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The Token Binding Protocol Version 1.0
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Abstract

This document specifies Version 1.0 of the Token Binding protocol. The Token Binding protocol allows client/server applications to create long-lived, uniquely identifiable TLS bindings spanning multiple TLS sessions and connections. Applications are then enabled to cryptographically bind security tokens to the TLS layer, preventing token export and replay attacks. To protect privacy, the Token Binding identifiers are only conveyed over TLS and can be reset by the user at any time.

Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

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1. Introduction

Servers often generate various security tokens (e.g. HTTP cookies, OAuth [RFC6749] tokens) for applications to present when accessing protected resources. In general, any party in possession of bearer security tokens gain access to certain protected resource(s).

Attackers take advantage of this by exporting bearer tokens from user's application connections or machines, presenting them to application servers, and impersonating authenticated users. The idea of Token Binding is to prevent such attacks by cryptographically binding application security tokens to the underlying TLS [RFC5246] layer.

A Token Binding is established by a user agent generating a private-public key pair (possibly within a secure hardware module, such as a Trusted Platform Module) per target server, providing the public key to the server, and proving possession of the corresponding private key, on every TLS connection to the server. The proof of possession involves signing the exported keying material (EKM) [RFC5705] from the TLS connection with the private key. The corresponding public key is included in the Token Binding identifier structure (described in the Section 3.2 "TokenBinding.tokenbindingid"). Token Bindings are long-lived, i.e., they encompass multiple TLS connections and TLS sessions between a given client and server. To protect privacy, Token Binding IDs are never conveyed over insecure connections and can be reset by the user at any time, e.g., when clearing browser cookies.

When issuing a security token to a client that supports Token Binding, a server includes the client's Token Binding ID (or its cryptographic hash) in the token. Later on, when a client presents a security token containing a Token Binding ID, the server verifies that the ID in the token matches the ID of the Token Binding established with the client. In the case of a mismatch, the server rejects the token (details are application-specific).

In order to successfully export and replay a bound security token, an attacker needs to also be able to use the client's private key, which is hard to do if the key is specially protected, e.g., generated in a secure hardware module.

1.1. Requirements Language

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.

2. Token Binding Protocol Overview

In the course of a TLS handshake, a client and server can use the Token Binding Negotiation TLS Extension [I-D.ietf-tokbind-negotiation] to negotiate the Token Binding

protocol version and the parameters (signature algorithm, length) of the Token Binding key. This negotiation does not require additional round-trips.

As described in [I-D.ietf-tokbind-negotiation], version 1.0 of the Token Binding protocol is represented by TB_ProtocolVersion.major = 1 and TB_ProtocolVersion.minor = 0 in the Token Binding Negotiation TLS Extension.

The Token Binding protocol consists of one message sent by the client to the server, proving possession of one or more client-generated asymmetric private keys. This message is not sent if the Token Binding Negotiation has been unsuccessful. The Token Binding message is sent with the application protocol data over TLS.

A server receiving the Token Binding message verifies that the key parameters in the message match the Token Binding parameters negotiated (e.g., via [I-D.ietf-tokbind-negotiation]), and then validates the signatures contained in the Token Binding message. If either of these checks fails, the server rejects the binding, along with all associated bound tokens. Otherwise, the Token Binding is successfully established with the ID contained in the Token Binding message.

When a server supporting the Token Binding protocol receives a bound token, the server compares the Token Binding ID in the token with the Token Binding ID established with the client. If the bound token came from a TLS connection without a Token Binding, or if the Token Binding IDs do not match, the token is rejected.

This document defines the format of the Token Binding protocol message, the process of establishing a Token Binding, the format of the Token Binding ID, and the process of validating a bound token. Token Binding Negotiation TLS Extension [I-D.ietf-tokbind-negotiation] describes the negotiation of the Token Binding protocol and key parameters. Token Binding over HTTP [I-D.ietf-tokbind-https] explains how the Token Binding message is encapsulated within HTTP/1.1 [RFC7230] or HTTP/2 [RFC7540] messages. [I-D.ietf-tokbind-https] also describes Token Binding between multiple communicating parties: User Agent, Identity Provider and Relying Party.

3. Token Binding Protocol Message

The Token Binding message is sent by the client to prove possession of one or more private keys held by the client. This message MUST be sent if the client and server successfully negotiated the use of the Token Binding protocol (e.g., via [I-D.ietf-tokbind-negotiation] or a

different mechanism), and MUST NOT be sent otherwise. This message MUST be sent in the client's first application protocol message. This message MAY also be sent in subsequent application protocol messages, proving possession of additional private keys held by the same client, which can be used to facilitate token binding between more than two communicating parties. For example, Token Binding over HTTP [I-D.ietf-tokbind-https] specifies an encapsulation of the Token Binding message in HTTP application protocol messages, as well as scenarios involving more than two communicating parties.

The Token Binding message format is defined using TLS Presentation Language (see Section 4 of [RFC5246]):

```
enum {
    rsa2048_pkcs1.5(0), rsa2048_pss(1), ecdsap256(2), (255)
} TokenBindingKeyParameters;

struct {
    opaque modulus<1..2^16-1>;
    opaque publicexponent<1..2^8-1>;
} RSAPublicKey;

struct {
    opaque point <1..2^8-1>;
} TB_ECPoint;

struct {
    TokenBindingKeyParameters key_parameters;
    uint16 key_length;  /* Length (in bytes) of the following
                           TokenBindingID.TokenBindingPublicKey */
    select (key_parameters) {
        case rsa2048_pkcs1.5:
        case rsa2048_pss:
            RSAPublicKey rsapubkey;
        case ecdsap256:
            TB_ECPoint point;
    } TokenBindingPublicKey;
} TokenBindingID;

enum {
    (255)        /* No initial TB_ExtensionType registrations */
} TB_ExtensionType;

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

```
enum {
    provided_token_binding(0), referred_token_binding(1), (255)
} TokenBindingType;

struct {
    TokenBindingType tokenbinding_type;
    TokenBindingID tokenbindingid;
    opaque signature<64..2^16-1>; /* Signature over the concatenation
                                     of tokenbinding_type,
                                     key_parameters and exported
                                     keying material (EKM) */
    TB_Extension extensions<0..2^16-1>;
} TokenBinding;

struct {
    TokenBinding tokenbindings<132..2^16-1>;
} TokenBindingMessage;
```

The Token Binding message consists of a series of TokenBinding structures, each containing the type of the token binding, the TokenBindingID, a signature using the Token Binding key, optionally followed by TB_Extension structures.

3.1. TokenBinding.tokenbinding_type

This document defines two Token Binding types:

- provided_token_binding - used to establish a Token Binding when connecting to a server.

- referred_token_binding - used when requesting tokens that are intended to be presented to a different server.

Token Binding over HTTP [I-D.ietf-tokbind-https] describes a use case for referred_token_binding where Token Bindings are established between multiple communicating parties: User Agent, Identity Provider and Relying Party. User Agent sends referred_token_binding to the Identity Provider in order to prove possession of the Token Binding key it uses with the Relying Party. The Identity Provider can then bind the token it is supplying (for presentation to the Relying Party) to the Token Binding ID contained in the referred_token_binding.

3.2. TokenBinding.tokenbindingid

The ID of the Token Binding established as a result of Token Binding message processing contains the identifier of the negotiated key parameters, the length (in bytes) of the Token Binding public key,

and the Token Binding public key itself. The Token Binding ID can be obtained from the TokenBinding structure by discarding the Token Binding type, signature and extensions.

When rsa2048_pkcs1.5 or rsa2048_pss is used, RSAPublicKey.modulus and RSAPublicKey.publicexponent contain the modulus and exponent of a 2048-bit RSA public key represented in big-endian format, with leading zero bytes omitted.

When ecdsap256 is used, TB_ECPoint.point contains the X coordinate followed by the Y coordinate of a Curve P-256 key. The X and Y coordinates are unsigned 32-byte integers encoded in big-endian format, preserving any leading zero bytes. Future specifications may define Token Binding keys using other elliptic curves with their corresponding signature and point formats.

Token Binding protocol implementations SHOULD make Token Binding IDs available to the application as opaque byte sequences, so that applications do not rely on a particular Token Binding ID structure. E.g., server applications will use Token Binding IDs when generating and verifying bound tokens.

3.3. TokenBinding.signature

When rsa2048_pkcs1.5 is used, TokenBinding.signature contains the signature generated using the RSASSA-PKCS1-v1_5 signature scheme defined in [RFC8017] with SHA256 as the hash function.

When rsa2048_pss is used, TokenBinding.signature contains the signature generated using the RSASSA-PSS signature scheme defined in [RFC8017] with SHA256 as the hash function. MGF1 with SHA256 MUST be used as the mask generation function, and the salt length MUST equal 32 bytes.

When ecdsap256 is used, TokenBinding.signature contains a pair of 32-byte integers, R followed by S, generated with ECDSA using Curve P-256 and SHA256 as defined in [ANSI.X9-62.2005] and [FIPS.186-4.2013]. R and S are encoded in big-endian format, preserving any leading zero bytes.

The signature is computed over the byte string representing the concatenation of:

- TokenBindingType value contained in the TokenBinding.tokenbinding_type field;
- TokenBindingKeyParameters value contained in the TokenBindingID.key_parameters field;

- Exported keying material (EKM) value obtained from the current TLS connection.

Please note that TLS 1.2 and earlier versions support renegotiation, which produces a new TLS master secret for the same connection, with associated session keys and EKM value. TokenBinding.signature MUST be a signature of the EKM value derived from the TLS master secret that produced the session keys encrypting the TLS application_data record(s) containing this TokenBinding. Such use of the current EKM for the TLS connection makes replay of bound tokens within renegotiated TLS sessions detectable, but requires the application to synchronize Token Binding message generation and verification with the TLS handshake state.

Specifications defining the use of Token Binding with application protocols, such as Token Binding over HTTP [I-D.ietf-tokbind-https], MAY prohibit the use of TLS renegotiation in combination with Token Binding, obviating the need for such synchronization. Alternatively, such specifications need to define a way to determine which EKM value corresponds to a given TokenBindingMessage, and a mechanism preventing a TokenBindingMessage from being split across TLS renegotiation boundaries (i.e., due to TLS message fragmentation - see Section 6.2.1 of [RFC5246]). Note that application layer messages conveying a TokenBindingMessage may cross renegotiation boundaries in ways that make processing difficult.

The EKM is obtained using the Keying Material Exporters for TLS defined in [RFC5705], by supplying the following input values:

- Label: The ASCII string "EXPORTER-Token-Binding" with no terminating NUL.

- Context value: No application context supplied.

- Length: 32 bytes.

3.4. TokenBinding.extensions

A Token Binding message may optionally contain a series of TB_Extension structures, each consisting of an extension_type and extension_data. The structure and meaning of extension_data depends on the specific extension_type.

Initially, no extension types are defined (see Section 6.3 "Token Binding Extensions Registry"). One of the possible uses of extensions envisioned at the time of this writing is attestation: cryptographic proof that allows the server to verify that the Token

Binding key is hardware-bound. The definitions of such Token Binding protocol extensions are outside the scope of this specification.

An implementation MUST ignore any unknown Token Binding types.

4. Establishing a Token Binding

4.1. Client Processing Rules

The client MUST include at least one TokenBinding structure in the Token Binding message. The key parameters used in the provided_token_binding MUST match those negotiated with the server (e.g., via [I-D.ietf-tokbind-negotiation] or a different mechanism).

The client MUST generate and store Token Binding keys in a secure manner that prevents key export. In order to prevent cooperating servers from linking user identities, the scope of the Token Binding keys MUST NOT be broader than the scope of the tokens, as defined by the application protocol.

When the client needs to send a referred_token_binding to the Identity Provider, the client SHALL construct the referred TokenBinding structure in the following manner:

- Set TokenBinding.tokenbinding_type to referred_token_binding.
- Set TokenBinding.tokenbindingid to the Token Binding ID used with the Relying Party.
- Generate TokenBinding.signature, using the EKM value of the TLS connection to the Identity Provider, the Token Binding key established with the Relying Party and the signature algorithm indicated by the associated key parameters. Note that these key parameters may differ from the key parameters negotiated with the Identity Provider.

Conveying referred Token Bindings in this fashion allows the Identity Provider to verify that the client controls the Token Binding key used with the Relying Party.

4.2. Server Processing Rules

The triple handshake vulnerability in TLS 1.2 and older TLS versions affects the security of the Token Binding protocol, as described in Section 7 "Security Considerations". Therefore, the server MUST NOT negotiate the use of the Token Binding protocol with these TLS versions, unless the server also negotiates the Extended Master

Secret [RFC7627] and Renegotiation Indication [RFC5746] TLS extensions.

If the use of the Token Binding protocol was not negotiated, but the client sends the Token Binding message, the server MUST reject any contained bindings. If the Token Binding type is "provided_token_binding", the server MUST verify that the signature algorithm (including elliptic curve in the case of ECDSA) and key length in the Token Binding message match those negotiated with this client (e.g., via [I-D.ietf-tokbind-negotiation] or a different mechanism). In the case of a mismatch, the server MUST reject the binding. Token Bindings of type "referred_token_binding" may use different key parameters than those negotiated with this client.

If the Token Binding message does not contain at least one TokenBinding structure, or if a signature contained in any TokenBinding structure is invalid, the server MUST reject the binding.

Servers MUST ignore any unknown extensions. Initially, no extension types are defined (see Section 6.3 "Token Binding Extensions Registry").

If all checks defined above have passed successfully, the Token Binding between this client and server is established. The Token Binding ID(s) conveyed in the Token Binding Message can be provided to the server-side application. The application may then use the Token Binding IDs for bound security token creation and validation, see Section 5.

If a Token Binding is rejected, any associated bound tokens MUST also be rejected by the server. The effect of this is application-specific, e.g., failing requests, a requirement for the client to re-authenticate and present a different token, or connection termination.

5. Bound Security Token Creation and Validation

Security tokens can be bound to the TLS layer in a variety of ways: by embedding the Token Binding ID or its cryptographic hash in the token, or by maintaining a database mapping tokens to Token Binding IDs. The specific method of generating bound security tokens is application-defined and beyond the scope of this document. Note that applicable security considerations are outlined in Section 7.

Either or both clients and servers MAY create bound security tokens. For example, HTTPS servers employing Token Binding for securing their HTTP cookies will bind these cookies. In the case of a server-

initiated challenge-response protocol employing Token Binding and TLS, the client can, for example, incorporate the Token Binding ID within the signed object it returns, thus binding the object.

Upon receipt of a security token, the server attempts to retrieve Token Binding ID information from the token and from the TLS connection with the client. Application-provided policy determines whether to honor non-bound (bearer) tokens. If the token is bound and a Token Binding has not been established for the client connection, the server MUST reject the token. If the Token Binding ID for the token does not match the Token Binding ID established for the client connection, the server MUST reject the token.

6. IANA Considerations

This section establishes three IANA registries on a new registry page entitled "Token Binding Protocol": "Token Binding Key Parameters", "Token Binding Types" and "Token Binding Extensions". It also registers a new TLS exporter label in the TLS Exporter Label Registry.

6.1. Token Binding Key Parameters Registry

This document establishes a registry for identifiers of Token Binding key parameters entitled "Token Binding Key Parameters" under the "Token Binding Protocol" heading.

Entries in this registry require the following fields:

- Value: The octet value that identifies a set of Token Binding key parameters (0-255).
- Description: The description of the Token Binding key parameters.
- Specification: A reference to a specification that defines the Token Binding key parameters.

This registry operates under the "Expert Review" policy as defined in [RFC8126]. The designated expert will require the inclusion of a reference to a permanent and readily available specification that enables the creation of interoperable implementations using the identified set of Token Binding key parameters.

An initial set of registrations for this registry follows:

Value: 0

Description: rsa2048_pkcs1.5

Specification: this document

Value: 1

Description: rsa2048_pss

Specification: this document

Value: 2

Description: ecdsap256

Specification: this document

6.2. Token Binding Types Registry

This document establishes a registry for Token Binding type identifiers entitled "Token Binding Types" under the "Token Binding Protocol" heading.

Entries in this registry require the following fields:

- Value: The octet value that identifies the Token Binding type (0-255).
- Description: The description of the Token Binding type.
- Specification: A reference to a specification that defines the Token Binding type.

This registry operates under the "Expert Review" policy as defined in [RFC8126]. The designated expert will require the inclusion of a reference to a permanent and readily available specification that enables the creation of interoperable implementations using the identified Token Binding type.

An initial set of registrations for this registry follows:

Value: 0

Description: provided_token_binding

Specification: this document

Value: 1

Description: referred_token_binding

Specification: this document

6.3. Token Binding Extensions Registry

This document establishes a registry for Token Binding extensions entitled "Token Binding Extensions" under the "Token Binding Protocol" heading.

Entries in this registry require the following fields:

- Value: The octet value that identifies the Token Binding extension (0-255).
- Description: The description of the Token Binding extension.
- Specification: A reference to a specification that defines the Token Binding extension.

This registry operates under the "Expert Review" policy as defined in [RFC8126]. The designated expert will require the inclusion of a reference to a permanent and readily available specification that enables the creation of interoperable implementations using the identified Token Binding extension. This document creates no initial registrations in the "Token Binding Extensions" registry.

6.4. Registration of Token Binding TLS Exporter Label

This document adds the following registration in the TLS Exporter Label Registry:

Value: EXPORTER-Token-Binding

DTLS-OK: Y

Reference: this document

7. Security Considerations

7.1. Security Token Replay

The goal of the Token Binding protocol is to prevent attackers from exporting and replaying security tokens, thereby impersonating legitimate users and gaining access to protected resources. Bound tokens can be replayed by malware present in User Agents, which may be undetectable by a server. However, in order to export bound tokens to other machines and successfully replay them, attackers also need to export corresponding Token Binding private keys. Token Binding private keys are therefore high-value assets and SHOULD be strongly protected, ideally by generating them in a hardware security module that prevents key export.

The manner in which a token is bound to the TLS layer is application-defined and beyond the scope of this document. However, the resulting bound token needs to be integrity-protected, so that an attacker cannot remove the binding or substitute a Token Binding ID of their choice without detection.

The Token Binding protocol does not prevent cooperating clients from sharing a bound token. A client could intentionally export a bound token with the corresponding Token Binding private key, or perform signatures using this key on behalf of another client.

7.2. Downgrade Attacks

The Token Binding protocol MUST be negotiated using a mechanism that prevents downgrade. E.g., [I-D.ietf-tokbind-negotiation] uses a TLS extension for Token Binding negotiation. TLS prevents active attackers from modifying the messages of the TLS handshake, therefore it is not possible for the attacker to remove or modify the Token Binding Negotiation TLS Extension. The signature algorithm and key length used in the TokenBinding of type "provided_token_binding" MUST match the negotiated parameters.

7.3. Privacy Considerations

The Token Binding protocol uses persistent, long-lived Token Binding IDs. To protect privacy, Token Binding IDs are never transmitted in clear text and can be reset by the user at any time, e.g. when clearing browser cookies. Some applications offer a special privacy mode where they don't store or use tokens supplied by the server, e.g., "in private" browsing. When operating in this special privacy mode, applications SHOULD use newly generated Token Binding keys and delete them when exiting this mode, or else SHOULD NOT negotiate Token Binding at all.

In order to prevent cooperating servers from linking user identities, the scope of the Token Binding keys MUST NOT be broader than the scope of the tokens, as defined by the application protocol.

A server can use tokens and Token Binding IDs to track clients. Client applications that automatically limit the lifetime or scope of tokens to maintain user privacy SHOULD apply the same validity time and scope limits to Token Binding keys.

7.4. Token Binding Key Sharing Between Applications

Existing systems provide a variety of platform-specific mechanisms for certain applications to share tokens, e.g. to enable single sign-on scenarios. For these scenarios to keep working with bound tokens, the applications that are allowed to share tokens will need to also share Token Binding keys. Care must be taken to restrict the sharing of Token Binding keys to the same group(s) of applications that share the same tokens.

7.5. Triple Handshake Vulnerability in TLS 1.2 and Older TLS Versions

The Token Binding protocol relies on the TLS Exporters [RFC5705] to associate a TLS connection with a Token Binding. The triple handshake attack [TRIPLE-HS] is a known vulnerability in TLS 1.2 and older TLS versions, allowing the attacker to synchronize keying material between TLS connections. The attacker can then successfully replay bound tokens. For this reason, the Token Binding protocol MUST NOT be negotiated with these TLS versions, unless the Extended Master Secret [RFC7627] and Renegotiation Indication [RFC5746] TLS extensions have also been negotiated.

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9. References

9.1. Normative References

[ANSI.X9-62.2005]
American National Standards Institute, "Public Key Cryptography for the Financial Services Industry, The Elliptic Curve Digital Signature Algorithm (ECDSA)", ANSI X9.62, 2005.

[FIPS.186-4.2013]
National Institute of Standards and Technology, "Digital Signature Standard (DSS)", FIPS 186-4, 2013.

[I-D.ietf-tokbind-https]
Popov, A., Nystrom, M., Balfanz, D., Langley, A., Harper, N., and J. Hodges, "Token Binding over HTTP", draft-ietf-tokbind-https-14 (work in progress), May 2018.

[I-D.ietf-tokbind-negotiation]
Popov, A., Nystrom, M., Balfanz, D., and A. Langley, "Transport Layer Security (TLS) Extension for Token Binding Protocol Negotiation", draft-ietf-tokbind-negotiation-12 (work in progress), May 2018.

[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/info/rfc2119>.

[RFC5246] Dierks, T. and E. Rescorla, "The Transport Layer Security (TLS) Protocol Version 1.2", RFC 5246, DOI 10.17487/RFC5246, August 2008, <https://www.rfc-editor.org/info/rfc5246>.

[RFC5705] Rescorla, E., "Keying Material Exporters for Transport Layer Security (TLS)", RFC 5705, DOI 10.17487/RFC5705, March 2010, <https://www.rfc-editor.org/info/rfc5705>.

[RFC5746] Rescorla, E., Ray, M., Dispensa, S., and N. Oskov, "Transport Layer Security (TLS) Renegotiation Indication Extension", RFC 5746, DOI 10.17487/RFC5746, February 2010, <https://www.rfc-editor.org/info/rfc5746>.

[RFC7230] Fielding, R., Ed. and J. Reschke, Ed., "Hypertext Transfer Protocol (HTTP/1.1): Message Syntax and Routing", RFC 7230, DOI 10.17487/RFC7230, June 2014, <https://www.rfc-editor.org/info/rfc7230>.

[RFC7540] Belshe, M., Peon, R., and M. Thomson, Ed., "Hypertext Transfer Protocol Version 2 (HTTP/2)", RFC 7540, DOI 10.17487/RFC7540, May 2015, <https://www.rfc-editor.org/info/rfc7540>.

[RFC7627] Bhargavan, K., Ed., Delignat-Lavaud, A., Pironti, A., Langley, A., and M. Ray, "Transport Layer Security (TLS) Session Hash and Extended Master Secret Extension", RFC 7627, DOI 10.17487/RFC7627, September 2015, <https://www.rfc-editor.org/info/rfc7627>.

[RFC8126] Cotton, M., Leiba, B., and T. Narten, "Guidelines for Writing an IANA Considerations Section in RFCs", BCP 26, RFC 8126, DOI 10.17487/RFC8126, June 2017, <https://www.rfc-editor.org/info/rfc8126>.

[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/info/rfc8174>.

9.2. Informative References

[RFC6749] Hardt, D., Ed., "The OAuth 2.0 Authorization Framework", RFC 6749, DOI 10.17487/RFC6749, October 2012, <https://www.rfc-editor.org/info/rfc6749>.

[RFC8017] Moriarty, K., Ed., Kaliski, B., Jonsson, J., and A. Rusch, "PKCS #1: RSA Cryptography Specifications Version 2.2", RFC 8017, DOI 10.17487/RFC8017, November 2016, <https://www.rfc-editor.org/info/rfc8017>.

[TRIPLE-HS] Bhargavan, K., Delignat-Lavaud, A., Fournet, C., Pironti, A., and P. Strub, "Triple Handshakes and Cookie Cutters: Breaking and Fixing Authentication over TLS. IEEE Symposium on Security and Privacy", 2014.

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