Workgroup: TLS
Internet-Draft: draft-ietf-tls-dtls-rrc-05
Updates: 6347 (if approved)
Published: 7 March 2022
Intended Status: Standards Track
Expires: 8 September 2022
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Return Routability Check for DTLS 1.2 and DTLS 1.3

Abstract

This document specifies a return routability check for use in context of the Connection ID (CID) construct for the Datagram Transport Layer Security (DTLS) protocol versions 1.2 and 1.3.

Discussion Venues

This note is to be removed before publishing as an RFC.

Discussion of this document takes place on the Transport Layer Security Working Group mailing list (tls@ietf.org), which is archived at https://mailarchive.ietf.org/arch/browse/tls/.

Source for this draft and an issue tracker can be found at https://github.com/tlswg/dtls-rrc.

Status of This Memo

Copyright Notice

Table of Contents

1. Introduction

In "classical" DTLS, selecting a security context of an incoming DTLS record is accomplished with the help of the 5-tuple, i.e.

source IP address, source port, transport protocol, destination IP address, and destination port. Changes to this 5 tuple can happen for a variety reasons over the lifetime of the DTLS session. In the IoT context, NAT rebinding is common with sleepy devices. Other examples include end host mobility and multi-homing. Without CID, if the source IP address and/or source port changes during the lifetime of an ongoing DTLS session then the receiver will be unable to locate the correct security context. As a result, the DTLS handshake has to be re-run. Of course, it is not necessary to re-run the full handshake if session resumption is supported and negotiated.

A CID is an identifier carried in the record layer header of a DTLS datagram that gives the receiver additional information for selecting the appropriate security context. The CID mechanism has been specified in [I-D.ietf-tls-dtls-connection-id] for DTLS 1.2 and in [I-D.ietf-tls-dtls13] for DTLS 1.3.

Section 6 of [I-D.ietf-tls-dtls-connection-id] describes how the use of CID increases the attack surface by providing both on-path and off-path attackers an opportunity for (D)DoS. It then goes on describing the steps a DTLS principal must take when a record with a CID is received that has a source address (and/or port) different from the one currently associated with the DTLS connection. However, the actual mechanism for ensuring that the new peer address is willing to receive and process DTLS records is left open. This document standardizes a return routability check (RRC) as part of the DTLS protocol itself.

The return routability check is performed by the receiving peer before the CID-to-IP address/port binding is updated in that peer's session state database. This is done in order to provide more confidence to the receiving peer that the sending peer is reachable at the indicated address and port.

Note however that, irrespective of CID, if RRC has been successfully negotiated by the peers, path validation can be used at any time by either endpoint. For instance, an endpoint might use RRC to check that a peer is still in possession of its address after a period of quiescence.

2. 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 BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

This document assumes familiarity with the CID format and protocol defined for DTLS 1.2 [I-D.ietf-tls-dtls-connection-id] and for DTLS 1.3 [I-D.ietf-tls-dtls13]. The presentation language used in this document is described in Section 4 of [RFC8446].

This document reuses the definition of "anti-amplification limit" from [RFC9000] to mean three times the amount of data received from an unvalidated address. This includes all DTLS records originating from that source address, excluding discarded ones.

3. RRC Extension

The use of RRC is negotiated via the rrc DTLS-only extension. On connecting, the client includes the rrc extension in its ClientHello if it wishes to use RRC. If the server is capable of meeting this requirement, it responds with a rrc extension in its ServerHello. The extension_type value for this extension is TBD1 and the extension_data field of this extension is empty. The client and server MUST NOT use RRC unless both sides have successfully exchanged rrc extensions.

Note that the RRC extension applies to both DTLS 1.2 and DTLS 1.3.

4. The Return Routability Check Message

When a record with CID is received that has the source address of the enclosing UDP datagram different from the one previously associated with that CID, the receiver MUST NOT update its view of the peer's IP address and port number with the source specified in the UDP datagram before cryptographically validating the enclosed record(s) but instead perform a return routability check.

```
enum {
    invalid(0),
    change_cipher_spec(20),
    alert(21),
    handshake(22),
    application_data(23),
    heartbeat(24),  /* RFC 6520 */
    return_routability_check(TBD2), /* NEW */
    (255)
} ContentType;

uint64 Cookie;

enum {
    path_challenge(0),
    path_response(1),
    path_delete(2),
    reserved(2..255)
} rrc_msg_type;

struct {
    rrc_msg_type msg_type;
    select (return_routability_check.msg_type) {
        case path_challenge: Cookie;
        case path_response:  Cookie;
        case path_delete:  Cookie;
    };
} return_routability_check;
```

The cookie is a 8-byte field containing arbitrary data.

The return_routability_check message MUST be authenticated and encrypted using the currently active security context.

5. Off-Path Packet Forwarding

An off-path attacker that can observe packets might forward copies of genuine packets to endpoints. If the copied packet arrives before the genuine packet, this will appear as a NAT rebinding. Any genuine packet will be discarded as a duplicate. If the attacker is able to continue forwarding packets, it might be able to cause migration to a path via the attacker. This places the attacker on-path, giving it the ability to observe or drop all subsequent packets.

This style of attack relies on the attacker using a path that has approximately the same characteristics as the direct path between endpoints. The attack is more reliable if relatively few packets are sent or if packet loss coincides with the attempted attack.

A data packet received on the original path that increases the maximum received packet number will cause the endpoint to move back to that path. Eliciting packets on this path increases the likelihood that the attack is unsuccessful.

Figure 1 demonstrates the case where a receiver receives a packet with a new source IP address and/or new port number. The receiver needs to determine whether this path change is caused by an attacker and will send a RRC message of type path_challenge (RRC-1) on the old path.

```
        new   +--------+  old
        path  |        |  path
       +----->|Receiver|<-----+
       |      |        |      |
       |      +--------+      |
       |                      |
       |                      |
       |                      |
       |                      |
       |                      |
 +-----------+                |
 | Attacker?|                 |
 +-----------+                |
       |                      |
       |                      |
       |                      |
       |      +--------+      |
       |      |        |      |
       +------| Sender |------+
              |        |
              +--------+
```

Figure 1: Off-Path Packet Forwarding Scenario

Three cases need to be considered:

Case 1: The old path is dead, which leads to a timeout of RRC-1.

As shown in Figure 2, a RRC message of type path_challenge (RRC-2) needs to be sent on the new path. In this situation the switch to the new path is considered legitimate. The sender will reply with RRC-3 containing a path_response on the new path.

```
...................>+--------+
.           ********|        |********
.           *+----->|Receiver|<-----+*
.           *| new  |        | old  |*
.     RRC-2 *| path +--------+ path |* RRC-1
.      with *|                      |* with
.     path- *|                      |* path-
. challenge *|                      |* challenge
.           *|                      |*
.           *|                      |*
.      +----------+                 |*
.      | Attacker |                 |*
.      +----------+                 |*
.           *|                      |v
.           *|                      |timeout
.           *|                      |
.RRC-3      *|      +--------+      |
.with       *|      |        |      |
.path-      *+------| Sender |------+
.response   *******>|        |
....................+--------+
```

Figure 2: Old path is dead

Case 2: The old path is alive but not preferred.

This case is shown in Figure 3 whereby the sender replies with a RRC-2 path_delete message on the old path. This triggers the receiver to send RRC-3 with a path-challenge along the new path. The sender will reply with RRC-4 containing a path_response along the new path.

```
  ...................>+--------+<....................
  .           ********|        |********            .
  .           *+----->|Receiver|<-----+*            .
  .           *| new  |        | old  |*            .
  .     RRC-3 *| path +--------+ path |* RRC-1      .
  .      with *|                      |* with       .
  .     path- *|                      |* path-      .
  . challenge *|                      |* challenge  .
  .           *|                      |*            .
  .           *|                      |*            .
  .      +----------+                 |*            .
  .      | Attacker |                 |*            .
  .      +----------+                 |*            .
  .           *|                      |*            .
  .           *|                      |*            .
  .           *|                      |*            .
  .RRC-4      *|      +--------+      |*       RRC-2.
  .with       *|      |        |      |*        with.
  .path-      *+------| Sender |------+*       path-.
  .response   *******>|        |<*******      delete.
  ....................+--------+.....................
```

Figure 3: Old path is not preferred

Case 3: The old path is alive and preferred.

This is most likely the result of an attacker. The sender replies with RRC-2 containing a path_response along the old path. The interaction is shown in Figure 4. This results in the connection being migrated back to the old path.

```
               +--------+<....................
               |        |********            .
        +----->|Receiver|<-----+*            .
        | new  |        | old  |*            .
        | path +--------+ path |* RRC-1      .
        |                      |* with       .
        |                      |* path-      .
        |                      |* challenge  .
        |                      |*            .
        |                      |*            .
  +----------+                 |*            .
  | Attacker |                 |*            .
  +----------+                 |*            .
        |                      |*            .
        |                      |*            .
        |                      |*            .
        |      +--------+      |*       RRC-2.
        |      |        |      |*        with.
        +------| Sender |------+*       path-.
               |        |<*******    response.
               +--------+.....................
```

Figure 4: Old path is preferred

Note that this defense is imperfect, but this is not considered a serious problem. If the path via the attack is reliably faster than the old path despite multiple attempts to use that old path, it is not possible to distinguish between an attack and an improvement in routing.

An endpoint could also use heuristics to improve detection of this style of attack. For instance, NAT rebinding is improbable if packets were recently received on the old path; similarly, rebinding is rare on IPv6 paths. Endpoints can also look for duplicated packets. Conversely, a change in connection ID is more likely to indicate an intentional migration rather than an attack. Note, however, changes in connection IDs are only supported in DTLS 1.3 but not in DTLS 1.2.

6. Path Validation Procedure

Note: This algorithm does not take the Section 5 scenario into account.

The receiver that observes the peer's address or port update MUST stop sending any buffered application data (or limit the data sent to the unvalidated address to the anti-amplification limit) and initiate the return routability check that proceeds as follows:

1. The receiver creates a return_routability_check message of type path_challenge and places the unpredictable cookie into the message.

2. The message is sent to the observed new address and a timer T (see Section 7.3) is started.

3. The peer endpoint, after successfully verifying the received return_routability_check message responds by echoing the cookie value in a return_routability_check message of type path_response.

4. When the initiator receives and verifies the return_routability_check message contains the sent cookie, it updates the peer address binding.

5. If T expires, or the address confirmation fails, the peer address binding is not updated.

After this point, any pending send operation is resumed to the bound peer address.

Section 7.1 and Section 7.2 contain the requirements for the initiator and responder roles, broken down per protocol phase.

7. Enhanced Path Validation Procedure

Note: This algorithm also takes the Section 5 scenario into account.

The receiver that observes the peer's address or port update MUST stop sending any buffered application data (or limit the data sent to the unvalidated address to the anti-amplification limit) and initiate the return routability check that proceeds as follows:

1. The receiver creates a return_routability_check message of type path_challenge and places the unpredictable cookie into the message.

2. The message is sent to the previously valid address, which corresponds to the old path. Additionally, a timer T, see Section 7.3, is started.

3. The peer endpoint verifies the received return_routability_check message. The action to be taken

depends on the preference of the path through which the message was received:

- If the path through which the message was received is preferred, a return_routability_check message of type path_response MUST be returned.

- If the path through which the message was received is not preferred, a return_routability_check message of type path_delete MUST be returned. In either case, the peer endpoint echoes the cookie value in the response.

4. The initiator receives and verifies that the return_routability_check message contains the previously sent cookie. The actions taken by the initiator differ based on the received message:

   - When a return_routability_check message of type path_response was received, the initiator MUST continue using the previously valid address, i.e. no switch to the new path takes place and the peer address binding is not updated.

   - When a return_routability_check message of type path_delete was received, the initiator MUST perform a return routability check on the observed new address, as described in Section 6.

5. If T expires, or the address confirmation fails, the peer address binding is not updated. In this case, the initiator MUST perform a return routability check on the observed new address, as described in Section 6.

After the path validation procedure is completed, any pending send operation is resumed to the bound peer address.

Section 7.1 and Section 7.2 contain the requirements for the initiator and responder roles, broken down per protocol phase.

7.1. Path Challenge Requirements

- The initiator MAY send multiple return_routability_check messages of type path_challenge to cater for packet loss on the probed path.

  - Each path_challenge SHOULD go into different transport packets. (Note that the DTLS implementation may not have control over the packetization done by the transport layer.)

  - The transmission of subsequent path_challenge messages SHOULD be paced to decrease the chance of loss.
  - Each path_challenge message MUST contain random data.

* The initiator MAY use padding using the record padding mechanism available in DTLS 1.3 (and in DTLS 1.2, when CID is enabled on the sending direction) up to the anti-amplification limit to probe if the path MTU (PMTU) for the new path is still acceptable.

7.2. Path Response/Delete Requirements

* The responder MUST NOT delay sending an elicited path_response or path_delete messages.
* The responder MUST send exactly one path_response or path_delete message for each received path_challenge.
* The responder MUST send the path_response or the path_delete on the path where the corresponding path_challenge has been received, so that validation succeeds only if the path is functional in both directions. The initiator MUST NOT enforce this behaviour.
* The initiator MUST silently discard any invalid path_response it receives.

Note that RRC does not cater for PMTU discovery on the reverse path. If the responder wants to do PMTU discovery using RRC, it should initiate a new path validation procedure.

7.3. Timer Choice

When setting T, implementations are cautioned that the new path could have a longer round-trip time (RTT) than the original.

In settings where there is external information about the RTT of the active path, implementations SHOULD use T = 3xRTT.

If an implementation has no way to obtain information regarding the RTT of the active path, a value of 1s SHOULD be used.

Profiles for specific deployment environments -- for example, constrained networks [I-D.ietf-uta-tls13-iot-profile] -- MAY specify a different, more suitable value.

8. Example

The example TLS 1.3 handshake shown in Figure 5 shows a client and a server negotiating the support for CID and for the RRC extension.

```
       Client                                           Server

Key  ^ ClientHello
Exch | + key_share
     | + signature_algorithms
     | + rrc
     v + connection_id=empty
                             -------->
                                               ServerHello  ^ Key
                                              +  key_share  | Exch
                                        + connection_id=100 |
                                                      + rrc v
                                      {EncryptedExtensions} ^  Server
                                       {CertificateRequest} v  Params
                                              {Certificate} ^
                                        {CertificateVerify} | Auth
                             <--------           {Finished} v

     ^ {Certificate}
Auth | {CertificateVerify}
     v {Finished}            -------->
       [Application Data]    <------->  [Application Data]

              +  Indicates noteworthy extensions sent in the
                 previously noted message.

              *  Indicates optional or situation-dependent
                 messages/extensions that are not always sent.

              {} Indicates messages protected using keys
                 derived from a [sender]_handshake_traffic_secret.

              [] Indicates messages protected using keys
                 derived from [sender]_application_traffic_secret_N.
```

Figure 5: Message Flow for Full TLS Handshake

Once a connection has been established the client and the server exchange application payloads protected by DTLS with an unilaterally used CIDs. In our case, the client is requested to use CID 100 for records sent to the server.

At some point in the communication interaction the IP address used by the client changes and, thanks to the CID usage, the security

context to interpret the record is successfully located by the
server. However, the server wants to test the reachability of the
client at his new IP address.

```
   Client                                             Server
   ------                                             ------

   Application Data            ========>
   <CID=100>
   Src-IP=A
   Dst-IP=Z
                               <========        Application Data
                                                    Src-IP=Z
                                                    Dst-IP=A


                           <<------------->>
                           <<   Some      >>
                           <<   Time      >>
                           <<   Later     >>
                           <<------------->>


   Application Data            ========>
   <CID=100>
   Src-IP=B
   Dst-IP=Z

                                          <<< Unverified IP
                                              Address B >>

                               <--------  Return Routability Check
                                          path_challenge(cookie)
                                                 Src-IP=Z
                                                 Dst-IP=B

   Return Routability Check    -------->
   path_response(cookie)
   Src-IP=B
   Dst-IP=Z

                                          <<< IP Address B
                                              Verified >>


                               <========        Application Data
                                                    Src-IP=Z
                                                    Dst-IP=B
```

Figure 6: Return Routability Example

9. Security and Privacy Considerations

Note that the return routability checks do not protect against flooding of third-parties if the attacker is on-path, as the attacker can redirect the return routability checks to the real peer (even if those datagrams are cryptographically authenticated). On-path adversaries can, in general, pose a harm to connectivity.

10. IANA Considerations

IANA is requested to allocate an entry to the TLS ContentType registry, for the return_routability_check(TBD2) message defined in this document. The return_routability_check content type is only applicable to DTLS 1.2 and 1.3.

IANA is requested to allocate the extension code point (TBD1) for the rrc extension to the TLS ExtensionType Values registry as described in Table 1.

Value	Extension Name	TLS 1.3	DTLS-Only	Recommended	Reference
TBD1	rrc	CH, SH	Y	N	RFC-THIS

Table 1: rrc entry in the TLS ExtensionType Values registry

11. Open Issues

Issues against this document are tracked at https://github.com/tlswg/dtls-rrc/issues

12. Acknowledgments

We would like to thank Achim Kraus, Hanno Becker, Hanno Boeck, Manuel Pegourie-Gonnard, Mohit Sahni and Rich Salz for their input to this document.

13. References

13.1. Normative References

[I-D.ietf-tls-dtls-connection-id] Rescorla, E., Tschofenig, H., Fossati, T., and A. Kraus, "Connection Identifiers for DTLS 1.2", Work in Progress, Internet-Draft, draft-ietf-tls-dtls-connection-id-13, 22 June 2021, <https://datatracker.ietf.org/doc/html/draft-ietf-tls-dtls-connection-id-13>.

[I-D.ietf-tls-dtls13] Rescorla, E., Tschofenig, H., and N. Modadugu, "The Datagram Transport Layer Security (DTLS) Protocol

Version 1.3", Work in Progress, Internet-Draft, draft-ietf-tls-dtls13-43, 30 April 2021, <https://datatracker.ietf.org/doc/html/draft-ietf-tls-dtls13-43>.

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

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

[RFC8446] Rescorla, E., "The Transport Layer Security (TLS) Protocol Version 1.3", RFC 8446, DOI 10.17487/RFC8446, August 2018, <https://www.rfc-editor.org/rfc/rfc8446>.

13.2. Informative References

[I-D.ietf-uta-tls13-iot-profile] Tschofenig, H. and T. Fossati, "TLS/DTLS 1.3 Profiles for the Internet of Things", Work in Progress, Internet-Draft, draft-ietf-uta-tls13-iot-profile-04, 7 March 2022, <https://datatracker.ietf.org/doc/html/draft-ietf-uta-tls13-iot-profile-04>.

[RFC9000] Iyengar, J., Ed. and M. Thomson, Ed., "QUIC: A UDP-Based Multiplexed and Secure Transport", RFC 9000, DOI 10.17487/RFC9000, May 2021, <https://www.rfc-editor.org/rfc/rfc9000>.

Appendix A. History

RFC EDITOR: PLEASE REMOVE THIS SECTION

draft-ietf-tls-dtls-rrc-05

* Added text about off-path packet forwarding

draft-ietf-tls-dtls-rrc-04

* Re-submitted draft to fix references

draft-ietf-tls-dtls-rrc-03

* Added details for challenge-response exchange

draft-ietf-tls-dtls-rrc-02

* Undo the TLS flags extension for negotiating RRC, use a new extension type

draft-ietf-tls-dtls-rrc-01

* Use the TLS flags extension for negotiating RRC

* Enhanced IANA consideration section

* Expanded example section

* Revamp message layout:

  - Use 8-byte fixed size cookies

  - Explicitly separate path challenge from response

draft-ietf-tls-dtls-rrc-00

* Draft name changed after WG adoption

draft-tschofenig-tls-dtls-rrc-01

* Removed text that overlapped with draft-ietf-tls-dtls-connection-id

draft-tschofenig-tls-dtls-rrc-00

* Initial version

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