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TLS 1.3 Extension for Certificate-based Authentication with an External Pre-Shared Key

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Abstract

This document specifies a TLS 1.3 extension that allows a server to authenticate with a combination of a certificate and an external pre-shared key (PSK).

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1. Introduction

The TLS 1.3 [RFC8446] handshake protocol provides two mutually exclusive forms of server authentication. First, the server can be authenticated by providing a signature certificate and creating a valid digital signature to demonstrate that it possesses the corresponding private key. Second, the server can be authenticated by demonstrating that it possesses a pre-shared key (PSK) that was established by a previous handshake. A PSK that is established in this fashion is called a resumption PSK. A PSK that is established by any other means is called an external PSK. This document specifies a TLS 1.3 extension permitting certificate-based server authentication to be combined with an external PSK as an input to the TLS 1.3 key schedule.

2. 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.

3. Motivation and Design Rationale

The invention of a large-scale quantum computer would pose a serious challenge for the cryptographic algorithms that are widely deployed today, including the digital signature algorithms that are used to authenticate the server in the TLS 1.3 handshake protocol. It is an open question whether or not it is feasible to build a large-scale quantum computer, and if so, when that might happen. However, if such a quantum computer is invented, many of the cryptographic algorithms and the security protocols that use them would become vulnerable.

The TLS 1.3 handshake protocol employs key agreement algorithms that could be broken by the invention of a large-scale quantum computer [I-D.hoffman-c2pq]. These algorithms include Diffie-Hellman (DH) [DH1977] and Elliptic Curve Diffie-Hellman (ECDH) [IEEE1363]. As a result, an adversary that stores a TLS 1.3 handshake protocol exchange today could decrypt the associated encrypted communications in the future when a large-scale quantum computer becomes available.

In the near-term, this document describes TLS 1.3 extension to protect today's communications from the future invention of a large-scale quantum computer by providing a strong external PSK as an input to the TLS 1.3 key schedule while preserving the authentication

provided by the existing certificate and digital signature mechanisms.

4. Extension Overview

This section provides a brief overview of the "tls_cert_with_extern_psk" extension.

The client includes the "tls_cert_with_extern_psk" extension in the ClientHello message. The "tls_cert_with_extern_psk" extension MUST be accompanied by the "key_share", "psk_key_exchange_modes", and "pre_shared_key" extensions. The "pre_shared_key" extension MUST be the last extension in the ClientHello message, and it provides a list of external PSK identifiers that the client is willing to use with this server. Since the "tls_cert_with_extern_psk" extension is intended to be used only with initial handshakes, it MUST NOT be sent alongside the "early_data" extension. These extensions are all described in Section 4.2 of [RFC8446].

If the server is willing to use one of the external PSKs listed in the "pre_shared_key" extension and perform certificate-based authentication, then the server includes the "tls_cert_with_extern_psk" extension in the ServerHello message. The "tls_cert_with_extern_psk" extension MUST be accompanied by the "key_share" and "pre_shared_key" extensions. If none of the external PSKs in the list provided by the client is acceptable to the server, then the "tls_cert_with_extern_psk" extension is omitted from the ServerHello message.

The successful negotiation of the "tls_cert_with_extern_psk" extension requires the TLS 1.3 key schedule processing to include both the selected external PSK and the (EC)DHE shared secret value. As a result, the Early Secret, Handshake Secret, and Master Secret values all depend upon the value of the selected external PSK.

The authentication of the server and optional authentication of the client depend upon the ability to generate a signature that can be validated with the public key in their certificates. The authentication processing is not changed in any way by the selected external PSK.

Each external PSK is associated with a single hash algorithm, which is required by Section 4.2.11 of [RFC8446]. The hash algorithm MUST be set when the PSK is established, with a default of SHA-256 if no hash algorithm is specified during establishment.

5. Certificate with External PSK Extension

This section specifies the "tls_cert_with_extern_psk" extension, which MAY appear in the ClientHello message and ServerHello message. It MUST NOT appear in any other messages. The "tls_cert_with_extern_psk" extension MUST NOT appear in the ServerHello message unless the "tls_cert_with_extern_psk" extension appeared in the preceding ClientHello message. If an implementation recognizes the "tls_cert_with_extern_psk" extension and receives it in any other message, then the implementation MUST abort the handshake with an "illegal_parameter" alert.

The general extension mechanisms enable clients and servers to negotiate the use of specific extensions. Clients request extended functionality from servers with the extensions field in the ClientHello message. If the server responds with a HelloRetryRequest message, then the client sends another ClientHello message as described in Section 4.1.2 of [RFC8446], and it MUST include the same "tls_cert_with_extern_psk" extension as the original ClientHello message or abort the handshake.

Many server extensions are carried in the EncryptedExtensions message; however, the "tls_cert_with_extern_psk" extension is carried in the ServerHello message. It is only present in the ServerHello message if the server recognizes the "tls_cert_with_extern_psk" extension and the server possesses one of the external PSKs offered by the client in the "pre_shared_key" extension in the ClientHello message.

The Extension structure is defined in [RFC8446]; it is repeated here for convenience.

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

The "extension_type" identifies the particular extension type, and the "extension_data" contains information specific to the particular extension type.

This document specifies the "tls_cert_with_extern_psk" extension, adding one new type to ExtensionType:

```
enum {
    tls_cert_with_extern_psk(TBD), (65535)
} ExtensionType;
```

The "tls_cert_with_extern_psk" extension is relevant when the client and server possess an external PSK in common that can be used as an input to the TLS 1.3 key schedule. The "tls_cert_with_extern_psk" extension is essentially a flag to use the external PSK in the key schedule, and it has the following syntax:

```
struct {
    select (Handshake.msg_type) {
        case client_hello: Empty;
        case server_hello: Empty;
    };
} CertWithExternPSK;
```

To use an external PSK with certificates, clients MUST provide the "tls_cert_with_extern_psk" extension, and it MUST be accompanied by the "key_share", "psk_key_exchange_modes", and "pre_shared_key" extensions in the ClientHello. If clients offer a "tls_cert_with_extern_psk" extension without all of these other extensions, servers MUST abort the handshake. The client MAY also find it useful to include the "supported_groups" extension. Note that Section 4.2 of [RFC8446] allows extensions to appear in any order, with the exception of the "pre_shared_key" extension, which MUST be the last extension in the ClientHello. Also, there MUST NOT be more than one instance of each extension in the ClientHello message.

The "key_share" extension is defined in Section 4.2.8 of [RFC8446].

The "psk_key_exchange_modes" extension is defined in Section 4.2.9 of [RFC8446]. The "psk_key_exchange_modes" extension restricts both the use of PSKs offered in this ClientHello and those which the server might supply via a subsequent NewSessionTicket. As a result, clients MUST include the psk_dhe_ke mode, and clients MAY also include the psk_ke mode to support a subsequent NewSessionTicket. Servers MUST select the psk_dhe_ke mode for the initial handshake. Servers MUST select a key exchange mode that is listed by the client for subsequent handshakes that include the resumption PSK from the initial handshake.

The "supported_groups" extension is defined in Section 4.2.7 of [RFC8446].

The "pre_shared_key" extension is defined in Section 4.2.11 of [RFC8446]. The syntax is repeated below for convenience. All of the listed PSKs MUST be external PSKs.

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

  opaque PskBinderEntry<32..255>;

  struct {
      PskIdentity identities<7..2^16-1>;
      PskBinderEntry binders<33..2^16-1>;
  } OfferedPsks;

  struct {
      select (Handshake.msg_type) {
          case client_hello: OfferedPsks;
          case server_hello: uint16 selected_identity;
      };
  } PreSharedKeyExtension;
```

The OfferedPsks contains the list of PSK identities and associated binders for the external PSKs that the client is willing to use with the server.

The identities are a list of external PSK identities that the client is willing to negotiate with the server. Each external PSK has an associated identity that is known to the client and the server; the associated identities may be know to other parties as well. In addition, the binder validation (see below) confirms that the client and server have the same key associated with the identity.

The obfuscated_ticket_age is not used for external PSKs; clients SHOULD set this value to 0, and servers MUST ignore the value.

The binders are a series of HMAC values, one for each external PSK offered by the client, in the same order as the identities list. The HMAC value is computed using the binder_key, which is derived from the external PSK, and a partial transcript of the current handshake. Generation of the binder_key from the external PSK is described in Section 7.1 of [RFC8446]. The partial transcript of the current handshake includes a partial ClientHello up to and including the PreSharedKeyExtension.identities field as described in Section 4.2.11.2 of [RFC8446].

The selected_identity contains the external PSK identity that the server selected from the list offered by the client. If none of the offered external PSKs in the list provided by the client are acceptable to the server, then the "tls_cert_with_extern_psk" extension MUST be omitted from the ServerHello message. The server MUST validate the binder value that corresponds to the selected external PSK as described in Section 4.2.11.2 of [RFC8446]. If the binder does not validate, the server MUST abort the handshake with an "illegal_parameter" alert. Servers SHOULD NOT attempt to validate multiple binders; rather they SHOULD select one of the offered external PSKs and validate only the binder that corresponds to that external PSK.

When the "tls_cert_with_extern_psk" extension is successfully negotiated, authentication of the server depends upon the ability to generate a signature that can be validated with the public key in the server's certificate. This is accomplished by the server sending the Certificate and CertificateVerify messages as described in Sections 4.4.2 and 4.4.3 of [RFC8446].

TLS 1.3 does not permit the server to send a CertificateRequest message when a PSK is being used. This restriction is removed when the "tls_cert_with_extern_psk" extension is negotiated, allowing certificate-based authentication for both the client and the server. If certificate-based client authentication is desired, this is accomplished by the client sending the Certificate and CertificateVerify messages as described in Sections 4.4.2 and 4.4.3 of [RFC8446].

Section 7.1 of [RFC8446] specifies the TLS 1.3 Key Schedule. The successful negotiation of the "tls_cert_with_extern_psk" extension requires the key schedule processing to include both the external PSK and the (EC)DHE shared secret value.

If the client and the server have different values associated with the selected external PSK identifier, then the client and the server will compute different values for every entry in the key schedule, which will lead to the termination of the connection with a "decrypt_error" alert.

6. IANA Considerations

IANA is requested to update the TLS ExtensionType Registry to include "tls_cert_with_extern_psk" with a value of TBD and the list of messages "CH, SH" in which the "tls_cert_with_extern_psk" extension may appear.

7. Security Considerations

The Security Considerations in [RFC8446] remain relevant.

TLS 1.3 [RFC8446] does not permit the server to send a CertificateRequest message when a PSK is being used. This restriction is removed when the "tls_cert_with_extern_psk" extension is offered by the client and accepted by the server. However, TLS 1.3 does not permit an external PSK to be used in the same fashion as a resumption PSK, and this extension does not alter those restrictions. Thus, a certificate MUST NOT be used with a resumption PSK.

Implementations must protect the external pre-shared key (PSK). Compromise of the external PSK will make the encrypted session content vulnerable to the future invention of a large-scale quantum computer.

Implementers should not transmit the same content on a connection that is protected with an external PSK and a connection that is not. Doing so may allow an eavesdropper to correlate the connections, making the content vulnerable to the future invention of a large-scale quantum computer.

Implementations must generate external PSKs with a secure key management technique, such as pseudo-random generation of the key or derivation of the key from one or more other secure keys. The use of inadequate pseudo-random number generators (PRNGs) to generate external PSKs can result in little or no security. An attacker may find it much easier to reproduce the PRNG environment that produced the external PSKs and searching the resulting small set of possibilities, rather than brute force searching the whole key space. The generation of quality random numbers is difficult. [RFC4086] offers important guidance in this area.

If the external PSK is known to any party other than the client and the server, then the external PSK MUST NOT be the sole basis for authentication. The reasoning is explained in [K2016] (see Section 4.2). When this extension is used, authentication is based on certificates, not the external PSK.

In this extension, the external PSK preserves secrecy if the (EC)DH key agreement is ever broken by cryptanalysis or the future invention of a large-scale quantum computer. As long as the attacker does not know the PSK and the key derivation algorithm remains unbroken, the attacker cannot derive the session secrets even if they are able to compute the (EC)DH shared secret.

TLS 1.3 key derivation makes use of the HKDF algorithm, which depends upon the HMAC construction and a hash function. This extension provides the desired protection for the session secrets as long as HMAC with the selected hash function is a pseudorandom function (PRF) [GGM1986].

In the future, if the (EC)DH key agreement is broken by cryptanalysis or the invention of a large-scale quantum computer, the forward secrecy advantages traditionally associated with ephemeral (EC)DH keys will no longer be relevant. Although the ephemeral private keys used during a given TLS session would be destroyed at the end of a session, preventing the attacker from later accessing them, the private keys would nevertheless be recoverable due to the break in the algorithm. A more general notion of "secrecy after key material is destroyed" would still be achievable using external PSKs, of course, provided that they are managed in a way that ensures their destruction when they are no longer needed, and with the assumption that the algorithms that use the external PSKs remain quantum-safe.

This specification does not require that external PSK is known only by the client and server. The external PSK may be known to a group. Since authentication depends on the public key in a certificate, knowledge of the external PSK by other parties does not enable impersonation. Since confidentiality depends on the shared secret from (EC)DH, knowledge of the external PSK by other parties does not enable eavesdropping. However, group members can record the traffic of other members, and then decrypt it if they ever gain access to a large-scale quantum computer. Also, when many parties know the external PSK, there are many opportunities for theft of the external PSK by an attacker. Once an attacker has the external PSK, they can decrypt stored traffic if they ever gain access to a large-scale quantum computer in the same manner as a legitimate group member.

TLS 1.3 [RFC8446] takes a conservative approach to PSKs; they are bound to a specific hash function and KDF. By contrast, TLS 1.2 [RFC5246] allows PSKs to be used with any hash function and the TLS 1.2 PRF. Thus, the safest approach is to use a PSK with either TLS 1.2 or TLS 1.3. However, any PSK that might be used with both TLS 1.2 and TLS 1.3 must be used with only one hash function, which is the one that is bound for use in TLS 1.3. This restriction is less than optimal when users want to provision a single PSK. While the constructions used in TLS 1.2 and TLS 1.3 are both based on HMAC [RFC2104], the constructions are different, and there is no known way in which reuse of the same PSK in TLS 1.2 and TLS 1.3 that would produce related outputs.

TLS 1.3 [RFC8446] has received careful security analysis, and some informal reasoning shows that the addition of this extension does not

introduce any security defects. This extension requires the use of certificates for authentication, but the processing of certificates is unchanged by this extension. This extension places an external PSK in the key schedule as part of the computation of the Early Secret. In the initial handshake without this extension, the Early Secret is computed as:

```
   Early Secret = HKDF-Extract(0, 0)
```

With this extension, the Early Secret is computed as:

```
   Early Secret = HKDF-Extract(External PSK, 0)
```

Any entropy contributed by the external PSK can only make the Early Secret better; the External PSK cannot make it worse. For these two reasons, TLS 1.3 continues to meet its security goals when this extension is used.

8. Privacy Considerations

Appendix E.6 of [RFC8446] discusses identity exposure attacks on PSKs. The guidance in this section remains relevant.

This extension makes use of external PSKs to improve resilience against attackers that gain access to a large-scale quantum computer in the future. This extension is always accompanied by the "pre_shared_key" extension to provide the PSK identities in plaintext in the ClientHello message. Passive observation of the these PSK identities will aid an attacker to track users of this extension.

9. Acknowledgments

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