whenever the underlying Secret changes (e.g., when changing from the handshake to application data keys or upon a key update).

7.3.1. Diffie-Hellman

A conventional Diffie-Hellman computation is performed. The negotiated key (Z) is converted to byte string by encoding in big-endian, padded with zeros up to the size of the prime. This byte string is used as the shared secret, and is used in the key schedule as specified above.

Note that this construction differs from previous versions of TLS which remove leading zeros.

7.3.2. Elliptic Curve Diffie-Hellman

For secp256r1, secp384r1 and secp521r1, ECDH calculations (including parameter and key generation as well as the shared secret calculation) are performed according to [IEEE1363] using the ECKAS-DH1 scheme with the identity map as key derivation function (KDF), so that the shared secret is the x-coordinate of the ECDH shared secret elliptic curve point represented as an octet string. Note that this octet string (Z in IEEE 1363 terminology) as output by FE2OSP, the Field Element to Octet String Conversion Primitive, has constant

length for any given field; leading zeros found in this octet string MUST NOT be truncated.

(Note that this use of the identity KDF is a technicality. The complete picture is that ECDH is employed with a non-trivial KDF because TLS does not directly use this secret for anything other than for computing other secrets.)

ECDH functions are used as follows:

- The public key to put into the `KeyShareEntry.key_exchange` structure is the result of applying the ECDH function to the secret key of appropriate length (into scalar input) and the standard public basepoint (into u-coordinate point input).
- The ECDH shared secret is the result of applying ECDH function to the secret key (into scalar input) and the peer's public key (into u-coordinate point input). The output is used raw, with no processing.

For X25519 and X448, see [[RFC7748](#)].

7.3.3. Exporters

[RFC5705] defines keying material exporters for TLS in terms of the TLS PRF. This document replaces the PRF with HKDF, thus requiring a new construction. The exporter interface remains the same. If context is provided, the value is computed as:

```
HKDF-Expand-Label(Secret, label, context_value, key_length)
```

Where `Secret` is either the `early_exporter_secret` or the `exporter_secret`. Implementations MUST use the `exporter_secret` unless explicitly specified by the application. When adding TLS 1.3 to TLS 1.2 stacks, the `exporter_secret` MUST be for the existing exporter interface.

If no context is provided, the value is computed as:

```
HKDF-Expand-Label(Secret, label, "", key_length)
```

Note that providing no context computes the same value as providing an empty context. As of this document's publication, no allocated exporter label is used with both modes. Future specifications MUST NOT provide an empty context and no context with the same label and SHOULD provide a context, possibly empty, in all exporter computations.

8. Compliance Requirements

8.1. MTI Cipher Suites

In the absence of an application profile standard specifying otherwise, a TLS-compliant application MUST implement the TLS_AES_128_GCM_SHA256 cipher suite and SHOULD implement the TLS_AES_256_GCM_SHA384 and TLS_CHACHA20_POLY1305_SHA256 cipher suites. (see [Appendix A.4](#))

A TLS-compliant application MUST support digital signatures with rsa_pkcs1_sha256 (for certificates), rsa_pss_sha256 (for CertificateVerify and certificates), and ecdsa_secp256r1_sha256. A TLS-compliant application MUST support key exchange with secp256r1 (NIST P-256) and SHOULD support key exchange with X25519 [[RFC7748](#)].

8.2. MTI Extensions

In the absence of an application profile standard specifying otherwise, a TLS-compliant application MUST implement the following TLS extensions:

- Supported Versions ("supported_versions"; [Section 4.2.1](#))
- Cookie ("cookie"; [Section 4.2.2](#))
- Signature Algorithms ("signature_algorithms"; [Section 4.2.3](#))
- Negotiated Groups ("supported_groups"; [Section 4.2.4](#))
- Key Share ("key_share"; [Section 4.2.5](#))
- Pre-Shared Key ("pre_shared_key"; [Section 4.2.6](#))
- Server Name Indication ("server_name"; [Section 3 of \[RFC6066\]](#))

All implementations MUST send and use these extensions when offering applicable features:

- "supported_versions" is REQUIRED for all ClientHello messages.
- "signature_algorithms" is REQUIRED for certificate authentication.
- "supported_groups" and "key_share" are REQUIRED for DHE or ECDHE key exchange.
- "pre_shared_key" is REQUIRED for PSK key agreement.

A client is considered to be attempting to negotiate using this specification if the ClientHello contains a "supported_versions" extension with a version indicating TLS 1.3. Such a ClientHello message MUST meet the following requirements:

- If not containing a "pre_shared_key" extension, it MUST contain both a "signature_algorithms" extension and a "supported_groups" extension.
- If containing a "supported_groups" extension, it MUST also contain a "key_share" extension, and vice versa. (an empty KeyShare.client_shares vector is permitted)

Servers receiving a ClientHello which does not conform to these requirements MUST abort the handshake with a "missing_extension" alert.

Additionally, all implementations MUST support use of the "server_name" extension with applications capable of using it. Servers MAY require clients to send a valid "server_name" extension. Servers requiring this extension SHOULD respond to a ClientHello lacking a "server_name" extension by terminating the connection with a "missing_extension" alert.

9. Security Considerations

Security issues are discussed throughout this memo, especially in [Appendix B](#), [Appendix C](#), and [Appendix D](#).

10. IANA Considerations

This document uses several registries that were originally created in [\[RFC4346\]](#). IANA has updated these to reference this document. The registries and their allocation policies are below:

- TLS Cipher Suite Registry: Values with the first byte in the range 0-254 (decimal) are assigned via Specification Required [\[RFC5226\]](#). Values with the first byte 255 (decimal) are reserved for Private Use [\[RFC5226\]](#).

IANA [SHALL add/has added] the cipher suites listed in [Appendix A.4](#) to the registry. The "Value" and "Description" columns are taken from the table. The "DTLS-OK" and "Recommended" columns are both marked as "Yes" for each new cipher suite. [[This assumes [\[I-D.sandj-tls-iana-registry-updates\]](#) has been applied.]]

- TLS ContentType Registry: Future values are allocated via Standards Action [[RFC5226](#)].
- TLS Alert Registry: Future values are allocated via Standards Action [[RFC5226](#)]. IANA [SHALL update/has updated] this registry to include values for "end_of_early_data" and "missing_extension".
- TLS HandshakeType Registry: Future values are allocated via Standards Action [[RFC5226](#)]. IANA [SHALL update/has updated] this registry to rename item 4 from "NewSessionTicket" to "new_session_ticket" and to add the "hello_retry_request", "encrypted_extensions", and "key_update" values.

This document also uses a registry originally created in [[RFC4366](#)]. IANA has updated it to reference this document. The registry and its allocation policy is listed below:

- TLS ExtensionType Registry: Values with the first byte in the range 0-254 (decimal) are assigned via Specification Required [[RFC5226](#)]. Values with the first byte 255 (decimal) are reserved for Private Use [[RFC5226](#)]. IANA [SHALL update/has updated] this registry to include the "key_share", "pre_shared_key", and "early_data" extensions as defined in this document.

IANA [shall update/has updated] this registry to add a "Recommended" column. IANA [shall/has] initially populated this column with the values in the table below. This table has been generated by marking Standards Track RFCs as "Yes" and all others as "No".

IANA [shall update/has updated] this registry to include a "TLS 1.3" column with the following six values: "Client", indicating that the server shall not send them. "Clear", indicating that they shall be in the ServerHello. "Encrypted", indicating that they shall be in the EncryptedExtensions block, "Certificate" indicating that they shall be in the Certificate block, "Ticket" indicating that they can appear in the NewSessionTicket message (only) and "No" indicating that they are not used in TLS 1.3. This column [shall be/has been] initially populated with the values in this document.

IANA [shall update/has updated] this registry to include a "HelloRetryRequest" column with the following two values: "Yes", indicating it may be sent in HelloRetryRequest, and "No", indicating it may not be sent in HelloRetryRequest. This column [shall be/has been] initially populated with the values in this document.

Extension	Recommended	TLS 1.3	HelloRetryRequest
server_name [RFC6066]	Yes	Encrypted	No
max_fragment_length [RFC6066]	Yes	Encrypted	No
client_certificate_url [RFC6066]	Yes	Encrypted	No
trusted_ca_keys [RFC6066]	Yes	Encrypted	No
truncated_hmac [RFC6066]	Yes	No	No
status_request [RFC6066]	Yes	Certificate	No
user_mapping [RFC4681]	Yes	Encrypted	No
client_authz [RFC5878]	No	No	No
server_authz [RFC5878]	No	No	No
cert_type [RFC6091]	Yes	Encrypted	No
supported_groups [RFC7919]	Yes	Encrypted	No
ec_point_formats [RFC4492]	Yes	No	No
srp [RFC5054]	No	No	No
signature_algorithms [RFC5246]	Yes	Client	No
use_srtp [RFC5764]	Yes	Encrypted	No
heartbeat [RFC6520]	Yes	Encrypted	No
application_layer_protocol_	Yes	Encrypted	No

negotiation [RFC7301]			d	
status_request_v2 [RFC6961]	Yes	Certificate		No
signed_certificate_timestamp [RFC6962]	No	Certificate		No
client_certificate_type [RFC7250]	Yes	Encrypted		No
server_certificate_type [RFC7250]	Yes	Certificate		No
padding [RFC7685]	Yes	Client		No
encrypt_then_mac [RFC7366]	Yes	No		No
extended_master_secret [RFC7627]	Yes	No		No
SessionTicket TLS [RFC4507]	Yes	No		No
renegotiation_info [RFC5746]	Yes	No		No
key_share [[this document]]	Yes	Clear		Yes
pre_shared_key [[this document]]	Yes	Clear		No
psk_key_exchange_modes [[this document]]	Yes	Client		No
early_data [[this document]]	Yes	Encrypted		No
cookie [[this document]]	Yes	Client		Yes
supported_versions [[this document]]	Yes	Client		No
ticket_early_data_info [[this document]]	Yes	Ticket		No
+-----+-----+-----+-----+				

IANA [SHALL update/has updated] this registry to include the values listed above that correspond to this document.

In addition, this document defines two new registries to be maintained by IANA

- TLS SignatureScheme Registry: Values with the first byte in the range 0-254 (decimal) are assigned via Specification Required [RFC5226]. Values with the first byte 255 (decimal) are reserved for Private Use [RFC5226]. Values with the first byte in the range 0-6 or with the second byte in the range 0-3 that are not currently allocated are reserved for backwards compatibility. This registry SHALL have a "Recommended" column. The registry [shall be/ has been] initially populated with the values described in Section 4.2.3. The following values SHALL be marked as "Recommended": ecdsa_secp256r1_sha256, ecdsa_secp384r1_sha384, rsa_pss_sha256, rsa_pss_sha384, rsa_pss_sha512, ed25519.

Finally, this document obsoletes the TLS HashAlgorithm Registry and the TLS SignatureAlgorithm Registry, both originally created in [RFC5246]. IANA [SHALL update/has updated] the TLS HashAlgorithm Registry to list values 7-223 as "Reserved" and the TLS SignatureAlgorithm Registry to list values 4-233 as "Reserved".

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[11.3.](#) URIs

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[Appendix A.](#) Protocol Data Structures and Constant Values

This section describes protocol types and constants. Values listed as `_RESERVED` were used in previous versions of TLS and are listed here for completeness. TLS 1.3 implementations **MUST NOT** send them but might receive them from older TLS implementations.

[A.1.](#) Record Layer

```
enum {
    invalid_RESERVED(0),
    change_cipher_spec_RESERVED(20),
    alert(21),
    handshake(22),
    application_data(23),
    (255)
} ContentType;

struct {
    ContentType type;
    ProtocolVersion legacy_record_version = 0x0301; /* TLS v1.x */
    uint16 length;
    opaque fragment[TLSPplaintext.length];
} TLSPplaintext;

struct {
    opaque content[TLSPplaintext.length];
    ContentType type;
    uint8 zeros[length_of_padding];
} TLSInnerPlaintext;

struct {
    ContentType opaque_type = 23; /* application_data */
    ProtocolVersion legacy_record_version = 0x0301; /* TLS v1.x */
    uint16 length;
    opaque encrypted_record[length];
} TLSCiphertext;
```

[A.2.](#) Alert Messages


```
enum { warning(1), fatal(2), (255) } AlertLevel;
```

```
enum {  
    close_notify(0),  
    end_of_early_data(1),  
    unexpected_message(10),  
    bad_record_mac(20),  
    decryption_failed_RESERVED(21),  
    record_overflow(22),  
    decompression_failure_RESERVED(30),  
    handshake_failure(40),  
    no_certificate_RESERVED(41),  
    bad_certificate(42),  
    unsupported_certificate(43),  
    certificate_revoked(44),  
    certificate_expired(45),  
    certificate_unknown(46),  
    illegal_parameter(47),  
    unknown_ca(48),  
    access_denied(49),  
    decode_error(50),  
    decrypt_error(51),  
    export_restriction_RESERVED(60),  
    protocol_version(70),  
    insufficient_security(71),  
    internal_error(80),  
    inappropriate_fallback(86),  
    user_canceled(90),  
    no_renegotiation_RESERVED(100),  
    missing_extension(109),  
    unsupported_extension(110),  
    certificate_unobtainable(111),  
    unrecognized_name(112),  
    bad_certificate_status_response(113),  
    bad_certificate_hash_value(114),  
    unknown_psk_identity(115),  
    certificate_required(116),  
    (255)
```

```
} AlertDescription;
```

```
struct {  
    AlertLevel level;  
    AlertDescription description;  
} Alert;
```


[A.3.](#) Handshake Protocol

```
enum {
    hello_request_RESERVED(0),
    client_hello(1),
    server_hello(2),
    new_session_ticket(4),
    hello_retry_request(6),
    encrypted_extensions(8),
    certificate(11),
    server_key_exchange_RESERVED(12),
    certificate_request(13),
    server_hello_done_RESERVED(14),
    certificate_verify(15),
    client_key_exchange_RESERVED(16),
    finished(20),
    key_update(24),
    (255)
} HandshakeType;

struct {
    HandshakeType msg_type;    /* handshake type */
    uint24 length;            /* bytes in message */
    select (Handshake.msg_type) {
        case client_hello:      ClientHello;
        case server_hello:      ServerHello;
        case hello_retry_request: HelloRetryRequest;
        case encrypted_extensions: EncryptedExtensions;
        case certificate_request: CertificateRequest;
        case certificate:        Certificate;
        case certificate_verify: CertificateVerify;
        case finished:           Finished;
        case new_session_ticket: NewSessionTicket;
        case key_update:         KeyUpdate;
    } body;
} Handshake;
```

[A.3.1.](#) Key Exchange Messages

```
uint16 ProtocolVersion;
opaque Random[32];

uint8 CipherSuite[2];    /* Cryptographic suite selector */

struct {
    ProtocolVersion legacy_version = 0x0303;    /* TLS v1.2 */
    Random random;
    opaque legacy_session_id<0..32>;
```



```
    CipherSuite cipher_suites<2..2^16-2>;
    opaque legacy_compression_methods<1..2^8-1>;
    Extension extensions<0..2^16-1>;
} ClientHello;

struct {
    ProtocolVersion version;
    Random random;
    CipherSuite cipher_suite;
    Extension extensions<0..2^16-1>;
} ServerHello;

struct {
    ProtocolVersion server_version;
    Extension extensions<2..2^16-1>;
} HelloRetryRequest;

struct {
    ExtensionType extension_type;
    opaque extension_data<0..2^16-1>;
} Extension;

enum {
    supported_groups(10),
    signature_algorithms(13),
    key_share(40),
    pre_shared_key(41),
    early_data(42),
    supported_versions(43),
    cookie(44),
    psk_key_exchange_modes(45),
    ticket_early_data_info(46),
    (65535)
} ExtensionType;

struct {
    NamedGroup group;
    opaque key_exchange<1..2^16-1>;
} KeyShareEntry;

struct {
    select (Handshake.msg_type) {
        case client_hello:
            KeyShareEntry client_shares<0..2^16-1>;

        case hello_retry_request:
            NamedGroup selected_group;
```



```
        case server_hello:
            KeyShareEntry server_share;
    };
} KeyShare;

struct {
    opaque identity<0..2^16-1>;
    uint32 obfuscated_ticket_age;
} PskIdentity;

opaque PskBinderEntry<32..255>;

struct {
    select (Handshake.msg_type) {
        case client_hello:
            PskIdentity identities<6..2^16-1>;
            PskBinderEntry binders<33..2^16-1>;

        case server_hello:
            uint16 selected_identity;
    };
} PreSharedKeyExtension;

enum { psk_ke(0), psk_dhe_ke(1), (255) } PskKeyExchangeMode;

struct {
    PskKeyExchangeMode ke_modes<1..255>;
} PskKeyExchangeModes;

struct {
} EarlyDataIndication;
```

[A.3.1.1.](#) Version Extension

```
struct {
    ProtocolVersion versions<2..254>;
} SupportedVersions;
```

[A.3.1.2.](#) Cookie Extension

```
struct {
    opaque cookie<1..2^16-1>;
} Cookie;
```


[A.3.1.3.](#) Signature Algorithm Extension

```
enum {  
    /* RSASSA-PKCS1-v1_5 algorithms */  
    rsa_pkcs1_sha1 (0x0201),  
    rsa_pkcs1_sha256 (0x0401),  
    rsa_pkcs1_sha384 (0x0501),  
    rsa_pkcs1_sha512 (0x0601),  
  
    /* ECDSA algorithms */  
    ecdsa_secp256r1_sha256 (0x0403),  
    ecdsa_secp384r1_sha384 (0x0503),  
    ecdsa_secp521r1_sha512 (0x0603),  
  
    /* RSASSA-PSS algorithms */  
    rsa_pss_sha256 (0x0804),  
    rsa_pss_sha384 (0x0805),  
    rsa_pss_sha512 (0x0806),  
  
    /* EdDSA algorithms */  
    ed25519 (0x0807),  
    ed448 (0x0808),  
  
    /* Reserved Code Points */  
    dsa_sha1_RESERVED (0x0202),  
    dsa_sha256_RESERVED (0x0402),  
    dsa_sha384_RESERVED (0x0502),  
    dsa_sha512_RESERVED (0x0602),  
    ecdsa_sha1_RESERVED (0x0203),  
    obsolete_RESERVED (0x0000..0x0200),  
    obsolete_RESERVED (0x0204..0x0400),  
    obsolete_RESERVED (0x0404..0x0500),  
    obsolete_RESERVED (0x0504..0x0600),  
    obsolete_RESERVED (0x0604..0x06FF),  
    private_use (0xFE00..0xFFFF),  
    (0xFFFF)  
} SignatureScheme;  
  
struct {  
    SignatureScheme supported_signature_algorithms<2..2^16-2>;  
} SignatureSchemeList;
```

[A.3.1.4.](#) Supported Groups Extension


```
enum {
    /* Elliptic Curve Groups (ECDHE) */
    obsolete_RESERVED (1..22),
    secp256r1 (23), secp384r1 (24), secp521r1 (25),
    obsolete_RESERVED (26..28),
    x25519 (29), x448 (30),

    /* Finite Field Groups (DHE) */
    ffdhe2048 (256), ffdhe3072 (257), ffdhe4096 (258),
    ffdhe6144 (259), ffdhe8192 (260),

    /* Reserved Code Points */
    ffdhe_private_use (0x01FC..0x01FF),
    ecdhe_private_use (0xFE00..0xFEFF),
    obsolete_RESERVED (0xFF01..0xFF02),
    (0xFFFF)
} NamedGroup;

struct {
    NamedGroup named_group_list<2..2^16-1>;
} NamedGroupList;
```

Values within "obsolete_RESERVED" ranges were used in previous versions of TLS and MUST NOT be offered or negotiated by TLS 1.3 implementations. The obsolete curves have various known/theoretical weaknesses or have had very little usage, in some cases only due to unintentional server configuration issues. They are no longer considered appropriate for general use and should be assumed to be potentially unsafe. The set of curves specified here is sufficient for interoperability with all currently deployed and properly configured TLS implementations.

[A.3.2.](#) Server Parameters Messages


```
struct {
    Extension extensions<0..2^16-1>;
} EncryptedExtensions;

opaque DistinguishedName<1..2^16-1>;

struct {
    opaque certificate_extension_oid<1..2^8-1>;
    opaque certificate_extension_values<0..2^16-1>;
} CertificateExtension;

struct {
    opaque certificate_request_context<0..2^8-1>;
    SignatureScheme
        supported_signature_algorithms<2..2^16-2>;
    DistinguishedName certificate_authorities<0..2^16-1>;
    CertificateExtension certificate_extensions<0..2^16-1>;
} CertificateRequest;
```

[A.3.3.](#) Authentication Messages

```
opaque ASN1Cert<1..2^24-1>;

struct {
    ASN1Cert cert_data;
    Extension extensions<0..2^16-1>;
} CertificateEntry;

struct {
    opaque certificate_request_context<0..2^8-1>;
    CertificateEntry certificate_list<0..2^24-1>;
} Certificate;

struct {
    SignatureScheme algorithm;
    opaque signature<0..2^16-1>;
} CertificateVerify;

struct {
    opaque verify_data[Hash.length];
} Finished;
```

[A.3.4.](#) Ticket Establishment


```

struct {
    uint32 ticket_lifetime;
    uint32 ticket_age_add;
    opaque ticket<1..2^16-1>;
    Extension extensions<0..2^16-2>;
} NewSessionTicket;

struct {
    uint32 max_early_data_size;
} TicketEarlyDataInfo;

```

[A.3.5.](#) Updating Keys

```

enum {
    update_not_requested(0), update_requested(1), (255)
} KeyUpdateRequest;

struct {
    KeyUpdateRequest request_update;
} KeyUpdate;

```

[A.4.](#) Cipher Suites

A symmetric cipher suite defines the pair of the AEAD algorithm and hash algorithm to be used with HKDF. Cipher suite names follow the naming convention:

```
CipherSuite TLS_AEAD_HASH = VALUE;
```

Component	Contents
TLS	The string "TLS"
AEAD	The AEAD algorithm used for record protection
HASH	The hash algorithm used with HKDF
VALUE	The two byte ID assigned for this cipher suite

This specification defines the following cipher suites for use with TLS 1.3.

Description	Value
TLS_AES_128_GCM_SHA256	{0x13,0x01}
TLS_AES_256_GCM_SHA384	{0x13,0x02}
TLS_CHACHA20_POLY1305_SHA256	{0x13,0x03}
TLS_AES_128_CCM_SHA256	{0x13,0x04}
TLS_AES_128_CCM_8_SHA256	{0x13,0x05}

The corresponding AEAD algorithms AEAD_AES_128_GCM, AEAD_AES_256_GCM, and AEAD_AES_128_CCM are defined in [RFC5116]. AEAD_CHACHA20_POLY1305 is defined in [RFC7539]. AEAD_AES_128_CCM_8 is defined in [RFC6655]. The corresponding hash algorithms are defined in [SHS].

Although TLS 1.3 uses the same cipher suite space as previous versions of TLS, TLS 1.3 cipher suites are defined differently, only specifying the symmetric ciphers, and cannot be used for TLS 1.2. Similarly, TLS 1.2 and lower cipher suites cannot be used with TLS 1.3.

New cipher suite values are assigned by IANA as described in [Section 10](#).

Appendix B. Implementation Notes

The TLS protocol cannot prevent many common security mistakes. This section provides several recommendations to assist implementors.

B.1. API considerations for 0-RTT

0-RTT data has very different security properties from data transmitted after a completed handshake: it can be replayed. Implementations SHOULD provide different functions for reading and writing 0-RTT data and data transmitted after the handshake, and SHOULD NOT automatically resend 0-RTT data if it is rejected by the server.

B.2. Random Number Generation and Seeding

TLS requires a cryptographically secure pseudorandom number generator (PRNG). In most cases, the operating system provides an appropriate facility such as /dev/urandom, which should be used absent other

(performance) concerns. It is generally preferable to use an existing PRNG implementation in preference to crafting a new one, and many adequate cryptographic libraries are already available under favorable license terms. Should those prove unsatisfactory, [\[RFC4086\]](#) provides guidance on the generation of random values.

[B.3.](#) Certificates and Authentication

Implementations are responsible for verifying the integrity of certificates and should generally support certificate revocation messages. Certificates should always be verified to ensure proper signing by a trusted Certificate Authority (CA). The selection and addition of trusted CAs should be done very carefully. Users should be able to view information about the certificate and root CA. Applications SHOULD also enforce minimum and maximum key sizes. For example, certification paths containing keys or signatures weaker than 2048-bit RSA or 224-bit ECDSA are not appropriate for secure applications.

[B.4.](#) Implementation Pitfalls

Implementation experience has shown that certain parts of earlier TLS specifications are not easy to understand, and have been a source of interoperability and security problems. Many of these areas have been clarified in this document, but this appendix contains a short list of the most important things that require special attention from implementors.

TLS protocol issues:

- Do you correctly handle handshake messages that are fragmented to multiple TLS records (see [Section 5.1](#))? Including corner cases like a ClientHello that is split to several small fragments? Do you fragment handshake messages that exceed the maximum fragment size? In particular, the certificate and certificate request handshake messages can be large enough to require fragmentation.
- Do you ignore the TLS record layer version number in all TLS records? (see [Appendix C](#))
- Have you ensured that all support for SSL, RC4, EXPORT ciphers, and MD5 (via the "signature_algorithms" extension) is completely removed from all possible configurations that support TLS 1.3 or later, and that attempts to use these obsolete capabilities fail correctly? (see [Appendix C](#))
- Do you handle TLS extensions in ClientHello correctly, including unknown extensions.

- When the server has requested a client certificate, but no suitable certificate is available, do you correctly send an empty Certificate message, instead of omitting the whole message (see [Section 4.4.1.3](#))?
- When processing the plaintext fragment produced by AEAD-Decrypt and scanning from the end for the ContentType, do you avoid scanning past the start of the cleartext in the event that the peer has sent a malformed plaintext of all-zeros?
- Do you properly ignore unrecognized cipher suites ([Section 4.1.2](#)), hello extensions ([Section 4.2](#)), named groups ([Section 4.2.4](#)), and signature algorithms ([Section 4.2.3](#))?

Cryptographic details:

- What countermeasures do you use to prevent timing attacks [[TIMING](#)]?
- When verifying RSA signatures, do you accept both NULL and missing parameters? Do you verify that the RSA padding doesn't have additional data after the hash value? [[FI06](#)]
- When using Diffie-Hellman key exchange, do you correctly preserve leading zero bytes in the negotiated key (see [Section 7.3.1](#))?
- Does your TLS client check that the Diffie-Hellman parameters sent by the server are acceptable, (see [Section 4.2.5.1](#))?
- Do you use a strong and, most importantly, properly seeded random number generator (see [Appendix B.2](#)) when generating Diffie-Hellman private values, the ECDSA "k" parameter, and other security-critical values? It is RECOMMENDED that implementations implement "deterministic ECDSA" as specified in [[RFC6979](#)].
- Do you zero-pad Diffie-Hellman public key values to the group size (see [Section 4.2.5.1](#))?
- Do you verify signatures after making them to protect against RSA-CRT key leaks? [[FW15](#)]

[B.5.](#) Client Tracking Prevention

Clients SHOULD NOT reuse a session ticket for multiple connections. Reuse of a session ticket allows passive observers to correlate different connections. Servers that issue session tickets SHOULD offer at least as many session tickets as the number of connections that a client might use; for example, a web browser using HTTP/1.1

[RFC7230] might open six connections to a server. Servers SHOULD issue new session tickets with every connection. This ensures that clients are always able to use a new session ticket when creating a new connection.

B.6. Unauthenticated Operation

Previous versions of TLS offered explicitly unauthenticated cipher suites based on anonymous Diffie-Hellman. These modes have been deprecated in TLS 1.3. However, it is still possible to negotiate parameters that do not provide verifiable server authentication by several methods, including:

- Raw public keys [[RFC7250](#)].
- Using a public key contained in a certificate but without validation of the certificate chain or any of its contents.

Either technique used alone is vulnerable to man-in-the-middle attacks and therefore unsafe for general use. However, it is also possible to bind such connections to an external authentication mechanism via out-of-band validation of the server's public key, trust on first use, or channel bindings [[RFC5929](#)]. [[NOTE: TLS 1.3 needs a new channel binding definition that has not yet been defined.]] If no such mechanism is used, then the connection has no protection against active man-in-the-middle attack; applications MUST NOT use TLS in such a way absent explicit configuration or a specific application profile.

Appendix C. Backward Compatibility

The TLS protocol provides a built-in mechanism for version negotiation between endpoints potentially supporting different versions of TLS.

TLS 1.x and SSL 3.0 use compatible ClientHello messages. Servers can also handle clients trying to use future versions of TLS as long as the ClientHello format remains compatible and the client supports the highest protocol version available in the server.

Prior versions of TLS used the record layer version number for various purposes. (TLSPlaintext.legacy_record_version & TLSCiphertext.legacy_record_version) As of TLS 1.3, this field is deprecated and its value MUST be ignored by all implementations. Version negotiation is performed using only the handshake versions. (ClientHello.legacy_version, ClientHello "supported_versions" extension & ServerHello.version) In order to maximize interoperability with older endpoints, implementations that negotiate

the use of TLS 1.0-1.2 SHOULD set the record layer version number to the negotiated version for the ServerHello and all records thereafter.

For maximum compatibility with previously non-standard behavior and misconfigured deployments, all implementations SHOULD support validation of certification paths based on the expectations in this document, even when handling prior TLS versions' handshakes. (see [Section 4.4.1.2](#))

TLS 1.2 and prior supported an "Extended Master Secret" [[RFC7627](#)] extension which digested large parts of the handshake transcript into the master secret. Because TLS 1.3 always hashes in the transcript up to the server CertificateVerify, implementations which support both TLS 1.3 and earlier versions SHOULD indicate the use of the Extended Master Secret extension in their APIs whenever TLS 1.3 is used.

[C.1.](#) Negotiating with an older server

A TLS 1.3 client who wishes to negotiate with such older servers will send a normal TLS 1.3 ClientHello containing 0x0303 (TLS 1.2) in ClientHello.legacy_version but with the correct version in the "supported_versions" extension. If the server does not support TLS 1.3 it will respond with a ServerHello containing an older version number. If the client agrees to use this version, the negotiation will proceed as appropriate for the negotiated protocol. A client resuming a session SHOULD initiate the connection using the version that was previously negotiated.

Note that 0-RTT data is not compatible with older servers. See [Appendix C.3](#).

If the version chosen by the server is not supported by the client (or not acceptable), the client MUST abort the handshake with a "protocol_version" alert.

Some legacy server implementations are known to not implement the TLS specification properly and might abort connections upon encountering TLS extensions or versions which it is not aware of.

Interoperability with buggy servers is a complex topic beyond the scope of this document. Multiple connection attempts may be required in order to negotiate a backwards compatible connection, however this practice is vulnerable to downgrade attacks and is NOT RECOMMENDED.

C.2. Negotiating with an older client

A TLS server can also receive a ClientHello indicating a version number smaller than its highest supported version. If the "supported_versions" extension is present, the server MUST negotiate using that extension as described in [Section 4.2.1](#). If the "supported_versions" extension is not present, the server MUST negotiate the minimum of ClientHello.legacy_version and TLS 1.2. For example, if the server supports TLS 1.0, 1.1, and 1.2, and legacy_version is TLS 1.0, the server will proceed with a TLS 1.0 ServerHello. If the server only supports versions greater than ClientHello.legacy_version, it MUST abort the handshake with a "protocol_version" alert.

Note that earlier versions of TLS did not clearly specify the record layer version number value in all cases (TLSPlaintext.legacy_record_version). Servers will receive various TLS 1.x versions in this field, however its value MUST always be ignored.

C.3. Zero-RTT backwards compatibility

0-RTT data is not compatible with older servers. An older server will respond to the ClientHello with an older ServerHello, but it will not correctly skip the 0-RTT data and fail to complete the handshake. This can cause issues when a client attempts to use 0-RTT, particularly against multi-server deployments. For example, a deployment could deploy TLS 1.3 gradually with some servers implementing TLS 1.3 and some implementing TLS 1.2, or a TLS 1.3 deployment could be downgraded to TLS 1.2.

A client that attempts to send 0-RTT data MUST fail a connection if it receives a ServerHello with TLS 1.2 or older. A client that attempts to repair this error SHOULD NOT send a TLS 1.2 ClientHello, but instead send a TLS 1.3 ClientHello without 0-RTT data.

To avoid this error condition, multi-server deployments SHOULD ensure a uniform and stable deployment of TLS 1.3 without 0-RTT prior to enabling 0-RTT.

C.4. Backwards Compatibility Security Restrictions

If an implementation negotiates use of TLS 1.2, then negotiation of cipher suites also supported by TLS 1.3 SHOULD be preferred, if available.

The security of RC4 cipher suites is considered insufficient for the reasons cited in [\[RFC7465\]](#). Implementations MUST NOT offer or negotiate RC4 cipher suites for any version of TLS for any reason.

Old versions of TLS permitted the use of very low strength ciphers. Ciphers with a strength less than 112 bits MUST NOT be offered or negotiated for any version of TLS for any reason.

The security of SSL 2.0 [\[SSL2\]](#) is considered insufficient for the reasons enumerated in [\[RFC6176\]](#), and MUST NOT be negotiated for any reason.

Implementations MUST NOT send an SSL version 2.0 compatible CLIENT-HELLO. Implementations MUST NOT negotiate TLS 1.3 or later using an SSL version 2.0 compatible CLIENT-HELLO. Implementations are NOT RECOMMENDED to accept an SSL version 2.0 compatible CLIENT-HELLO in order to negotiate older versions of TLS.

Implementations MUST NOT send or accept any records with a version less than 0x0300.

The security of SSL 3.0 [\[SSL3\]](#) is considered insufficient for the reasons enumerated in [\[RFC7568\]](#), and MUST NOT be negotiated for any reason.

Implementations MUST NOT send a ClientHello.legacy_version or ServerHello.version set to 0x0300 or less. Any endpoint receiving a Hello message with ClientHello.legacy_version or ServerHello.version set to 0x0300 MUST abort the handshake with a "protocol_version" alert.

Implementations MUST NOT use the Truncated HMAC extension, defined in [Section 7 of \[RFC6066\]](#), as it is not applicable to AEAD algorithms and has been shown to be insecure in some scenarios.

[Appendix D](#). Overview of Security Properties

A complete security analysis of TLS is outside the scope of this document. In this section, we provide an informal description the desired properties as well as references to more detailed work in the research literature which provides more formal definitions.

We cover properties of the handshake separately from those of the record layer.

D.1. Handshake

The TLS handshake is an Authenticated Key Exchange (AKE) protocol which is intended to provide both one-way authenticated (server-only) and mutually authenticated (client and server) functionality. At the completion of the handshake, each side outputs its view on the following values:

- A "session key" (the master secret) from which can be derived a set of working keys.
- A set of cryptographic parameters (algorithms, etc.)
- The identities of the communicating parties.

We assume that the attacker has complete control of the network in between the parties [[RFC3552](#)]. Even under these conditions, the handshake should provide the properties listed below. Note that these properties are not necessarily independent, but reflect the protocol consumers' needs.

Establishing the same session key. The handshake needs to output the same session key on both sides of the handshake, provided that it completes successfully on each endpoint (See [[CK01](#)]; defn 1, part 1).

Secrecy of the session key. The shared session key should be known only to the communicating parties, not to the attacker (See [[CK01](#)]; defn 1, part 2). Note that in a unilaterally authenticated connection, the attacker can establish its own session keys with the server, but those session keys are distinct from those established by the client.

Peer Authentication. The client's view of the peer identity should reflect the server's identity. If the client is authenticated, the server's view of the peer identity should match the client's identity.

Uniqueness of the session key: Any two distinct handshakes should produce distinct, unrelated session keys.

Downgrade protection. The cryptographic parameters should be the same on both sides and should be the same as if the peers had been communicating in the absence of an attack (See [[BBFKZG16](#)]; defns 8 and 9).

Forward secret If the long-term keying material (in this case the signature keys in certificate-based authentication modes or the

PSK in PSK-(EC)DHE modes) are compromised after the handshake is complete, this does not compromise the security of the session key (See [[DOW92](#)]).

Protection of endpoint identities. The server's identity (certificate) should be protected against passive attackers. The client's identity should be protected against both passive and active attackers.

Informally, the signature-based modes of TLS 1.3 provide for the establishment of a unique, secret, shared, key established by an (EC)DHE key exchange and authenticated by the server's signature over the handshake transcript, as well as tied to the server's identity by a MAC. If the client is authenticated by a certificate, it also signs over the handshake transcript and provides a MAC tied to both identities. [[SIGMA](#)] describes the analysis of this type of key exchange protocol. If fresh (EC)DHE keys are used for each connection, then the output keys are forward secret.

The PSK and resumption-PSK modes bootstrap from a long-term shared secret into a unique per-connection short-term session key. This secret may have been established in a previous handshake. If PSK-(EC)DHE modes are used, this session key will also be forward secret. The resumption-PSK mode has been designed so that the resumption master secret computed by connection N and needed to form connection N+1 is separate from the traffic keys used by connection N, thus providing forward secrecy between the connections.

The PSK binder value forms a binding between a PSK and the current handshake, as well as between the session where the PSK was established and the session where it was used. This binding transitively includes the original handshake transcript, because that transcript is digested into the values which produce the Resumption Master Secret. This requires that both the KDF used to produce the resumption master secret and the MAC used to compute the binder be collision resistant. These are properties of HKDF and HMAC respectively when used with collision resistant hash functions and producing output of at least 256 bits. Any future replacement of these functions MUST also provide collision resistance. Note: The binder does not cover the binder values from other PSKs, though they are included in the Finished MAC.

If an exporter is used, then it produces values which are unique and secret (because they are generated from a unique session key). Exporters computed with different labels and contexts are computationally independent, so it is not feasible to compute one from another or the session secret from the exported value. Note: exporters can produce arbitrary-length values. If exporters are to

be used as channel bindings, the exported value **MUST** be large enough to provide collision resistance. The exporters provided in TLS 1.3 are derived from the same handshake contexts as the early traffic keys and the application traffic keys respectively, and thus have similar security properties. Note that they do not include the client's certificate; future applications which wish to bind to the client's certificate may need to define a new exporter that includes the full handshake transcript.

For all handshake modes, the Finished MAC (and where present, the signature), prevents downgrade attacks. In addition, the use of certain bytes in the random nonces as described in [Section 4.1.3](#) allows the detection of downgrade to previous TLS versions.

As soon as the client and the server have exchanged enough information to establish shared keys, the remainder of the handshake is encrypted, thus providing protection against passive attackers. Because the server authenticates before the client, the client can ensure that it only reveals its identity to an authenticated server. Note that implementations must use the provided record padding mechanism during the handshake to avoid leaking information about the identities due to length.

The 0-RTT mode of operation generally provides the same security properties as 1-RTT data, with the two exceptions that the 0-RTT encryption keys do not provide full forward secrecy and that the server is not able to guarantee full uniqueness of the handshake (non-replayability) without keeping potentially undue amounts of state. See [Section 4.2.8](#) for one mechanism to limit the exposure to replay.

The reader should refer to the following references for analysis of the TLS handshake [[CHSV16](#)] [[FGSW16](#)] [[LXZFH16](#)].

[D.2.](#) Record Layer

The record layer depends on the handshake producing a strong session key which can be used to derive bidirectional traffic keys and nonces. Assuming that is true, and the keys are used for no more data than indicated in [Section 5.5](#) then the record layer should provide the following guarantees:

Confidentiality. An attacker should not be able to determine the plaintext contents of a given record.

Integrity. An attacker should not be able to craft a new record which is different from an existing record which will be accepted by the receiver.

Order protection/non-replayability An attacker should not be able to cause the receiver to accept a record which it has already accepted or cause the receiver to accept record N+1 without having first processed record N.

Length concealment. Given a record with a given external length, the attacker should not be able to determine the amount of the record that is content versus padding.

Forward security after key change. If the traffic key update mechanism described in [Section 4.5.3](#) has been used and the previous generation key is deleted, an attacker who compromises the endpoint should not be able to decrypt traffic encrypted with the old key.

Informally, TLS 1.3 provides these properties by AEAD-protecting the plaintext with a strong key. AEAD encryption [[RFC5116](#)] provides confidentiality and integrity for the data. Non-replayability is provided by using a separate nonce for each record, with the nonce being derived from the record sequence number ([Section 5.3](#)), with the sequence number being maintained independently at both sides thus records which are delivered out of order result in AEAD deprotection failures.

The plaintext protected by the AEAD function consists of content plus variable-length padding. Because the padding is also encrypted, the attacker cannot directly determine the length of the padding, but may be able to measure it indirectly by the use of timing channels exposed during record processing (i.e., seeing how long it takes to process a record). In general, it is not known how to remove this type of channel because even a constant time padding removal function will then feed the content into data-dependent functions.

Generation N+1 keys are derived from generation N keys via a key derivation function [Section 7.2](#). As long as this function is truly one way, it is not possible to compute the previous keys after a key change (forward secrecy). However, TLS does not provide security for data which is sent after the traffic secret is compromised, even after a key update (backward secrecy); systems which want backward secrecy must do a fresh handshake and establish a new session key with an (EC)DHE exchange.

The reader should refer to the following references for analysis of the TLS record layer.

Appendix E. Working Group Information

The discussion list for the IETF TLS working group is located at the e-mail address tls@ietf.org [1]. Information on the group and information on how to subscribe to the list is at <https://www.ietf.org/mailman/listinfo/tls>

Archives of the list can be found at: <https://www.ietf.org/mail-archive/web/tls/current/index.html>

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