

Datagram Transport Layer Security

Status of This Memo

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Abstract

This document specifies Version 1.0 of the Datagram Transport Layer Security (DTLS) protocol. The DTLS protocol provides communications privacy for datagram protocols. The protocol allows client/server applications to communicate in a way that is designed to prevent eavesdropping, tampering, or message forgery. The DTLS protocol is based on the Transport Layer Security (TLS) protocol and provides equivalent security guarantees. Datagram semantics of the underlying transport are preserved by the DTLS protocol.

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1. Introduction

TLS [TLS] is the most widely deployed protocol for securing network traffic. It is widely used for protecting Web traffic and for e-mail protocols such as IMAP [IMAP] and POP [POP]. The primary advantage of TLS is that it provides a transparent connection-oriented channel. Thus, it is easy to secure an application protocol by inserting TLS between the application layer and the transport layer. However, TLS must run over a reliable transport channel -- typically TCP [TCP]. It therefore cannot be used to secure unreliable datagram traffic.

However, over the past few years an increasing number of application layer protocols have been designed that use UDP transport. In particular protocols such as the Session Initiation Protocol (SIP) [SIP] and electronic gaming protocols are increasingly popular. (Note that SIP can run over both TCP and UDP, but that there are situations in which UDP is preferable). Currently, designers of these applications are faced with a number of unsatisfactory choices. First, they can use IPsec [RFC2401]. However, for a number of reasons detailed in [WHYIPSEC], this is only suitable for some applications. Second, they can design a custom application layer security protocol. SIP, for instance, uses a subset of S/MIME to

secure its traffic. Unfortunately, although application layer security protocols generally provide superior security properties (e.g., end-to-end security in the case of S/MIME), they typically require a large amount of effort to design -- in contrast to the relatively small amount of effort required to run the protocol over TLS.

In many cases, the most desirable way to secure client/server applications would be to use TLS; however, the requirement for datagram semantics automatically prohibits use of TLS. Thus, a datagram-compatible variant of TLS would be very desirable. This memo describes such a protocol: Datagram Transport Layer Security (DTLS). DTLS is deliberately designed to be as similar to TLS as possible, both to minimize new security invention and to maximize the amount of code and infrastructure reuse.

1.1. Requirements Terminology

In this document, the keywords "MUST", "MUST NOT", "REQUIRED", "SHOULD", "SHOULD NOT", and "MAY" are to be interpreted as described in RFC 2119 [REQ].

2. Usage Model

The DTLS protocol is designed to secure data between communicating applications. It is designed to run in application space, without requiring any kernel modifications.

Datagram transport does not require or provide reliable or in-order delivery of data. The DTLS protocol preserves this property for payload data. Applications such as media streaming, Internet telephony, and online gaming use datagram transport for communication due to the delay-sensitive nature of transported data. The behavior of such applications is unchanged when the DTLS protocol is used to secure communication, since the DTLS protocol does not compensate for lost or re-ordered data traffic.

3. Overview of DTLS

The basic design philosophy of DTLS is to construct "TLS over datagram". The reason that TLS cannot be used directly in datagram environments is simply that packets may be lost or reordered. TLS has no internal facilities to handle this kind of unreliability, and therefore TLS implementations break when rehosted on datagram transport. The purpose of DTLS is to make only the minimal changes to TLS required to fix this problem. To the greatest extent possible, DTLS is identical to TLS. Whenever we need to invent new mechanisms, we attempt to do so in such a way that preserves the style of TLS.

Unreliability creates problems for TLS at two levels:

1. TLS's traffic encryption layer does not allow independent decryption of individual records. If record N is not received, then record N+1 cannot be decrypted.
2. The TLS handshake layer assumes that handshake messages are delivered reliably and breaks if those messages are lost.

The rest of this section describes the approach that DTLS uses to solve these problems.

3.1. Loss-Insensitive Messaging

In TLS's traffic encryption layer (called the TLS Record Layer), records are not independent. There are two kinds of inter-record dependency:

1. Cryptographic context (CBC state, stream cipher key stream) is chained between records.
2. Anti-replay and message reordering protection are provided by a MAC that includes a sequence number, but the sequence numbers are implicit in the records.

The fix for both of these problems is straightforward and well known from IPsec ESP [ESP]: add explicit state to the records. TLS 1.1 [TLS11] is already adding explicit CBC state to TLS records. DTLS borrows that mechanism and adds explicit sequence numbers.

3.2. Providing Reliability for Handshake

The TLS handshake is a lockstep cryptographic handshake. Messages must be transmitted and received in a defined order, and any other order is an error. Clearly, this is incompatible with reordering and

message loss. In addition, TLS handshake messages are potentially larger than any given datagram, thus creating the problem of fragmentation. DTLS must provide fixes for both of these problems.

3.2.1. Packet Loss

DTLS uses a simple retransmission timer to handle packet loss. The following figure demonstrates the basic concept, using the first phase of the DTLS handshake:

```

Client                                Server
-----                                -----
ClientHello                          ----->

                                   X<-- HelloVerifyRequest
                                   (lost)

[Timer Expires]

ClientHello                          ----->
(retransmit)

```

Once the client has transmitted the ClientHello message, it expects to see a HelloVerifyRequest from the server. However, if the server's message is lost the client knows that either the ClientHello or the HelloVerifyRequest has been lost and retransmits. When the server receives the retransmission, it knows to retransmit. The server also maintains a retransmission timer and retransmits when that timer expires.

Note: timeout and retransmission do not apply to the HelloVerifyRequest, because this requires creating state on the server.

3.2.2. Reordering

In DTLS, each handshake message is assigned a specific sequence number within that handshake. When a peer receives a handshake message, it can quickly determine whether that message is the next message it expects. If it is, then it processes it. If not, it queues it up for future handling once all previous messages have been received.

3.2.3. Message Size

TLS and DTLS handshake messages can be quite large (in theory up to $2^{24}-1$ bytes, in practice many kilobytes). By contrast, UDP datagrams are often limited to <1500 bytes if fragmentation is not

desired. In order to compensate for this limitation, each DTLS handshake message may be fragmented over several DTLS records. Each DTLS handshake message contains both a fragment offset and a fragment length. Thus, a recipient in possession of all bytes of a handshake message can reassemble the original unfragmented message.

3.3. Replay Detection

DTLS optionally supports record replay detection. The technique used is the same as in IPsec AH/ESP, by maintaining a bitmap window of received records. Records that are too old to fit in the window and records that have previously been received are silently discarded. The replay detection feature is optional, since packet duplication is not always malicious, but can also occur due to routing errors. Applications may conceivably detect duplicate packets and accordingly modify their data transmission strategy.

4. Differences from TLS

As mentioned in Section 3, DTLS is intentionally very similar to TLS. Therefore, instead of presenting DTLS as a new protocol, we present it as a series of deltas from TLS 1.1 [TLS11]. Where we do not explicitly call out differences, DTLS is the same as in [TLS11].

4.1. Record Layer

The DTLS record layer is extremely similar to that of TLS 1.1. The only change is the inclusion of an explicit sequence number in the record. This sequence number allows the recipient to correctly verify the TLS MAC. The DTLS record format is shown below:

```
struct {
    ContentType type;
    ProtocolVersion version;
    uint16 epoch;                // New field
    uint48 sequence_number;      // New field
    uint16 length;
    opaque fragment[DTLSPlaintext.length];
} DTLSPlaintext;
```

type

Equivalent to the type field in a TLS 1.1 record.

version

The version of the protocol being employed. This document describes DTLS Version 1.0, which uses the version { 254, 255 }. The version value of 254.255 is the 1's complement of DTLS Version 1.0. This maximal spacing between TLS and DTLS version

numbers ensures that records from the two protocols can be easily distinguished. It should be noted that future on-the-wire version numbers of DTLS are decreasing in value (while the true version number is increasing in value.)

epoch

A counter value that is incremented on every cipher state change.

sequence_number

The sequence number for this record.

length

Identical to the length field in a TLS 1.1 record. As in TLS 1.1, the length should not exceed 2^{14} .

fragment

Identical to the fragment field of a TLS 1.1 record.

DTLS uses an explicit sequence number, rather than an implicit one, carried in the sequence_number field of the record. As with TLS, the sequence number is set to zero after each ChangeCipherSpec message is sent.

If several handshakes are performed in close succession, there might be multiple records on the wire with the same sequence number but from different cipher states. The epoch field allows recipients to distinguish such packets. The epoch number is initially zero and is incremented each time the ChangeCipherSpec messages is sent. In order to ensure that any given sequence/epoch pair is unique, implementations MUST NOT allow the same epoch value to be reused within two times the TCP maximum segment lifetime. In practice, TLS implementations rarely rehandshake and we therefore do not expect this to be a problem.

4.1.1. Transport Layer Mapping

Each DTLS record MUST fit within a single datagram. In order to avoid IP fragmentation [MOGUL], DTLS implementations SHOULD determine the MTU and send records smaller than the MTU. DTLS implementations SHOULD provide a way for applications to determine the value of the PMTU (or, alternately, the maximum application datagram size, which is the PMTU minus the DTLS per-record overhead). If the application attempts to send a record larger than the MTU, the DTLS implementation SHOULD generate an error, thus avoiding sending a packet which will be fragmented.

Note that unlike IPsec, DTLS records do not contain any association identifiers. Applications must arrange to multiplex between associations. With UDP, this is presumably done with host/port number.

Multiple DTLS records may be placed in a single datagram. They are simply encoded consecutively. The DTLS record framing is sufficient to determine the boundaries. Note, however, that the first byte of the datagram payload must be the beginning of a record. Records may not span datagrams.

Some transports, such as DCCP [DCCP] provide their own sequence numbers. When carried over those transports, both the DTLS and the transport sequence numbers will be present. Although this introduces a small amount of inefficiency, the transport layer and DTLS sequence numbers serve different purposes, and therefore for conceptual simplicity it is superior to use both sequence numbers. In the future, extensions to DTLS may be specified that allow the use of only one set of sequence numbers for deployment in constrained environments.

Some transports, such as DCCP, provide congestion control for traffic carried over them. If the congestion window is sufficiently narrow, DTLS handshake retransmissions may be held rather than transmitted immediately, potentially leading to timeouts and spurious retransmission. When DTLS is used over such transports, care should be taken not to overrun the likely congestion window. In the future, a DTLS-DCCP mapping may be specified to provide optimal behavior for this interaction.

4.1.1.1. PMTU Discovery

In general, DTLS's philosophy is to avoid dealing with PMTU issues. The general strategy is to start with a conservative MTU and then update it if events during the handshake or actual application data transport phase require it.

The PMTU SHOULD be initialized from the interface MTU that will be used to send packets. If the DTLS implementation receives an RFC 1191 [RFC1191] ICMP Destination Unreachable message with the "fragmentation needed and DF set" Code (otherwise known as Datagram Too Big), it should decrease its PMTU estimate to that given in the ICMP message. A DTLS implementation SHOULD allow the application to occasionally reset its PMTU estimate. The DTLS implementation SHOULD also allow applications to control the status of the DF bit. These controls allow the application to perform PMTU discovery. RFC 1981 [RFC1981] procedures SHOULD be followed for IPv6.

One special case is the DTLS handshake system. Handshake messages should be set with DF set. Because some firewalls and routers screen out ICMP messages, it is difficult for the handshake layer to distinguish packet loss from an overlarge PMTU estimate. In order to allow connections under these circumstances, DTLS implementations SHOULD back off handshake packet size during the retransmit backoff described in Section 4.2.4. For instance, if a large packet is being sent, after 3 retransmits the handshake layer might choose to fragment the handshake message on retransmission. In general, choice of a conservative initial MTU will avoid this problem.

4.1.2. Record Payload Protection

Like TLS, DTLS transmits data as a series of protected records. The rest of this section describes the details of that format.

4.1.2.1. MAC

The DTLS MAC is the same as that of TLS 1.1. However, rather than using TLS's implicit sequence number, the sequence number used to compute the MAC is the 64-bit value formed by concatenating the epoch and the sequence number in the order they appear on the wire. Note that the DTLS epoch + sequence number is the same length as the TLS sequence number.

TLS MAC calculation is parameterized on the protocol version number, which, in the case of DTLS, is the on-the-wire version, i.e., {254, 255 } for DTLS 1.0.

Note that one important difference between DTLS and TLS MAC handling is that in TLS MAC errors must result in connection termination. In DTLS, the receiving implementation MAY simply discard the offending record and continue with the connection. This change is possible because DTLS records are not dependent on each other in the way that TLS records are.

In general, DTLS implementations SHOULD silently discard data with bad MACs. If a DTLS implementation chooses to generate an alert when it receives a message with an invalid MAC, it MUST generate `bad_record_mac` alert with level fatal and terminate its connection state.

4.1.2.2. Null or Standard Stream Cipher

The DTLS NULL cipher is performed exactly as the TLS 1.1 NULL cipher.

The only stream cipher described in TLS 1.1 is RC4, which cannot be randomly accessed. RC4 MUST NOT be used with DTLS.

4.1.2.3. Block Cipher

DTLS block cipher encryption and decryption are performed exactly as with TLS 1.1.

4.1.2.4. New Cipher Suites

Upon registration, new TLS cipher suites MUST indicate whether they are suitable for DTLS usage and what, if any, adaptations must be made.

4.1.2.5. Anti-replay

DTLS records contain a sequence number to provide replay protection. Sequence number verification SHOULD be performed using the following sliding window procedure, borrowed from Section 3.4.3 of [RFC 2402].

The receiver packet counter for this session MUST be initialized to zero when the session is established. For each received record, the receiver MUST verify that the record contains a Sequence Number that does not duplicate the Sequence Number of any other record received during the life of this session. This SHOULD be the first check applied to a packet after it has been matched to a session, to speed rejection of duplicate records.

Duplicates are rejected through the use of a sliding receive window. (How the window is implemented is a local matter, but the following text describes the functionality that the implementation must exhibit.) A minimum window size of 32 MUST be supported, but a window size of 64 is preferred and SHOULD be employed as the default. Another window size (larger than the minimum) MAY be chosen by the receiver. (The receiver does not notify the sender of the window size.)

The "right" edge of the window represents the highest validated Sequence Number value received on this session. Records that contain Sequence Numbers lower than the "left" edge of the window are rejected. Packets falling within the window are checked against a list of received packets within the window. An efficient means for performing this check, based on the use of a bit mask, is described in Appendix C of [RFC 2401].

If the received record falls within the window and is new, or if the packet is to the right of the window, then the receiver proceeds to MAC verification. If the MAC validation fails, the receiver MUST discard the received record as invalid. The receive window is updated only if the MAC verification succeeds.

4.2. The DTLS Handshake Protocol

DTLS uses all of the same handshake messages and flows as TLS, with three principal changes:

1. A stateless cookie exchange has been added to prevent denial of service attacks.
2. Modifications to the handshake header to handle message loss, reordering, and fragmentation.
3. Retransmission timers to handle message loss.

With these exceptions, the DTLS message formats, flows, and logic are the same as those of TLS 1.1.

4.2.1. Denial of Service Countermeasures

Datagram security protocols are extremely susceptible to a variety of denial of service (DoS) attacks. Two attacks are of particular concern:

1. An attacker can consume excessive resources on the server by transmitting a series of handshake initiation requests, causing the server to allocate state and potentially to perform expensive cryptographic operations.
2. An attacker can use the server as an amplifier by sending connection initiation messages with a forged source of the victim. The server then sends its next message (in DTLS, a Certificate message, which can be quite large) to the victim machine, thus flooding it.

In order to counter both of these attacks, DTLS borrows the stateless cookie technique used by Photuris [PHOTURIS] and IKE [IKE]. When the client sends its ClientHello message to the server, the server MAY respond with a HelloVerifyRequest message. This message contains a stateless cookie generated using the technique of [PHOTURIS]. The client MUST retransmit the ClientHello with the cookie added. The server then verifies the cookie and proceeds with the handshake only if it is valid. This mechanism forces the attacker/client to be able to receive the cookie, which makes DoS attacks with spoofed IP addresses difficult. This mechanism does not provide any defense against DoS attacks mounted from valid IP addresses.

The exchange is shown below:

```

Client                                Server
-----
ClientHello                          ----->
                                     <----- HelloVerifyRequest
                                     (contains cookie)

ClientHello                          ----->
(with cookie)

[Rest of handshake]
```

DTLS therefore modifies the ClientHello message to add the cookie value.

```

struct {
    ProtocolVersion client_version;
    Random random;
    SessionID session_id;
    opaque cookie<0..32>;                                // New field
    CipherSuite cipher_suites<2..2^16-1>;
    CompressionMethod compression_methods<1..2^8-1>;
} ClientHello;
```

When sending the first ClientHello, the client does not have a cookie yet; in this case, the Cookie field is left empty (zero length).

The definition of HelloVerifyRequest is as follows:

```

struct {
    ProtocolVersion server_version;
    opaque cookie<0..32>;
} HelloVerifyRequest;
```

The HelloVerifyRequest message type is hello_verify_request(3).

The server_version field is defined as in TLS.

When responding to a HelloVerifyRequest the client MUST use the same parameter values (version, random, session_id, cipher_suites, compression_method) as it did in the original ClientHello. The server SHOULD use those values to generate its cookie and verify that they are correct upon cookie receipt. The server MUST use the same version number in the HelloVerifyRequest that it would use when sending a ServerHello. Upon receipt of the ServerHello, the client MUST verify that the server version values match.

The DTLS server SHOULD generate cookies in such a way that they can be verified without retaining any per-client state on the server. One technique is to have a randomly generated secret and generate cookies as: `Cookie = HMAC(Secret, Client-IP, Client-Parameters)`

When the second `ClientHello` is received, the server can verify that the `Cookie` is valid and that the client can receive packets at the given IP address.

One potential attack on this scheme is for the attacker to collect a number of cookies from different addresses and then reuse them to attack the server. The server can defend against this attack by changing the `Secret` value frequently, thus invalidating those cookies. If the server wishes that legitimate clients be able to handshake through the transition (e.g., they received a cookie with `Secret 1` and then sent the second `ClientHello` after the server has changed to `Secret 2`), the server can have a limited window during which it accepts both secrets. [IKEv2] suggests adding a version number to cookies to detect this case. An alternative approach is simply to try verifying with both secrets.

DTLS servers SHOULD perform a cookie exchange whenever a new handshake is being performed. If the server is being operated in an environment where amplification is not a problem, the server MAY be configured not to perform a cookie exchange. The default SHOULD be that the exchange is performed, however. In addition, the server MAY choose not to do a cookie exchange when a session is resumed. Clients MUST be prepared to do a cookie exchange with every handshake.

If `HelloVerifyRequest` is used, the initial `ClientHello` and `HelloVerifyRequest` are not included in the calculation of the `verify_data` for the `Finished` message.

4.2.2. Handshake Message Format

In order to support message loss, reordering, and fragmentation, DTLS modifies the TLS 1.1 handshake header:

```
struct {
    HandshakeType msg_type;
    uint24 length;
    uint16 message_seq;
    uint24 fragment_offset;
    uint24 fragment_length;
    select (HandshakeType) {
        case hello_request: HelloRequest;
        case client_hello: ClientHello;
```

// New field
// New field
// New field

```

        case hello_verify_request: HelloVerifyRequest; // New type
        case server_hello: ServerHello;
        case certificate: Certificate;
        case server_key_exchange: ServerKeyExchange;
        case certificate_request: CertificateRequest;
        case server_hello_done: ServerHelloDone;
        case certificate_verify: CertificateVerify;
        case client_key_exchange: ClientKeyExchange;
        case finished: Finished;
    } body;
} Handshake;

```

The first message each side transmits in each handshake always has `message_seq = 0`. Whenever each new message is generated, the `message_seq` value is incremented by one. When a message is retransmitted, the same `message_seq` value is used. For example:

```

Client                                Server
-----                                -
ClientHello (seq=0) ----->
                                X<-- HelloVerifyRequest (seq=0)
                                (lost)

[Timer Expires]

ClientHello (seq=0) ----->
(retransmit)
                                <----- HelloVerifyRequest (seq=0)

ClientHello (seq=1) ----->
(with cookie)
                                <----- ServerHello (seq=1)
                                <----- Certificate (seq=2)
                                <----- ServerHelloDone (seq=3)

```

[Rest of handshake]

Note, however, that from the perspective of the DTLS record layer, the retransmission is a new record. This record will have a new `DTLSPlaintext.sequence_number` value.

DTLS implementations maintain (at least notionally) a `next_receive_seq` counter. This counter is initially set to zero. When a message is received, if its sequence number matches `next_receive_seq`, `next_receive_seq` is incremented and the message is

processed. If the sequence number is less than `next_receive_seq`, the message MUST be discarded. If the sequence number is greater than `next_receive_seq`, the implementation SHOULD queue the message but MAY discard it. (This is a simple space/bandwidth tradeoff).

4.2.3. Message Fragmentation and Reassembly

As noted in Section 4.1.1, each DTLS message MUST fit within a single transport layer datagram. However, handshake messages are potentially bigger than the maximum record size. Therefore, DTLS provides a mechanism for fragmenting a handshake message over a number of records.

When transmitting the handshake message, the sender divides the message into a series of `N` contiguous data ranges. These ranges MUST NOT be larger than the maximum handshake fragment size and MUST jointly contain the entire handshake message. The ranges SHOULD NOT overlap. The sender then creates `N` handshake messages, all with the same `message_seq` value as the original handshake message. Each new message is labelled with the `fragment_offset` (the number of bytes contained in previous fragments) and the `fragment_length` (the length of this fragment). The length field in all messages is the same as the length field of the original message. An unfragmented message is a degenerate case with `fragment_offset=0` and `fragment_length=length`.

When a DTLS implementation receives a handshake message fragment, it MUST buffer it until it has the entire handshake message. DTLS implementations MUST be able to handle overlapping fragment ranges. This allows senders to retransmit handshake messages with smaller fragment sizes during path MTU discovery.

Note that as with TLS, multiple handshake messages may be placed in the same DTLS record, provided that there is room and that they are part of the same flight. Thus, there are two acceptable ways to pack two DTLS messages into the same datagram: in the same record or in separate records.

4.2.4. Timeout and Retransmission

DTLS messages are grouped into a series of message flights, according to the diagrams below. Although each flight of messages may consist of a number of messages, they should be viewed as monolithic for the purpose of timeout and retransmission.

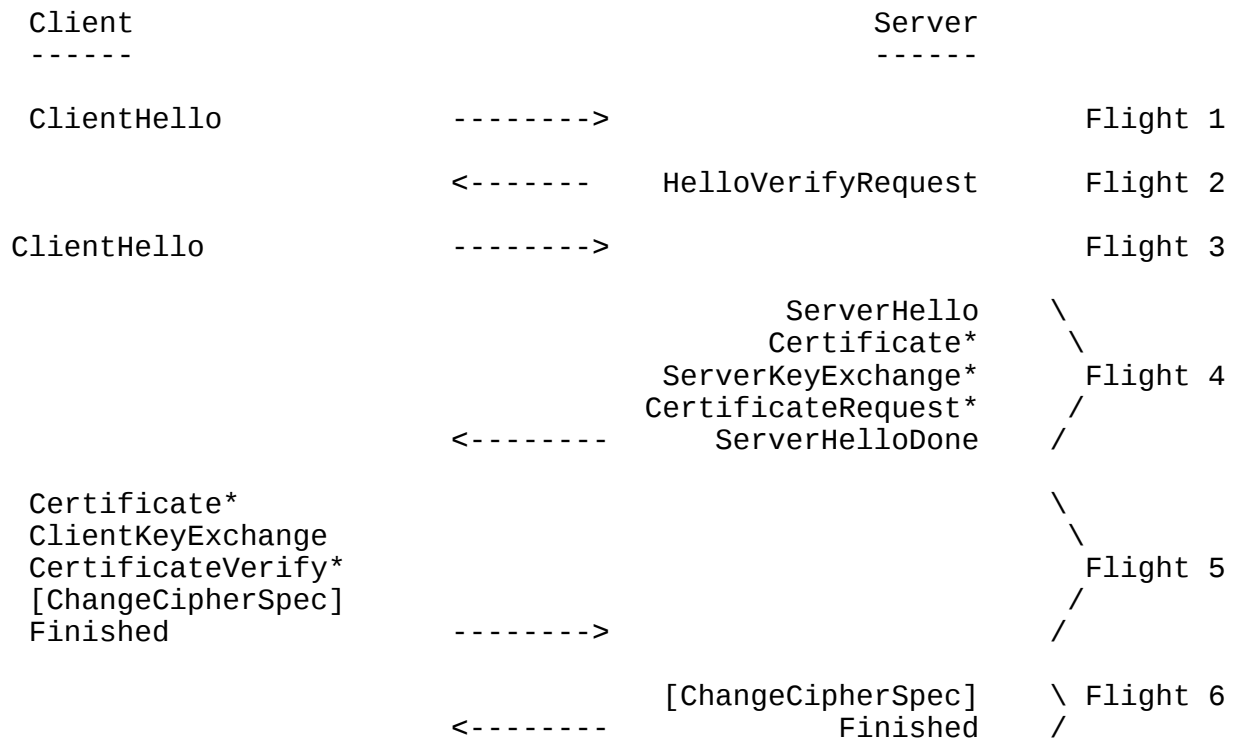
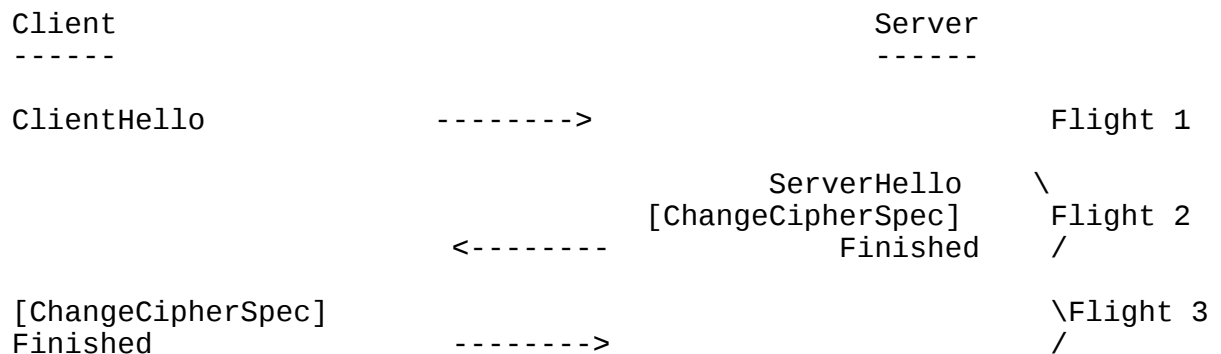


Figure 1. Message flights for full handshake

Figure 2. Message flights for session-resuming handshake
(no cookie exchange)

DTLS uses a simple timeout and retransmission scheme with the following state machine. Because DTLS clients send the first message (ClientHello), they start in the PREPARING state. DTLS servers start in the WAITING state, but with empty buffers and no retransmit timer.

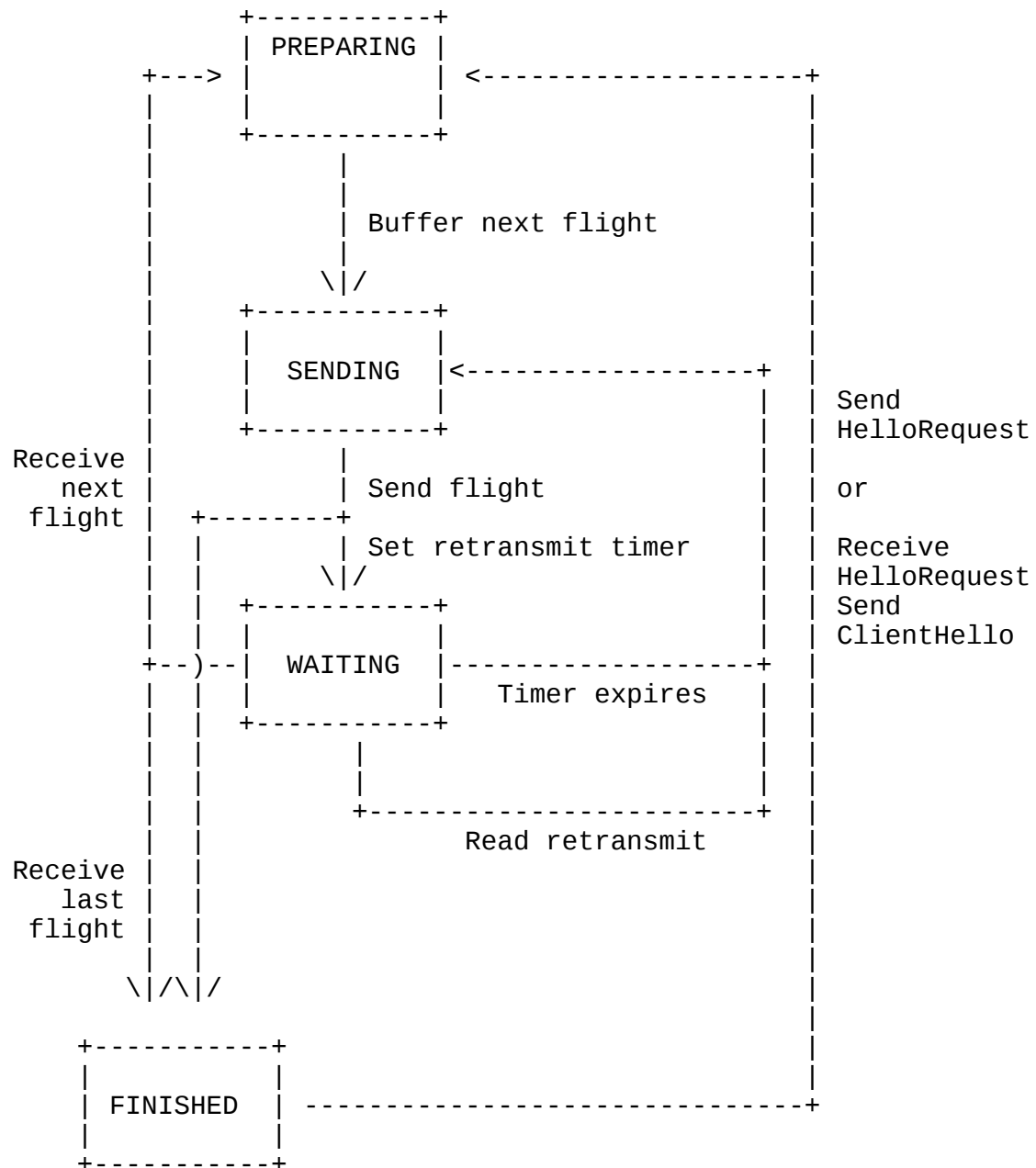


Figure 3. DTLS timeout and retransmission state machine

The state machine has three basic states.

In the PREPARING state the implementation does whatever computations are necessary to prepare the next flight of messages. It then buffers them up for transmission (emptying the buffer first) and enters the SENDING state.

In the SENDING state, the implementation transmits the buffered flight of messages. Once the messages have been sent, the implementation then enters the FINISHED state if this is the last flight in the handshake. Or, if the implementation expects to receive more messages, it sets a retransmit timer and then enters the WAITING state.

There are three ways to exit the WAITING state:

1. The retransmit timer expires: the implementation transitions to the SENDING state, where it retransmits the flight, resets the retransmit timer, and returns to the WAITING state.
2. The implementation reads a retransmitted flight from the peer: the implementation transitions to the SENDING state, where it retransmits the flight, resets the retransmit timer, and returns to the WAITING state. The rationale here is that the receipt of a duplicate message is the likely result of timer expiry on the peer and therefore suggests that part of one's previous flight was lost.
3. The implementation receives the next flight of messages: if this is the final flight of messages, the implementation transitions to FINISHED. If the implementation needs to send a new flight, it transitions to the PREPARING state. Partial reads (whether partial messages or only some of the messages in the flight) do not cause state transitions or timer resets.

Because DTLS clients send the first message (ClientHello), they start in the PREPARING state. DTLS servers start in the WAITING state, but with empty buffers and no retransmit timer.

When the server desires a rehandshake, it transitions from the FINISHED state to the PREPARING state to transmit the HelloRequest. When the client receives a HelloRequest it transitions from FINISHED to PREPARING to transmit the ClientHello.

4.2.4.1. Timer Values

Though timer values are the choice of the implementation, mishandling of the timer can lead to serious congestion problems; for example, if many instances of a DTLS time out early and retransmit too quickly on a congested link. Implementations SHOULD use an initial timer value

of 1 second (the minimum defined in RFC 2988 [RFC2988]) and double the value at each retransmission, up to no less than the RFC 2988 maximum of 60 seconds. Note that we recommend a 1-second timer rather than the 3-second RFC 2988 default in order to improve latency for time-sensitive applications. Because DTLS only uses retransmission for handshake and not dataflow, the effect on congestion should be minimal.

Implementations SHOULD retain the current timer value until a transmission without loss occurs, at which time the value may be reset to the initial value. After a long period of idleness, no less than 10 times the current timer value, implementations may reset the timer to the initial value. One situation where this might occur is when a rehandshake is used after substantial data transfer.

4.2.5. ChangeCipherSpec

As with TLS, the ChangeCipherSpec message is not technically a handshake message but MUST be treated as part of the same flight as the associated Finished message for the purposes of timeout and retransmission.

4.2.6. Finished Messages

Finished messages have the same format as in TLS. However, in order to remove sensitivity to fragmentation, the Finished MAC MUST be computed as if each handshake message had been sent as a single fragment. Note that in cases where the cookie exchange is used, the initial ClientHello and HelloVerifyRequest MUST NOT be included in the Finished MAC.

4.2.7. Alert Messages

Note that Alert messages are not retransmitted at all, even when they occur in the context of a handshake. However, a DTLS implementation SHOULD generate a new alert message if the offending record is received again (e.g., as a retransmitted handshake message). Implementations SHOULD detect when a peer is persistently sending bad messages and terminate the local connection state after such misbehavior is detected.

4.3. Summary of new syntax

This section includes specifications for the data structures that have changed between TLS 1.1 and DTLS.

4.3.1. Record Layer

```
struct {
    ContentType type;
    ProtocolVersion version;
    uint16 epoch;                               // New field
    uint48 sequence_number;                     // New field
    uint16 length;
    opaque fragment[DTLSPplaintext.length];
} DTLSPplaintext;

struct {
    ContentType type;
    ProtocolVersion version;
    uint16 epoch;                               // New field
    uint48 sequence_number;                     // New field
    uint16 length;
    opaque fragment[DTLSCcompressed.length];
} DTLSCcompressed;

struct {
    ContentType type;
    ProtocolVersion version;
    uint16 epoch;                               // New field
    uint48 sequence_number;                     // New field
    uint16 length;
    select (CipherSpec.cipher_type) {
        case block: GenericBlockCipher;
    } fragment;
} DTLSCiphertext;
```

4.3.2. Handshake Protocol

```
enum {
    hello_request(0), client_hello(1), server_hello(2),
    hello_verify_request(3),                               // New field
    certificate(11), server_key_exchange (12),
    certificate_request(13), server_hello_done(14),
    certificate_verify(15), client_key_exchange(16),
    finished(20), (255)
} HandshakeType;

struct {
    HandshakeType msg_type;
    uint24 length;
    uint16 message_seq;                                   // New field
    uint24 fragment_offset;                               // New field
    uint24 fragment_length;                               // New field
}
```

```

select (HandshakeType) {
  case hello_request: HelloRequest;
  case client_hello: ClientHello;
  case server_hello: ServerHello;
  case hello_verify_request: HelloVerifyRequest; // New field
  case certificate: Certificate;
  case server_key_exchange: ServerKeyExchange;
  case certificate_request: CertificateRequest;
  case server_hello_done: ServerHelloDone;
  case certificate_verify: CertificateVerify;
  case client_key_exchange: ClientKeyExchange;
  case finished: Finished;
} body;
} Handshake;

struct {
  ProtocolVersion client_version;
  Random random;
  SessionID session_id;
  opaque cookie<0..32>; // New field
  CipherSuite cipher_suites<2..2^16-1>;
  CompressionMethod compression_methods<1..2^8-1>;
} ClientHello;

struct {
  ProtocolVersion server_version;
  opaque cookie<0..32>;
} HelloVerifyRequest;

```

5. Security Considerations

This document describes a variant of TLS 1.1 and therefore most of the security considerations are the same as those of TLS 1.1 [TLS11], described in Appendices D, E, and F.

The primary additional security consideration raised by DTLS is that of denial of service. DTLS includes a cookie exchange designed to protect against denial of service. However, implementations which do not use this cookie exchange are still vulnerable to DoS. In particular, DTLS servers which do not use the cookie exchange may be used as attack amplifiers even if they themselves are not experiencing DoS. Therefore, DTLS servers **SHOULD** use the cookie exchange unless there is good reason to believe that amplification is not a threat in their environment. Clients **MUST** be prepared to do a cookie exchange with every handshake.

6. Acknowledgements

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7. IANA Considerations

This document uses the same identifier space as TLS [TLS11], so no new IANA registries are required. When new identifiers are assigned for TLS, authors MUST specify whether they are suitable for DTLS.

This document defines a new handshake message, `hello_verify_request`, whose value has been allocated from the TLS HandshakeType registry defined in [TLS11]. The value "3" has been assigned by the IANA.

8. References

8.1. Normative References

- [RFC1191] Mogul, J. and S. Deering, "Path MTU discovery", RFC 1191, November 1990.
- [RFC1981] McCann, J., Deering, S., and J. Mogul, "Path MTU Discovery for IP version 6", RFC 1981, August 1996.
- [RFC2401] Kent, S. and R. Atkinson, "Security Architecture for the Internet Protocol", RFC 2401, November 1998.
- [RFC2988] Paxson, V. and M. Allman, "Computing TCP's Retransmission Timer", RFC 2988, November 2000.
- [TCP] Postel, J., "Transmission Control Protocol", STD 7, RFC 793, September 1981.
- [TLS11] Dierks, T. and E. Rescorla, "The Transport Layer Security (TLS) Protocol Version 1.1", RFC 4346, April 2006.

8.2. Informative References

- [AESCACHE] Bernstein, D.J., "Cache-timing attacks on AES"
<http://cr.yp.to/antiforgery/cachetiming-20050414.pdf>.
- [AH] Kent, S. and R. Atkinson, "IP Authentication Header", RFC 2402, November 1998.
- [DCCP] Kohler, E., Handley, M., Floyd, S., Padhye, J., "Datagram Congestion Control Protocol", Work in Progress, 10 March 2005.
- [DNS] Mockapetris, P., "Domain names - implementation and specification", STD 13, RFC 1035, November 1987.
- [DTLS] Modadugu, N., Rescorla, E., "The Design and Implementation of Datagram TLS", Proceedings of ISOC NDSS 2004, February 2004.
- [ESP] Kent, S. and R. Atkinson, "IP Encapsulating Security Payload (ESP)", RFC 2406, November 1998.
- [IKE] Harkins, D. and D. Carrel, "The Internet Key Exchange (IKE)", RFC 2409, November 1998.
- Kaufman, C., "Internet Key Exchange (IKEv2) Protocol", RFC 4306, December 2005.
- [IMAP] Crispin, M., "INTERNET MESSAGE ACCESS PROTOCOL - VERSION 4rev1", RFC 3501, March 2003.
- [PHOTURIS] Karn, P. and W. Simpson, "ICMP Security Failures Messages", RFC 2521, March 1999.
- [POP] Myers, J. and M. Rose, "Post Office Protocol - Version 3", STD 53, RFC 1939, May 1996.
- [REQ] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, March 1997.
- [SCTP] Stewart, R., Xie, Q., Morneault, K., Sharp, C., Schwarzbauer, H., Taylor, T., Rytina, I., Kalla, M., Zhang, L., and V. Paxson, "Stream Control Transmission Protocol", RFC 2960, October 2000.

- [SIP] Rosenberg, J., Schulzrinne, H., Camarillo, G., Johnston, A., Peterson, J., Sparks, R., Handley, M., and E. Schooler, "SIP: Session Initiation Protocol", RFC 3261, June 2002.
- [TLS] Dierks, T. and C. Allen, "The TLS Protocol Version 1.0", RFC 2246, January 1999.
- [WHYIPSEC] Bellare, S., "Guidelines for Mandating the Use of IPsec", Work in Progress, October 2003.

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