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Rate-Limited Token Issuance Protocol

Abstract

This document specifies a variant of the Privacy Pass issuance protocol that allows for tokens to be rate-limited on a per-origin basis. This enables origins to use tokens for use cases that need to restrict access from anonymous clients.

Discussion Venues

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

Discussion of this document takes place on the Privacy Pass Working Group mailing list (privacy-pass@ietf.org), which is archived at https://mailarchive.ietf.org/arch/browse/privacy-pass/.

Source for this draft and an issue tracker can be found at https://github.com/ietf-wg-privacypass/draft-ietf-privacypass-rate-limit-tokens.

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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Table of Contents

1. Introduction
  1.1. Motivation
  1.2. Protocol Overview
  1.3. Properties and Requirements
2. Terminology
3. Configuration
4. Token Challenge Requirements
5. Issuance Protocol
  5.1. State Requirements
    5.1.1. Client State
    5.1.2. Attester State
    5.1.3. Issuer State
  5.2. Issuance HTTP Headers
  5.3. Client-to-Attester Request
  5.4. Attester-to-Issuer Request
  5.5. Issuer-to-Attester Response
  5.6. Attester-to-Client Response
6. Encrypting Origin Token Requests and Responses
  6.1. Client to Issuer Encapsulation
  6.2. Issuer to Client Encapsulation
7. Anonymous Issuer Origin ID Computation
  7.1. Client Behavior
    7.1.1. Request Key
    7.1.2. Request Signature
  7.2. Attester Behavior (Client Request Validation)
  7.3. Issuer Behavior
  7.4. Attester Behavior (Index Computation)
8. Security Considerations
  8.1. Client Secret Use
  8.2. Custom Token Request Encapsulation
  8.3. Channel Security
  8.4. Token Request Unlinkability and Unforgeability

8.5. Information Disclosure
9. Privacy Considerations
9.1. Client Token State and Origin Tracking
9.2. Origin Verification
9.3. Client Identification with Unique Encapsulation Keys
9.4. Origin Identification
9.5. Collusion Among Different Entities
10. Deployment Considerations
10.1. Token Key Management
11. IANA considerations
11.1. Token Type
11.1.1. ECDSA-based Token Type
11.1.2. Ed25519-based Token Type
11.2. HTTP Headers
12. References
12.1. Normative References
12.2. Informative References
Appendix A. Acknowledgements
Appendix B. Test Vectors
B.1. Origin Name Encryption Test Vector
B.2. Anonymous Origin ID Test Vector
Authors' Addresses

1. Introduction

This document specifies a variant of the Privacy Pass issuance protocol (as defined in [ARCH]) that allows for tokens to be rate-limited on a per-origin basis. This enables origins to use tokens for use cases that need to restrict access from anonymous clients.

The base Privacy Pass issuance protocol [ISSUANCE] defines stateless anonymous tokens, which can either be publicly verifiable or not.

This variant build upon the publicly verifiable issuance protocol that uses RSA Blind Signatures [BLINDSIG], and allows tokens to be rate-limited on a per-origin basis. This means that a client will only be able to receive a limited number of tokens associated with a given origin server within a fixed period of time.

This issuance protocol registers the Rate-Limited Blind RSA token type (Section 11.1), to be used with the PrivateToken HTTP authentication scheme defined in [AUTHSCHEME].

1.1. Motivation

A client that wishes to keep its IP address private can hide its IP address using a proxy service or a VPN. However, doing so severely limits the client's ability to access services and content, since

servers might not be able to enforce their policies without a stable and unique client identifier.

Privacy Pass tokens in general allow clients to provide anonymous attestation of various properties. The tokens generated by the basic issuance protocol ([ISSUANCE]) can be used to verify that a client meets a particular bar for attestation, but cannot be used by a redeeming server to rate-limit specific clients. This is because there is no mechanism in the issuance protocol to link repeated client token requests in order to apply rate-limiting.

There are several use cases for rate-limiting anonymous clients that are common on the Internet. These routinely use client IP address tracking, among other characteristics, to implement rate-limiting.

One example of this use case is rate-limiting website accesses to a client to help prevent abusive behavior. Operations that are sensitive to abuse, such as account creation on a website or logging into an account, often employ rate-limiting as a defense-in-depth strategy. Additional verification can be required by these pages when a client exceeds a set rate-limit.

Another example of this use case is a metered paywall, where an origin limits the number of page requests from each unique user over a period of time before the user is required to pay for access. The origin typically resets this state periodically, say, once per month. For example, an origin may serve ten (major content) requests in a month before a paywall is enacted. Origins may want to differentiate quick refreshes from distinct accesses.

For some applications, the basic issuance protocol from [ISSUANCE] could be used to implement rate limits. In particular, the 'Joint Attester and Issuer' model from [ARCH] could be used to restrict the number of tokens issued to individual clients over a time window. However, in this deployment model, the Attester and Issuer would learn all origins used by a specific client, thereby coupling sensitive attestation and redemption contexts. In some cases this might be a significant portion of browsing history.

1.2. Protocol Overview

The issuance protocol defined in this document decouples sensitive information in the attestation context, such as the client identity, from the information in the redemption context, such as the origin. It does so by employing the 'Split Origin, Attester, Issuer' model. In this model, the Issuer learns redemption information like origin identity (used to determine per-origin rate limit policies), and the Attester learns attestation information like client identity (used to keep track of the previous instances of token issuance).

Figure 1 shows how this interaction works for client requests that are within the rate limit. The Client's token request to the Attester (constructed according to Section 5.3, and forwarded to the Issuer according to Section 5.4) contains encrypted information that the Issuer uses to identify the relevant rate limit policy to apply. This rate limit policy is returned to the Attester (according to Section 5.5), which then checks whether or not the Client is within this policy. If yes, the Attester forwards the issuer token response to the Client (according to Section 5.6) so that the resulting token can be redeemed by the Origin.

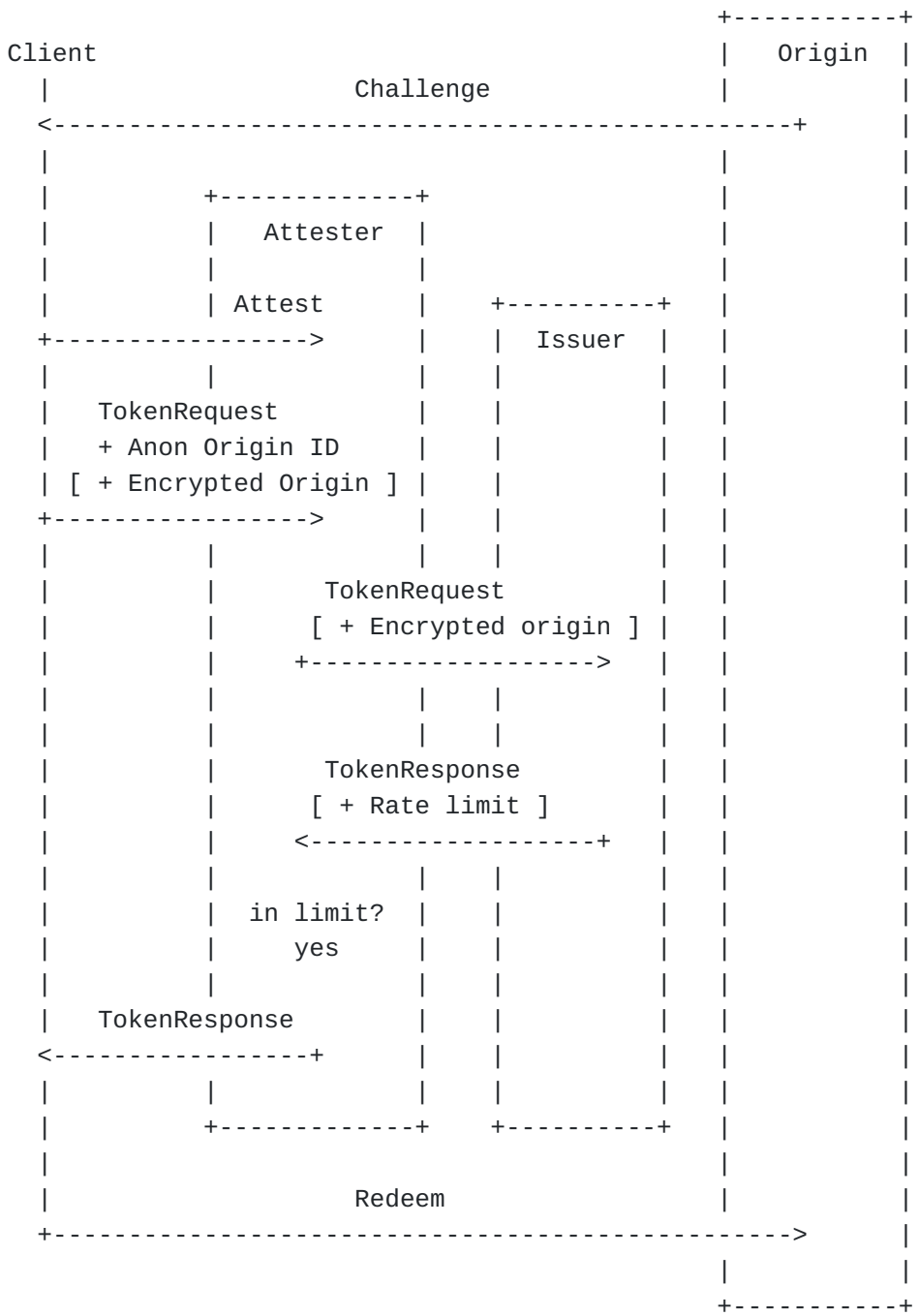


Figure 1: Successful rate-limited issuance

Figure 2 shows how this interaction works for client requests that exceed the rate limit. The Client's request to the Issuer and the Issuer's response to the Attester are the same. However, in this scenario, the Client is not within the rate limit, so the Attester responds to the Client with an error instead of the issuer's token response.

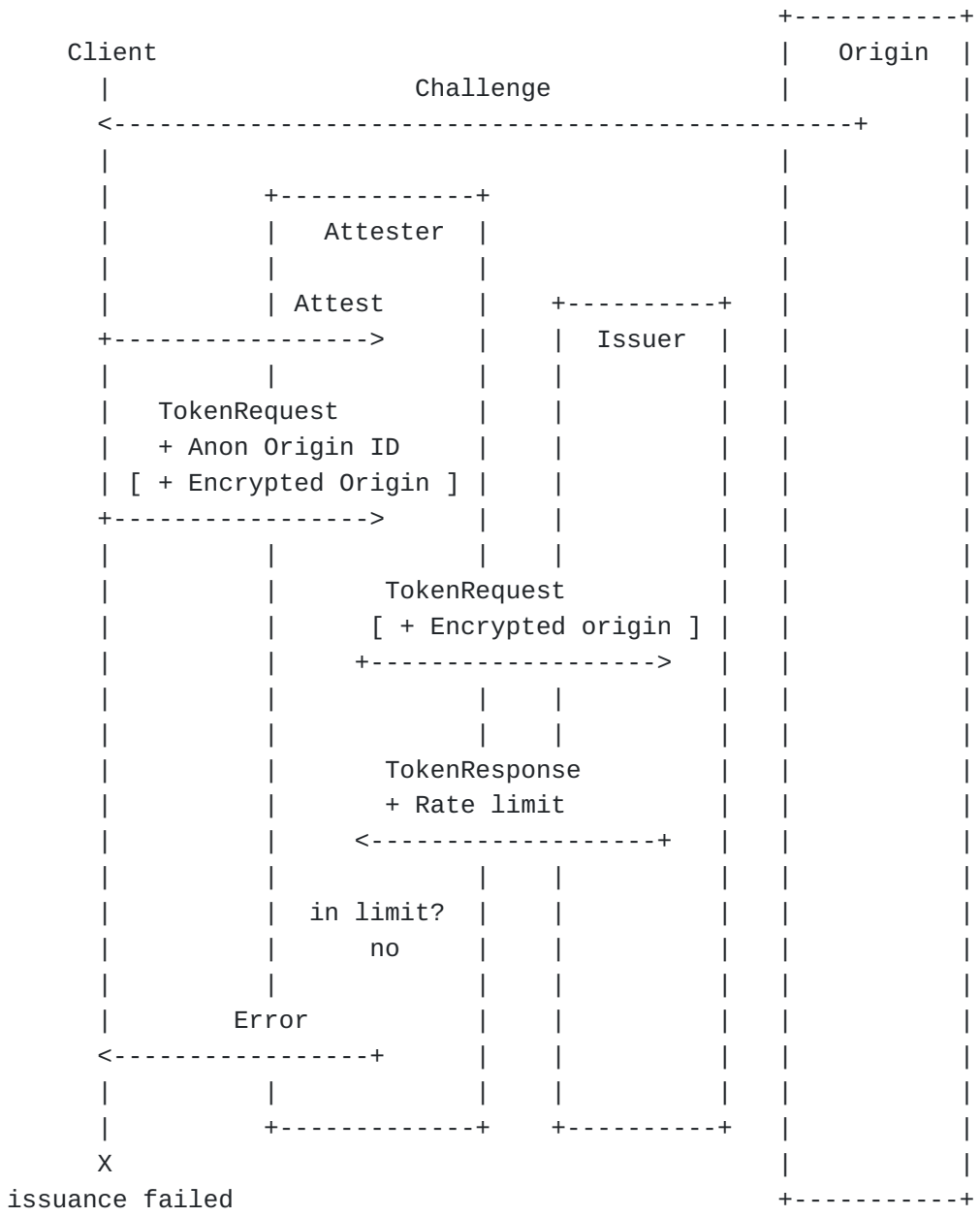


Figure 2: Failed rate-limited issuance

Each Issuer has a window over which a rate limit policy is applied. The window begins upon a Client's first token request and ends after

the window time elapses, after which the Client's rate limit state is reset. Issuers apply the rate limit policy corresponding to a Client's encrypted Origin by using a per-Origin secret key to produce the token response. Attesters enforce the rate limit by combining the Issuer's response with a per-Client value, yielding an (Anonymous) Issuer Origin ID that is stable for all client requests to the designated Origin. The Anonymous Issuer Origin ID is used to track and enforce the Client rate limit.

Issuers can rotate the secret they use when applying rate limits as desired. If a rotation event happens during a Client's active policy window, the Attester would compute a different Anonymous Issuer Origin ID and mistakenly conclude that the Client is acccessing a new Origin. To mitigate this, Client's provide a stable Anonymous Origin ID in their request to the Attester, which is constant for all requests to that Origin. This allows the Attester to detect when Issuer rotation events occur without affecting Client rate limits.

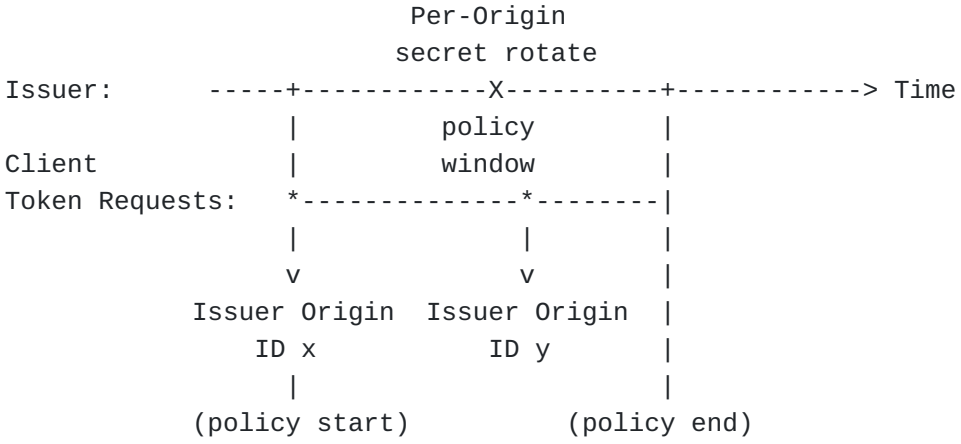


Figure 3: Issuer policy window rotation

Unlike the basic issuance protocol [ISSUANCE], the rate-limited issuance protocol in this document has additional functional and state requirements for Client, Attester, and Issuer. Section 5.1.2 describes the state that the Attester must track in order to enforce these limits, Section 5.1.1 describes the Client state necessary for successive token requests with the Attester, and Section 5.1.3 describes the state necessary for the Issuer to apply rate limits. The functional description of each participant in this protocol is explained in Section 5

1.3. Properties and Requirements

For rate-limited token issuance, the Attester, Issuer, and Origin as defined in [ARCH] each have partial knowledge of the Client's

identity and actions, and each entity only knows enough to serve its function (see Section 2 for more about the pieces of information):

- The Attester knows the Client's identity and learns the Client's public key (Client Key), the Issuer being targeted (Issuer Name), the period of time for which the Issuer's policy is valid (Issuer Policy Window), the number of tokens the Issuer is willing to issue within the current policy window, and the number of tokens issued to a given Client for the claimed Origin in the policy window. The Attester does not know the identity of the Origin the Client is trying to access (Origin Name), but knows a Client-anonymized identifier for it (Anonymous Origin ID).

- The Issuer knows a per-Origin secret (Issuer Origin Secret) and policy about client access, and learns the Origin's identity (Origin Name) during issuance. The Issuer does not learn the Client's identity or information about the Client's access pattern.

- The Origin knows the Issuer to which it will delegate an incoming Client (Issuer Name), and can verify that any tokens presented by the Client were signed by the Issuer. The Origin does not learn which Attester was used by a Client for issuance.

Since an Issuer applies policies on behalf of Origins, a Client is required to reveal the Origin's identity to the delegated Issuer. It is a requirement of this protocol that the Attester not learn the Origin's identity so that, despite knowing the Client's identity, an Attester cannot track and concentrate information about Client activity.

An Issuer expects an Attester to verify its Clients' identities correctly, but an Issuer cannot confirm an Attester's efficacy or the Attester-Client relationship directly without learning the Client's identity. Similarly, an Origin does not know the Attester's identity, but ultimately relies on the Attester to correctly verify or authenticate a Client for the Origin's policies to be correctly enforced. An Issuer therefore chooses to issue tokens to only known and reputable Attesters; the Issuer can employ its own methods to determine the reputation of a Attester.

An Attester is expected to employ a stable Client identifier, such as an IP address, a device identifier, or an account at the Attester, that can serve as a reasonable proxy for a user with some creation and maintenance cost on the user.

For the Issuance protocol, a Client is expected to create and maintain stable and explicit secrets for time periods that are on the scale of Issuer policy windows. Changing these secrets

arbitrarily during a policy window can result in token issuance failure for the rest of the policy window; see Section 5.1.1 for more details. A Client can use a service offered by its Attester or a third-party to store these secrets, but it is a requirement of this protocol that the Attester not be able to learn these secrets.

The privacy guarantees of this issuance protocol, specifically those around separating the identity of the Client from the names of the Origins that it accesses, are based on the expectation that there is not collusion between the entities that know about Client identity and those that know about Origin identity. Clients choose and share information with Attesters, and Origins choose and share policy with Issuers; however, the Attester is generally expected to not be colluding with Issuers or Origins. If this occurs, it can become possible for an Attester to learn or infer which Origins a Client is accessing, or for an Origin to learn or infer the Client identity. For further discussion, see Section 9.5.

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.

Unless otherwise specified, this document encodes protocol messages in TLS notation from [TLS13], Section 3.

This draft includes pseudocode that uses the functions and conventions defined in [HPKE].

Encoding an integer to a sequence of bytes in network byte order is described using the function "encode(n, v)", where "n" is the number of bytes and "v" is the integer value. The function "len()" returns the length of a sequence of bytes.

The following terms are defined in [ARCH] and are used throughout this document:

- Client: An entity that provides authorization tokens to services across the Internet, in return for authorization.

- Issuer: An entity that produces Privacy Pass tokens to clients.

- Attester: An entity that can attest to properties about the client, including previous patterns of access.

- Origin: The server from which the client can redeem tokens.

- *Issuance Protocol: The protocol exchange that involves the client, attester, and issuer, used to generate tokens.

The following terms are defined in [AUTHSCHEME], which defines the interactions between clients and origins:

- *Issuer Name: The name that identifies the Issuer, which is an entity that can generate tokens for a Client using one or more issuance protocols.

- *Token Key: Keying material that can be used with an issuance protocol to create a signed token.

- *Origin Name: The name that identifies the Origin, as included in a TokenChallenge.

Additionally, this document defines several terms that are unique to the rate-limited issuance protocol:

- *Issuer Policy Window: The period over which an Issuer will track access policy, defined in terms of seconds and represented as a uint64. The state that the Attester keeps for a Client is specific to a policy window. The effective policy window for a specific Client starts when the Client first sends a request associated with an Issuer.

- *Issuer Encapsulation Key: The public key used to encrypt values such as Origin Name in requests from Clients to the Issuer, so that Attesters cannot learn the Origin Name value. Each Issuer Encapsulation Key is used across all requests on the Issuer, for different Origins.

- *Anonymous Origin ID: An identifier that is generated by the Client and marked on requests to the Attester, which represents a specific Origin anonymously. The Client generates a stable Anonymous Origin ID for each Origin Name, to allow the Attester to count token access without learning the Origin Name.

- *Client Key: A public key chosen by the Client and shared only with the Attester; see Section 8.4 for more details about this restriction.

- *Client Secret: The secret key used by the Client during token issuance, whose public key (Client Key) is shared with the Attester.

- *Issuer Origin Secret: A per-origin secret key used by the Issuer during token issuance, whose public key is not shared with anyone.

*Anonymous Issuer Origin ID: An identifier that is generated by Issuer based on an Issuer Origin Secret that is per-Client and per-Origin. See Section 5.6 for details of derivation.

3. Configuration

Issuers MUST provide the following parameters for configuration:

1. Issuer Policy Window: a uint64 of seconds as defined in Section 2.

2. Issuer Request URI: a token request URL for generating access tokens. For example, an Issuer URL might be https://issuer.example.net/token-request. This parameter uses resource media type "text/plain".

3. Issuer Encapsulation Key: a EncapsulationKey structure as defined below to use when encapsulating information, such as the origin name, to the Issuer in issuance requests. This parameter uses resource media type "application/issuer-encap-key". The Npk parameter corresponding to the HpkeKdfId can be found in [HPKE].

```
opaque HpkePublicKey[Npk]; // defined in RFC9180
uint16 HpkeKemId;          // defined in RFC9180
uint16 HpkeKdfId;          // defined in RFC9180
uint16 HpkeAeadId;         // defined in RFC9180

struct {
  uint8 key_id;
  HpkeKemId kem_id;
  HpkePublicKey public_key;
  HpkeKdfId kdf_id;
  HpkeAeadId aead_id;
} EncapsulationKey;
```

The Issuer parameters can be obtained from an Issuer via a directory object, which is a JSON object whose field names and values are raw values and URLs for the parameters.

Field Name	Value
issuer-policy-window	Issuer Policy Window as a JSON number
issuer-request-uri	Issuer Request URI resource URL as a JSON string
encap-keys	List of Encapsulation Key values, each as a base64url encoded EncapsulationKey value

Table 1

Issuers MAY advertise multiple encap-keys to support key rotation, where the order of the keys in the list indicates preference as with token-keys.

As an example, the Issuer's JSON directory could look like:

```
{
  "issuer-token-window": 86400,
  "issuer-request-uri": "https://issuer.example.net/token-request",
  "encap-keys": [
    <encoded EncapsulationKey>
  ]
}
```

Issuers MUST support at least one Token Key per origin. Issuers MAY support multiple Token Key values for the same Origin in order to support rotation. Origin configuration for Issuers is out of scope for this document, and so the mechanism by which Origins obtain their Token Key value is not specified here.

Issuer directory resources have the media type "application/json" and are located at the well-known location /.well-known/token-issuer-directory.

4. Token Challenge Requirements

Clients receive challenges for tokens, as described in [AUTHSCHEME].

For the rate-limited token issuance protocol described in this document, the name of the origin is sent in an encrypted message from the Client to the Issuer. If the TokenChallenge.origin_info field contains a single origin name, that origin name is used. If the origin_info field contains multiple origin names, the client selects the single origin name that presented the challenge. If the origin_info field is empty, the encrypted message is the empty string "".

The HTTP authentication challenge also SHOULD contain the following additional attribute:

* "issuer-encap-key", which contains a base64url encoding of a EncapsulationKey as defined in Section 3 to use when encrypting the Origin Name in issuance requests.

5. Issuance Protocol

This section describes the Issuance protocol for a Client to request and receive a token from an Issuer. Token issuance involves a Client, Attester, and Issuer, with the following steps:

1. The Client sends a token request containing a token request, encrypted origin name, and one-time-use public key and signature to the Attester

2. The Attester validates the request contents, specifically checking the request signature, and proxies the request to the Issuer

3. The Issuer validates the request against the signature, and processes its contents, and produces a token response sent back to the Attester

4. The Attester verifies the response and proxies the response to the Client

The Issuance protocol is designed such that Client, Attester, and Issuer learn only what is necessary for completing the protocol; see Section 8.5 for more details.

The Issuance protocol has a number of underlying cryptographic dependencies for operation:

- RSA Blind Signatures [BLINDSIG], for issuing and constructing Tokens. This support is the same as used in the base publicly verifiable token issuance protocol [ISSUANCE]

- [HPKE], for encrypting the origin server name in transit between Client and Issuer across the Attester.

- Signatures with key blinding, as described in [KEYBLINDING], for verifying correctness of Client requests.

Clients and Issuers are required to implement all of these dependencies, whereas Attesters are required to implement signature with key blinding support.

5.1. State Requirements

The Issuance protocol requires each participating endpoint to maintain some necessary state, as described in this section.

5.1.1. Client State

A Client is required to have the following information, derived from a given TokenChallenge:

- Origin Name, a hostname referring to the Origin [RFC6454]. This is the name of the Origin that issued the token challenge. One or more names can be listed in the TokenChallenge.origin_info field. Rate-limited token issuance relies on the client selecting a single origin name from this list if multiple are present.

- Token Key, a blind signature public key specific to the Origin. This key is owned by the Issuer identified by the TokenChallenge.issuer_name.

- Issuer Encapsulation Key, a public key used to encrypt request information corresponding to the Issuer identified by TokenChallenge.issuer_name.

Clients maintain a stable Client Key that they use for all communication with a specific Attester. Client Key is a public key, where the corresponding private key Client Secret is known only to the client.

If the client loses this (Client Key, Client Secret), they may generate a new tuple. The Attester will enforce if a client is allowed to use this new Client Key. See Section 5.1.2 for details on this enforcement.

Clients also need to be able to generate an Anonymous Origin ID value that corresponds to the Origin Name, to send in requests to the Attester.

Anonymous Origin ID MUST be a stable and unpredictable 32-byte value computed by the Client. Clients MUST NOT change this value across token requests for the same Origin Name. Doing so will result in token issuance failure (specifically, when an Attester rejects a request upon detecting two Anonymous Origin ID values that map to the same Origin).

One possible mechanism for implementing this identifier is for the Client to store a mapping between the Origin Name and a randomly generated Anonymous Origin ID for future requests. Alternatively, the Client can compute a PRF keyed by a per-client secret (Client Secret) over the Origin Name, e.g., Anonymous Origin ID = HKDF(secret=Client Secret, salt="", info=Origin Name).

5.1.2. Attester State

An Attester is required to maintain state for every authenticated Client. The mechanism of identifying a Client is specific to each Attester, and is not defined in this document. As examples, the Attester could use device-specific certificates or account authentication to identify a Client.

Attesters need to enforce that Clients don't change their Client Key frequently, to ensure Clients can't regularly evade the per-client policy as seen by the issuer. Attesters MUST NOT allow Clients to change their Client Key more than once within a policy window, or in the subsequent policy window after a previous Client Key change. Alternative schemes where the Attester stores the encrypted (Client Key, Client Secret) tuple on behalf of the client are possible but not described here.

Attesters are expected to know both the Issuer Policy Window and current Issuer Encapsulation Key for any Issuer Name to which they allow access. This information can be retrieved using the URIs defined in Section 3. The current Issuer Encapsulation Key value is used to check the value of the issuer_encap_key_id in Client-generated requests (Section 5.3) to reject requests where clients are using unique key IDs. Such unique keys could indicate a key-targeting attack that intends de-anonymize a client to the Issuer. In order to handle encapsulation key rotation, the Attester needs to know the current key value and the previou key value, and remember the last time the value changed to ensure that it does not happen too frequently (such as no more than once per policy window, or no more than once per day).

For each Client-Issuer pair, an Attester maintains a policy window start and end time for each Issuer from which a Client requests a token.

For each tuple of (Client Key, Anonymous Origin ID, policy window), the Attester maintains the following state:

- A counter of successful tokens issued
- Whether or not a previous request was rejected by the Issuer
- The previous rate limit provided by the Issuer
- The last received Anonymous Issuer Origin ID value for this Anonymous Origin ID, if any

The Issuer-provided rate limit for a single Origin is intended to not change more frequently than once per policy window. If the Attester detects a change of rate limit multiple times for the state

kept for a single policy window, it SHOULD reject tokens issued in the remainder of the policy window.

5.1.3. Issuer State

Issuers maintain a stable Issuer Origin Secret that they use in calculating values returned to the Attester for each origin. If this value changes, it will open up a possibility for Clients to request extra tokens for an Origin without being limited, within a policy window. See Section 10.1 for details about generating and rotating the Issuer Origin Secret.

Issuers are expected to have the private key that corresponds to Issuer Encapsulation Key, which allows them to decrypt the Origin Name values in requests.

For each Origin, Issuers need to know what rate limit to enforce during a policy window. Issuers SHOULD NOT use unique values for specific Origins, which would allow Attesters to recognize an Origin being accessed by multiple Clients. Each Origin limit is allowed to change, but SHOULD NOT change more often than once per policy window, to ensure that the limit is useful.

5.2. Issuance HTTP Headers

The Issuance protocol defines four new HTTP headers that are used in requests and responses between Clients, Attesters, and Issuers (see Section 11.2).

The "Sec-Token-Origin" is an Item Structured Header [RFC8941]. Its value MUST be a Byte Sequence. This header is sent both on Client-to-Attester requests (Section 5.3) and on Issuer-to-Attester responses (Section 5.5). Its ABNF is:

```
Sec-Token-Origin = sf-binary
```

The "Sec-Token-Client" is an Item Structured Header [RFC8941]. Its value MUST be a Byte Sequence. This header is sent on Client-to-Attester requests (Section 5.3), and contains the bytes of Client Key. Its ABNF is:

```
Sec-Token-Client = sf-binary
```

The "Sec-Token-Request-Blind" is an Item Structured Header [RFC8941]. Its value MUST be a Byte Sequence. This header is sent on Client-to-Attester requests (Section 5.3), and contains a per-request nonce value. Its ABNF is:

```
Sec-Token-Request-Blind = sf-binary
```

The "Sec-Token-Request-Key" is an Item Structured Header [RFC8941]. Its value MUST be a Byte Sequence. This header is sent on Client-to-Attester requests (Section 5.3), and contains a per-request public key. Its ABNF is:

```
Sec-Token-Request-Key = sf-binary
```

The "Sec-Token-Limit" is an Item Structured Header [RFC8941]. Its value MUST be an Integer. This header is sent on Issuer-to-Attester responses (Section 5.5), and contains the number of times a Client can retrieve a token for the requested Origin within a policy window, as set by the Issuer. Its ABNF is:

```
Sec-Token-Limit = sf-integer
```

5.3. Client-to-Attester Request

The Client and Attester MUST use a secure and Attester-authenticated HTTPS connection. They MAY use mutual authentication or mechanisms such as TLS certificate pinning, to mitigate the risk of channel compromise; see Section 8 for additional about this channel.

Requests to the Attester need to indicate the Issuer Name to which issuance requests will be forwarded. Attesters SHOULD provide Clients with a URI template that contains one variable that contains the Issuer Name, "issuer", using Level 3 URI template encoding as defined in Section 1.2 of [RFC6570].

An example of an Attester URI templates is shown below:

```
https://attester.net/token-request{?issuer}
```

Attesters and Clients MAY agree on other mechanisms to specify the Issuer Name in requests.

The Client first creates an issuance request message for a random value nonce using the input TokenChallenge challenge and the Issuer key identifier key_id as follows:

```
nonce = random(32)
context = SHA256(challenge)
token_input = concat(0x0003, nonce, context, key_id)
blinded_msg, blind_inv = rsabssa_blind(pkI, token_input)
```

The Client then uses Client Key to generate its one-time-use request public key request_key and blind request_blind as described in Section 7.1.

The Client then computes token_key_id as the least significant byte of the Token Key ID, where the Token Key ID is generated as

SHA256(public_key) and public_key is a DER-encoded SubjectPublicKeyInfo object carrying Token Key. The Client then constructs a InnerTokenRequest value, denoted origin_token_request, combining token_key_id, blinded_msg, and a padded representation of the origin name as follows:

```
struct {
  uint8_t token_key_id;
  uint8_t blinded_msg[Nk];
  uint8_t padded_origin_name<0..2^16-1>;
} InnerTokenRequest;
```

This structure is initialized and then encrypted using Issuer Encryption Key, producing encrypted_token_request, as described in Section 6.

Finally, the Client uses Client Secret to produce request_signature as described in Section 7.1.2.

The Client then constructs a TokenRequest structure. This TokenRequest structure is based on the publicly verifiable token issuance path in [ISSUANCE], adding fields for the encrypted origin name and request signature.

```
struct {
   uint16_t token_type = 0x0003;
   uint8_t request_key[Npk];
   uint8_t issuer_encap_key_id[32];
   uint8_t encrypted_token_request<1..2^16-1>;
   uint8_t request_signature[Nsig];
} TokenRequest;
```

The structure fields are defined as follows:

- "token_type" is a 2-octet integer, which matches the type in the challenge.

- "request_key" is the request_key value generated above.

- "issuer_encap_key_id" is a collision-resistant hash that identifies the Issuer Encryption Key, generated as SHA256(EncapsulationKey).

- "encrypted_token_request" is an encrypted structure that contains an InnerTokenRequest value, calculated as described in Section 6.

- "request_signature" is computed as described in Section 7.1.2.

The Client then generates an HTTP POST request to send through the Attester to the Issuer, with the TokenRequest as the body. The media

type for this request is "message/token-request". The Client includes the "Sec-Token-Origin" header, whose value is Anonymous Origin ID; the "Sec-Token-Client" header, whose value is Client Key; and the "Sec-Token-Request-Blind" header, whose value is request_blind. The Client sends this request to the Attester's proxy URI. An example request is shown below, where the Issuer Name is "issuer.net" and the Attester URI template is "https://attester.net/token-request{?issuer}"

```
:method = POST
:scheme = https
:authority = attester.net
:path = /token-request?issuer=issuer.net
accept = message/token-response
cache-control = no-cache, no-store
content-type = message/token-request
content-length = <Length of TokenRequest>
sec-token-origin = Anonymous Origin ID
sec-token-client = Client Key
sec-token-request-blind = request_blind

<Bytes containing the TokenRequest>
```

If the Attester detects a token_type in the TokenRequest that it does not recognize or support, it MUST reject the request with an HTTP 400 error.

The Attester also checks to validate that the issuer_encap_key_id in the client's TokenRequest matches a known Issuer Encapsulation Key public key for the Issuer. For example, the Attester can fetch this key using the API defined in Section 3. This check is done to help ensure that the Client has not been given a unique key that could allow the Issuer to fingerprint or target the Client. If the key does not match, the Attester rejects the request with an HTTP 400 error. Note that this can lead to failures in the event of Issuer Issuer Encapsulation Key rotation; see Section 9 for considerations.

The Attester finally validates the Client's stable mapping request as described in Section 7.2. If this fails, the Attester MUST return an HTTP 400 error to the Client.

If the Attester accepts the request, it will look up the state stored for this Client. It will look up the count of previously generate tokens for this Client using the same Anonymous Origin ID. See Section 5.1.2 for more details.

If the Attester has stored state that a previous request for this Anonymous Origin ID was rejected by the Issuer in the current policy

window, it SHOULD reject the request without forwarding it to the Issuer.

If the Attester detects this Client has changed their Client Key more frequently than allowed as described in Section 5.1.2, it SHOULD reject the request without forwarding it to the Issuer.

5.4. Attester-to-Issuer Request

Assuming all checks in Section 5.3 succeed, the Attester generates an HTTP POST request to send to the Issuer with the Client's TokenRequest as the body. The Attester MUST NOT add information that will uniquely identify a Client, or associate the request with a small set of possible Clients. Extensions to this protocol MAY allow Attesters to add information that can be used to separate large populations, such as providing information about the country or region to which a Client belongs. An example request is shown below.

```
:method = POST
:scheme = https
:authority = issuer.net
:path = /token-request
accept = message/token-response
cache-control = no-cache, no-store
content-type = message/token-request
content-length = <Length of TokenRequest>

<Bytes containing the TokenRequest>
```

The Attester and the Issuer MUST use a secure and Issuer-authenticated HTTPS connection. Also, Issuers MUST authenticate Attesters, either via mutual TLS or another form of application-layer authentication. They MAY additionally use mechanisms such as TLS certificate pinning, to mitigate the risk of channel compromise; see Section 8 for additional about this channel.

Upon receipt of the forwarded request, the Issuer validates the following conditions:

- The TokenRequest contains a supported token_type
- The TokenRequest.issuer_encap_key_id correspond to known Issuer Encapsulation Keys held by the Issuer.
- The TokenRequest.encrypted_token_request can be decrypted using the Issuer's private key (the private key associated with Issuer Encapsulation Key), and contains a valid InnerTokenRequest whose unpadded origin name matches an Origin Name that is served by the Issuer. The Origin name associated with the InnerTokenRequest value might be the empty string "", as described in Section 6, in

which case the Issuer applies a cross-origin policy if supported. If a cross-origin policy is not supported, this condition is not met.

If any of these conditions is not met, the Issuer MUST return an HTTP 400 error to the Attester, which will forward the error to the client.

The Issuer determines the correct Issuer Key by using the decrypted Origin Name and InnerTokenRequest.token_key_id values. If there is no Token Key whose truncated key ID matches InnerTokenRequest.token_key_id, the Issuer MUST return an HTTP 401 error to Attester, which will forward the error to the client. The Attester learns that the client's view of the Origin key was invalid in the process.

5.5. Issuer-to-Attester Response

If the Issuer is willing to give a token to the Client, the Issuer decrypts TokenRequest.encrypted_token_request to discover a InnerTokenRequest value. If this fails, the Issuer rejects the request with a 400 error. Otherwise, the Issuer validates and processes the token request with Issuer Origin Secret corresponding to the designated Origin as described in Section 7.3. If this fails, the Issuer rejects the request with a 400 error. Otherwise, the output is index_key.

The Issuer completes the issuance flow by computing a blinded response as follows:

```
blind_sig = rsabssa_blind_sign(skP, InnerTokenRequest.blinded_msg)
```

skP is the private key corresponding to the per-Origin Token Key, known only to the Issuer. The Issuer then encrypts blind_sig to the Client as described in Section 6.2, yielding encrypted_token_response.

The Issuer generates an HTTP response with status code 200 whose body consists of blind_sig, with the content type set as "message/token-response", the index_key set in the "Sec-Token-Origin" header, and the limit of tokens allowed for a Client for the Origin within a policy window set in the "Sec-Token-Limit" header. This limit SHOULD NOT be unique to a specific Origin, such that the Attester could use the value to infer which Origin the Client is accessing (see Section 9).

```
:status = 200
content-type = message/token-response
content-length = <Length of blind_sig>
sec-token-origin = index_key
sec-token-limit = Token limit

<Bytes containing the encrypted_token_response>
```

5.6. Attester-to-Client Response

Upon receipt of a successful response from the Issuer, the Attester extracts the "Sec-Token-Origin" header, and uses the value to determine Anonymous Issuer Origin ID as described in Section 7.4.

If the "Sec-Token-Origin" is missing, or if the same Anonymous Issuer Origin ID was previously received in a response for a different Anonymous Origin ID within the same policy window, the Attester MUST drop the token and respond to the client with an HTTP 400 status. If there is not an error, the Anonymous Issuer Origin ID is stored alongside the state for the Anonymous Origin ID.

The Attester also extracts the "Sec-Token-Limit" header, and compares the limit against the previous count of accesses for this Client for the Anonymous Origin ID. If the count is greater than or equal to the limit, the Attester drops the token and responds to the client with an HTTP 429 (Too Many Requests) error.

For all other cases, the Attester forwards all HTTP responses unmodified to the Client as the response to the original request for this issuance.

When the Attester detects successful token issuance, it MUST increment the counter in its state for the number of tokens issued to the Client for the Anonymous Origin ID.

Upon receipt, the Client decrypts the blind_sig from encrypted_token_response as described in Section 6.2. If successful, the Client then processes the response as follows:

```
authenticator = rsabssa_finalize(pkI, token_input, blind_sig, blind_inv)
```

If this succeeds, the Client then constructs a token as described in [AUTHSCHEME] as follows:

```
struct {
    uint16_t token_type = 0x0003
    uint8_t nonce[32];
    uint8_t context[32];
    uint8_t token_key_id[Nid];
    uint8_t authenticator[Nk]
} Token;
```

6. Encrypting Origin Token Requests and Responses

Clients encapsulate token request information to the Issuer using the Issuer Encapsulation Key. Issuers decrypt the token request using their corresponding private key. This process yields the decrypted token request as well as a shared encryption context between Client and Issuer. Issuers encapsulate their token response to the Client using an ephemeral key derived from this shared encryption context. This process ensures that the Attester learns neither the token request or response information.

Client to Issuer encapsulation is described in Section 6.1, and Issuer to Client encapsulation is described in Section 6.2.

6.1. Client to Issuer Encapsulation

Given a EncapsulationKey (Issuer Encapsulation Key), Clients produce encrypted_token_request using the following values:

- the one octet key identifier from the Name Key, keyID, with the corresponding KEM identified by kemID, the public key from the configuration, pkI, and;

- a selected combination of KDF, identified by kdfID, and AEAD, identified by aeadID.

Beyond the key configuration inputs, Clients also require the following inputs defined in Section 5.3: token_key_id, blinded_msg, request_key, origin_name, and issuer_encap_key_id.

Together, these are used to encapsulate an InnerTokenRequest and produce an encrypted token request (encrypted_token_request).

origin_name contains the name of the origin that initiated the challenge, as taken from the TokenChallenge.origin_info field. If the TokenChallenge.origin_info field is empty, origin_name is set to the empty string "".

The process for generating encrypted_token_request from blinded_msg, request_key, and origin_name values is as follows:

1. Compute an [HPKE] context using pkI, yielding context and encapsulation key enc.

2. Construct associated data, aad, by concatenating the values of keyID, kemID, kdfID, aeadID, and all other values of the TokenRequest structure.

3. Pad origin_name with N zero bytes, where N = 31 - ((L - 1) % 32) and L is the length of origin_name. If L is 0, N = 32. Denote this padding process as the function pad.

4. Encrypt (seal) the padded origin_name with aad as associated data using context, yielding ciphertext ct.

5. Concatenate the values of aad, enc, and ct, yielding encrypted_token_request.

Note that enc is of fixed-length, so there is no ambiguity in parsing this structure.

In pseudocode, this procedure is as follows:

```
enc, context = SetupBaseS(pkI, "InnerTokenRequest")
aad = concat(encode(1, keyID),
             encode(2, kemID),
             encode(2, kdfID),
             encode(2, aeadID),
             encode(2, token_type),
             encode(Npk, request_key),
             encode(32, issuer_encap_key_id))
padded_origin_name = pad(origin_name)
inner_token_request_enc = concat(encode(1, token_key_id),
                                 encode(Nk, blinded_msg),
                                 encode(2, len(padded_origin_name)),
                                 encode(len(padded_origin_name), padded_
ct = context.Seal(aad, inner_token_request_enc)
encrypted_token_request = concat(enc, ct)
```

Issuers reverse this procedure to recover the InnerTokenRequest value by computing the AAD as described above and decrypting encrypted_token_request with their private key skI (the private key corresponding to pkI). The origin_name value is recovered from InnerTokenRequest.padded_origin_name by stripping off padding bytes. In pseudocode, this procedure is as follows:

```
enc, ct = parse(encrypted_token_request)
aad = concat(encode(1, keyID),
             encode(2, kemID),
             encode(2, kdfID),
             encode(2, aeadID),
             encode(2, token_type),
             encode(Npk, request_key),
             encode(32, issuer_encap_key_id))
context = SetupBaseR(enc, skI, "TokenRequest")
inner_token_request_enc, error = context.Open(aad, ct)
```

The InnerTokenRequest.blinded_msg, InnerTokenRequest.token_key_id, and unpadded origin_name values are used by the Issuer as described in Section 5.4.

6.2. Issuer to Client Encapsulation

Given an HPKE context context computed in Section 6.1, Issuers encapsulate their token response blind_sig, yielding an encrypted token response encrypted_token_response, to the Client as follows:

1. Export a secret secret from context, using the string "OriginTokenResponse" as context. The length of this secret is max(Nn, Nk), where Nn and Nk are the length of AEAD key and nonce associated with context.

2. Generate a random value of length max(Nn, Nk) bytes, called response_nonce.

3. Extract a pseudorandom key prk using the Extract function provided by the KDF algorithm associated with context. The ikm input to this function is secret; the salt input is the concatenation of enc (from enc_request) and response_nonce

4. Use the Expand function provided by the same KDF to extract an AEAD key key, of length Nk - the length of the keys used by the AEAD associated with context. Generating key uses a label of "key".

5. Use the same Expand function to extract a nonce nonce of length Nn - the length of the nonce used by the AEAD. Generating nonce uses a label of "nonce".

6. Encrypt blind_sig, passing the AEAD function Seal the values of key, nonce, empty aad, and a pt input of request, which yields ct.

7. Concatenate response_nonce and ct, yielding an Encapsulated Response enc_response. Note that response_nonce is of fixed-

length, so there is no ambiguity in parsing either response_nonce or ct.

In pseudocode, this procedure is as follows:

```
secret = context.Export("OriginTokenResponse", Nk)
response_nonce = random(max(Nn, Nk))
salt = concat(enc, response_nonce)
prk = Extract(salt, secret)
aead_key = Expand(prk, "key", Nk)
aead_nonce = Expand(prk, "nonce", Nn)
ct = Seal(aead_key, aead_nonce, "", blind_sig)
encrypted_token_response = concat(response_nonce, ct)
```

Clients decrypt encrypted_token_response by reversing this process. That is, they first parse enc_response into response_nonce and ct. They then follow the same process to derive values for aead_key and aead_nonce.

The client uses these values to decrypt ct using the Open function provided by the AEAD. Decrypting might produce an error, as follows:

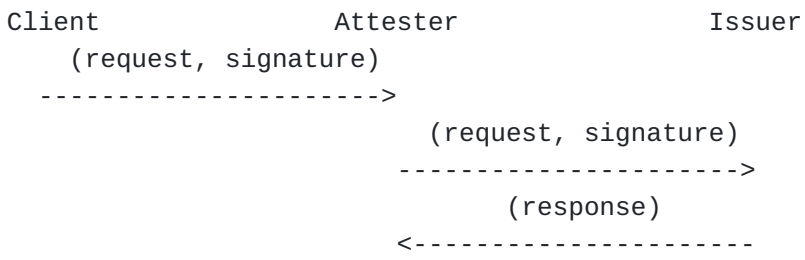
```
blind_sig, error = Open(aead_key, aead_nonce, "", ct)
```

7. Anonymous Issuer Origin ID Computation

This section describes the Client, Attester, and Issuer behavior in computing Anonymous Issuer Origin ID, the stable mapping based on client identity and origin name. At a high level, this functionality computes y = F(x, k), where x is a per-Client secret and k is a per-Origin secret, subject to the following constraints:

- The Attester only learns y if the Client in possession of x engages with the protocol;
- The Attester prevents a Client with private input x from running the protocol for input x' that is not equal to x;
- The Issuer does not learn x, nor does it learn when two requests correspond to the same private value x; and
- Neither the Client nor Attester learn k.

The interaction between Client, Attester, and Issuer in computing this functionality is shown below.



The protocol for computing this functionality is divided into sections for each of the participants. Section 7.1 describes Client behavior for initiating the computation with its per-Client secret, Section 7.2 describes Attester behavior for verifying Client requests, Section 7.3 describes Issuer behavior for computing the mapping with its per-Origin secret, and Section 7.4 describes the final Attester step for computing the client-origin index.

The index computation is based on a signature scheme with key blinding and unblinding support, denoted BKS, as described in Section 3 of [KEYBLINDING]. Such a scheme has the following functions:

- BKS-KeyGen(): Generate a random private and public key pair (sk, pk).

- BKS-BlindKeyGen(): Generate a random blinding key bk.

- BKS-BlindPublicKey(pk, bk, ctx): Produce a blinded public key based on the input public key pk, blind key bk, and context ctx.

- BKS-UnblindPublicKey(pk, bk, ctx): Produce an unblinded public key based on the input blinded public key pk, blind bk, and context ctx.

- BKS-Verify(pk, msg, sig): Verify signature sig over input message msg against the public key pk, producing a boolean value indicating success.

- BKS-BlindKeySign(sk_sign, sk_blind, ctx, msg): Sign input message msg with signing key sk_sign, blind key sk_blind, and context ctx and produce a signature of size Nsig bytes.

- BKS-SerializePrivatekey(sk): Serialize a private key to a byte string of length Nsk.

- BKS-DeserializePrivatekey(buf): Attempt to deserialize a private key from an Nsk-byte string buf. This function can fail if buf does not represent a valid private key.

- BKS-SerializePublicKey(pk): Serialize a public key to a byte string of length Npk.

- *BKS-DeserializePublicKey(buf): Attempt to deserialize a public key of length Npk. This function can fail if buf does not represent a valid public key.

Additionally, each BKS scheme has a corresponding hash function, denoted Hash. The implementation of each of these functions depends on the issuance protocol token type. See Section 11.1 for more details.

7.1. Client Behavior

This section describes the Client behavior for generating an one-time-use request key and signature. Clients provide their Client Secret as input to the request key generation step, and the rest of the token request inputs to the signature generation step.

7.1.1. Request Key

Clients produce request_key by masking Client Key and Client Secret with a randomly chosen blind. Let pk_sign and sk_sign denote Client Key and Client Secret, respectively. This process is done as follows:

1. Generate a random blind key, sk_blind.

2. Blind pk_sign with sk_blind to compute a blinded public key, request_key.

3. Output the blinded public key.

In pseudocode, this is as follows:

```
sk_blind = BKS-BlindKeyGen()
ctx = concat(encode(2, token_type)), "ClientBlind")
blinded_key = BKS-BlindPublicKey(pk_sign, sk_blind, ctx)
request_key = BKS-SerializePublicKey(blinded_key)
request_blind = BKS-SerializePrivatekey(sk_blind)
```

7.1.2. Request Signature

Clients produce a signature of their request by signing its entire contents consisting of the following values defined in Section 5.3: token_key_id, blinded_msg, request_key, issuer_encap_key_id, and encrypted_token_request. This process requires the blind value sk_blind produced during the Section 7.1.1 process. As above, let pk and sk denote Client Key and Client Secret, respectively. Given these values, this signature process works as follows:

1. Concatenate all signature inputs to yield a message to sign.

2. Compute a signature with the blind sk_blind over the input message using Client Secret, sk_sign as the signing key.

3. Output the signature.

In pseudocode, this is as follows:

```
message = concat(token_type,
                 request_key,
                 issuer_encap_key_id,
                 encode(2, len(encrypted_token_request)),
                 encrypted_token_request)
ctx = concat(encode(2, token_type)), "ClientBlind")
request_signature = BKS-BlindKeySign(sk_sign, sk_blind, ctx, message)
```

7.2. Attester Behavior (Client Request Validation)

Given a TokenRequest request containing request_key, request_signature, and request_blind, as well as Client Key pk_blind, Attesters verify the signature as follows:

1. Check that request_key is a valid public key. If this fails, abort.

2. Check that request_blind is a valid private key. If this fails, abort.

3. Blind the Client Key pk_sign by blind sk_blind, yielding a blinded key. If this does not match request_key, abort.

4. Verify request_signature over the contents of the request, excluding the signature itself, using request_key. If signature verification fails, abort.

In pseudocode, this is as follows:

```
blind_key = BKS-DeserializePublicKey(request_key)
sk_blind = BKS-DeserializePrivatekey(request_blind)
ctx = concat(encode(2, token_type)), "ClientBlind")
pk_blind = BKS-BlindPublicKey(pk_sign, sk_blind, ctx)
if pk_blind != blind_key:
  raise InvalidParameterError

context = parse(request[..len(request)-Nsig]) // this matches context co
valid = BKS-Verify(blind_key, context, request_signature)
if not valid:
  raise InvalidSignatureError
```

7.3. Issuer Behavior

Given an Issuer Origin Secret (denoted sk_origin) and a TokenRequest, from which request_key and request_signature are parsed, Issuers verify the request signature and compute a response as follows:

1. Check that request_key is a valid public key. If this fails, abort.

2. Verify request_signature over the contents of the request, excluding the signature itself, using request_key. If signature verification fails, abort.

3. Blind request_key by Issuer Origin Secret, sk_origin, yielding an index key.

4. Output the index key.

In pseudocode, this is as follows:

```
blind_key = BKS-DeserializePublicKey(request_key)
context = parse(request[..len(request)-Nsig]) // this matches context co
valid = BKS-Verify(blind_key, context, request_signature)
if not valid:
  raise InvalidSignatureError

ctx = concat(encode(2, token_type)), "IssuerBlind")
evaluated_key = BKS-BlindPublicKey(request_key, sk_origin, ctx)
index_key = BKS-SerializePublicKey(evaluated_key)
```

7.4. Attester Behavior (Index Computation)

Given an Issuer response index_key, Client blind sk_blind, and Client Key (denoted pk_sign), Attesters complete the Anonymous Issuer Origin ID computation as follows:

1. Check that index_key is a valid public key. If this fails, abort.

2. Unblind the index_key using the Client blind sk_blind, yielding the index result.

3. Run HKDF [RFC5869] with the hash function corresponding to the BKS scheme, using the index result as the secret, Client Key pk_sign as the salt, and ASCII string "anon_issuer_origin_id" as the info string, yielding Anonymous Issuer Origin ID.

In pseudocode, this is as follows:

```
evaluated_key = BKS-DeserializePublicKey(index_key)
ctx = concat(encode(2, token_type)), "ClientBlind")
unblinded_key = BKS-UnblindPublicKey(evaluated_key, sk_blind, ctx)

index_result = BKS-SerializePublicKey(unblinded_key)
pk_encoded = BKS-SerializePublicKey(pk_sign)

anon_issuer_origin_id = HKDF-Hash(secret=index_result,
  salt=pk_encoded, info="anon_issuer_origin_id")
```

8. Security Considerations

This section describes security considerations relevant to the use of this protocol.

8.1. Client Secret Use

The Client Secret key is used for two purposes in this protocol: (1) computing request signatures and (2) computing the Anonymous Issuer Origin ID (with the corresponding public key). This is necessary to ensure the client associated with the Anonymous Issuer Origin ID is the same client that produced a corresponding request. In general, using the same cryptographic key for two distinct purposes is considered bad practice. However, analysis of this protocol demonstrates that it is safe in this context. The Client Secret MUST NOT be used for any purpose outside of this protocol.

8.2. Custom Token Request Encapsulation

The protocol in this document uses [HPKE] directly to encrypt token request information to the issuer while also authenticating information exposed to the attester. Oblivious HTTP [OHTTP], which is a protocol built on top of HPKE for request encapsulation, is not suitable for this purpose since it does not allow clients to additionally authenticate application-layer information that is visible to intermediaries, which is the case for the data visible to the Attester.

8.3. Channel Security

An attacker that can act as an intermediate between Attester and Issuer communication can influence or disrupt the ability for the Issuer to correctly rate-limit token issuance. All communication channels use server-authenticated HTTPS. Some connections, e.g., between an Attester and an Issuer, require mutual authentication between both endpoints. Where appropriate, endpoints MAY use further enhancements such as TLS certificate pinning to mitigate the risk of channel compromise.

8.4. Token Request Unlinkability and Unforgeability

Client token requests are constructed such that an Issuer cannot distinguish between any two token requests from the same Client and two requests from different Clients. We refer to this property as issuance unlinkability. This property is achieved by the way the tokens are constructed. In particular, TokenRequest.request_key and TokenRequest.request_signature are the only value in a TokenRequest that is derived from per-Client information, i.e., the Client Secret.

TokenRequest.request_key is computed using a freshly generated blind for each token request. As a result, the value of TokenRequest.request_key in one token request is statistically independent from Client Key. Similarly, TokenRequest.request_signature is computed using the same freshly generated blind as TokenRequest.request_key for each token request, and the resulting signature is therefore independent from signatures produced using Client Secret. More details about this unlinkability property can be found in [KEYBLINDING].

This unlinkability property is only intended for requests observed by the Issuer. In contrast, the Attester is required to link requests from the same Client together for the purposes of enforcing rate limits. This Attester does this by observing the Client Key. Importantly, the Client Key is not sent to the Issuer during the issuance flow, as doing this would allow the Issuer to trivially link two requests to the same Client.

The token request signature is also required to be unforgeable. Informally, unforgeability means that no entity can produce a valid (message, signature) pair for any blinding key without access to the private signing key. Importantly, the means the Attester cannot forge signatures on behalf of a given Client in an attempt to learn the origin name.

8.5. Information Disclosure

The protocol in this document is designed such that information pertaining to issuance of a token is limited to parties that need it for completing the protocol. In particular, honest-but-curious Attesters learn only the Anonymous Issuer Origin ID as described in Section 7, any per-Client information necessary for attestation, and the target Issuer for a given token request. The Attester does not directly learn the origin name associated with a given token request, though it does learn the distribution of tokens across Client interactions. This auxiliary information could be used to infer the Origin for a given token. For example, if an Issuer has only two configured Origins, each with a different token request

pattern, then the distribution of Client tokens might reveal the Origin associated with a given token.

Malicious or otherwise compromised Attesters can choose to not follow the protocol described in this specification, allowing, for example, Clients to bypass rate limits imposed by Origins. Moreover, malicious Attesters could reveal the per-request blind (request_blind) to Issuers, breaking the unlinkability property described in Section 8.4.

Honest-but-curious Issuers only learn the Attester that vouches for a particular Client's token request and the origin name associated with a token request. Issuers do not learn the Anonymous Issuer Origin ID or any per-Client information used when creating a token request.

Conversely, malicious Issuers that do not follow the protocol can choose to not validate the token request signature, thereby allowing others to forge token requests in an attempt to learn the origin name. Malicious Issuers can also rotate token signing keys or Issuer Origin Secret values frequently in an attempt to bypass Attester-enforced rate limits. Both of these are detectable by the Attester, though. Issuers can also lie about per-origin rate limits without detection, e.g., by increasing the limit to a value well beyond any configured limit by an Origin, or return different limits for different origins to the Attester.

Clients learn the output token. They do not learn the Anonymous Issuer Origin ID, though the security of the protocol does not depend on keeping this value secret from Clients. Moreover, even malicious Clients cannot tamper with per-Client state stored on the Attester for other Clients, as doing so requires knowledge of their unique Client Secret.

9. Privacy Considerations

This section describes privacy considerations relevant to use of this protocol.

9.1. Client Token State and Origin Tracking

Origins SHOULD only generate token challenges based on client action, such as when a user loads a website. Clients SHOULD ignore token challenges if an Origin tries to force the client to present tokens multiple times without any new client-initiated action. Failure to do so can allow malicious origins to track clients across contexts. Specifically, an origin can abuse per-user token limits for tracking by assigning each new client a random token count and observing whether or not the client can successfully redeem that many tokens in a given context. If any token redemption fails, then

the origin learns information about how many tokens that client had previously been issued.

By rejecting repeated or duplicative challenges within a single context, the origin only learns a single bit of information: whether or not the client had any token quota left in the given policy window.

9.2. Origin Verification

Rate-limited tokens are defined in terms of a Client authenticating to an Origin, where the "origin" is used as defined in [RFC6454]. In order to limit cross-origin correlation, Clients MUST verify that the name of the origin that is providing the HTTP authentication challenge is present in the TokenChallenge.origin_info list ([AUTHSCHEME]), where the matching logic is defined for same-origin policies in [RFC6454]. Clients MAY further limit which authentication challenges they are willing to respond to, for example by only accepting challenges when the origin is a web site to which the user navigated.

9.3. Client Identification with Unique Encapsulation Keys

Client activity could be linked if an Origin and Issuer collude to have unique keys targeted at specific Clients or sets of Clients.

As with the basic issuance protocol [ISSUANCE], the token_key_id is truncated to a single octet to mitigate the risk of unique keys per client.

To mitigate the risk of a targeted Issuer Encapsulation Key, the Attester can observe and validate the issuer_encap_key_id presented by the Client to the Issuer. As described in Section 5.3, Attesters MUST validate that the issuer_encap_key_id in the Client's TokenRequest matches a known Issuer Encapsulation Key public key for the Issuer. The Attester needs to support key rotation, but ought to disallow very rapid key changes, which could indicate that an Origin is colluding with an Issuer to try to rotate the key for each new Client in order to link the client activity.

9.4. Origin Identification

As stated in Section 1.3, the design of this protocol is such that Attesters cannot learn the identity of origins that Clients are accessing. The Origin Name itself is encrypted in the request between the Client and the Issuer, so the Attester cannot directly

learn the value. However, in order to prevent the Attester from inferring the value, additional constraints need to be added:

- Each Issuer SHOULD serve tokens to a large number of Origins. A one-to-one relationship between Origin and Issuer would allow an Attester to infer which Origin is accessed simply by observing the Issuer identity.

- Issuers SHOULD NOT return rate-limit values that are specific to Origins, such that an Attester can infer which Origin is accessed by observing the rate limit. This can be mitigated by having many Origins share the same rate-limit value.

- If an Issuer changes the rate-limit values for a single Origin, that change occurring at the same time across multiple Clients could allow Attesters to recognize an Origin in common across Clients. To mitigate this, Issuers either can change the limits for multiple Origins simultaneously, or have an Origin switch to a separate Issuer.

Some deployments MAY choose to relax these requirements, such as in cases where the origins being accessed are ubiquitous or do not correspond to user-specific behavior.

9.5. Collusion Among Different Entities

Collusion among the different entities in the Privacy Pass architecture can result in exposure of a client's per-origin access patterns.

For this issuance protocol, Issuers and Attesters should be run by mutually distinct organizations to limit information sharing. A single entity running an Issuer and Attester for a single token issuance flow can view the origins being accessed by a given client. Running the Issuer and Attester in this 'single Issuer/Attester' fashion reduces the privacy promises of no one entity being able to learn Client browsing patterns. This may be desirable for a redemption flow that is limited to specific Issuers and Attesters, but should be avoided where hiding origin names from the Attester is desirable.

If a Attester and Origin are able to collude, they can correlate a client's identity and origin access patterns through timestamp correlation. The timing of a request to an Origin and subsequent token issuance to a Attester can reveal the Client identity (as known to the Attester) to the Origin, especially if repeated over multiple accesses.

10. Deployment Considerations

10.1. Token Key Management

Issuers SHOULD generate new (Token Key, Issuer Origin Secret) values regularly, and SHOULD maintain old and new secrets to allow for graceful updates. The RECOMMENDED rotation interval is two times the length of the policy window for that information. During generation, issuers must ensure the token_key_id (the 8-bit prefix of SHA256(Token Key)) is different from all other token_key_id values for that Origin currently in rotation. One way to ensure this uniqueness is via rejection sampling, where a new key is generated until its token_key_id is unique among all currently in rotation for the Origin.

11. IANA considerations

11.1. Token Type

This document updates the "Token Type" Registry ([AUTHSCHEME]) with the following value:

Value	Name	Publicly Verifiable	Public Metadata	Private Metadata	Nk	Nid	Reference
0x0003	Rate-Limited Blind RSA(SHA-384, 2048-bit) with ECDSA(P-384, SHA-384)	Y	N	N	512	32	This document
0x0004	Rate-Limited Blind RSA(SHA-384, 2048-bit) with Ed25519(SHA-512)	Y	N	N	512	32	This document

Table 2: Token Types

The details of the signature scheme with key blinding and unblinding functions for each token type above are described in the following sections.

11.1.1. ECDSA-based Token Type

This section describes the implementation details of the signature scheme with key blinding and unblinding functions introduced in

Section 7 using [ECDSA] with P-384 as the underlying elliptic curve and SHA-384 as the corresponding hash function.

- *BKS-KeyGen(): Generate a random ECDSA private and public key pair (sk, pk).

- *BKS-BlindKeyGen(): Generate a random ECDSA private key bk.

- *BKS-BlindPublicKey(pk, bk, ctx): Produce a blinded public key based on the input public key pk, blind bk, and context ctx according to [KEYBLINDING], Section 6.1.

- *BKS-UnblindPublicKey(pk, bk, ctx): Produce an unblinded public key based on the input blinded public key pk, blind bk, and context ctx according to [KEYBLINDING], Section 6.1.

- *BKS-Verify(pk, msg, sig): Verify the DER-encoded [X690] BKS-Sig-Value signature sig over input message msg against the ECDSA public key pk, producing a boolean value indicating success.

- *BKS-BlindKeySign(sk_sign, sk_blind, ctx, msg): Sign input message msg with signing key sk_sign, blind sk_blind, and context ctx according to [KEYBLINDING], Section 6.2, and serializes the resulting signature pair (r, s) in "raw" form, i.e., as the concatenation of two 48-byte, big endian scalars, yielding an Nsig=96 byte signature.

- *BKS-SerializePrivatekey(sk): Serialize an ECDSA private key using the Field-Element-to-Octet-String conversion according to [SECG].

- *BKS-DeserializePrivatekey(buf): Attempt to deserialize an ECDSA private key from a 48-byte string buf using Octet-String-to-Field-Element from [SECG]. This function can fail if buf does not represent a valid private key.

- *BKS-SerializePublicKey(pk): Serialize an ECDSA public key using the compressed Elliptic-Curve-Point-to-Octet-String method according to [SECG].

- *BKS-DeserializePublicKey(buf): Attempt to deserialize a public key using the compressed Octet-String-to-Elliptic-Curve-Point method according to [SECG], and then performs partial public-key validation as defined in section 5.6.2.3.4 of [KEYAGREEMENT]. This validation includes checking that the coordinates are in the correct range, that the point is on the curve, and that the point is not the point at infinity.

11.1.2. Ed25519-based Token Type

This section describes the implementation details of the signature scheme with key blinding and unblinding functions introduced in Section 7 using Ed25519 as described in [RFC8032].

- BKS-KeyGen(): Generate a random Ed25519 private and public key pair (sk, pk), where sk is randomly generated 32 bytes (See [RFC4086] for information about randomness generation) and pk is computed according to [RFC8032], Section 5.1.5.

- BKS-BlindKeyGen(): Generate and output 32 random bytes.

- BKS-BlindPublicKey(pk, bk, ctx): Produce a blinded public key based on the input public key pk, blind bk, and context ctx according to [KEYBLINDING], Section 5.1.

- BKS-UnblindPublicKey(pk, bk, ctx): Produce an unblinded public key based on the input blinded public key pk, blind bk, and context ctx according to [KEYBLINDING], Section 5.1.

- BKS-Verify(pk, msg, sig): Verify the signature sig over input message msg against the Ed25519 public key pk, as defined in [RFC8032], Section 5.1.7, producing a boolean value indicating success.

- BKS-BlindKeySign(sk_sign, sk_blind, ctx, msg): Sign input message msg with signing key sk_sign, blind sk_blind, and context ctx according to [KEYBLINDING], Section 5.2, yielding an Nsig=64 byte signature.

- BKS-SerializePrivatekey(sk): Identity function which outputs sk as an Nsk=32 byte buffer.

- BKS-DeserializePrivatekey(buf): Identity function which outputs buf interpreted as sk.

- BKS-SerializePublicKey(pk): Identity function which outputs pk as an Npk=32 byte buffer.

- BKS-DeserializePublicKey(buf): Identity function which outputs buf interpreted as pk.

11.2. HTTP Headers

This document registers four new headers for use on the token issuance path in the "Permanent Message Header Field Names" <https://www.iana.org/assignments/message-headers>.

Header Field Name	Protocol	Status	Reference
Sec-Token-Origin	http	std	This document
Sec-Token-Client	http	std	This document
Sec-Token-Request-Blind	http	std	This document
Sec-Token-Limit	http	std	This document

Figure 4: Registered HTTP Header

12. References

12.1. Normative References

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Appendix A. Acknowledgements

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Appendix B. Test Vectors

This section includes test vectors for Origin Name encryption in Section 6 and Anonymous Origin ID computation in Section 7. Test vectors for the token request and response protocol can be found in [ISSUANCE].

B.1. Origin Name Encryption Test Vector

The test vector below for the procedure in Section 6 lists the following values:

* origin_name: The Origin Name to encrypt, represented as a hexadecimal string.

* kem_id, kdf_id, aead_id: The HPKE algorithms comprising the ciphersuite DHKEM(X25519, HKDF-SHA256), HKDF-SHA256, AES-128-GCM.

* issuer_encap_key_seed: The seed used to derive the private key corresponding to Issuer Encapsulation Key via the DeriveKeyPair function as defined in Section 7.1.3. of [HPKE], represented as a hexadecimal string.

*issuer_encap_key: The public Issuer Encapsulation Key, represented as a hexadecimal string.

*token_type: The type of the protocol specified in this document.

*token_key_id: The ID of Token Key computed as in Section 5.3, a single octet.

*blinded_msg: A random blinded_msg value, represented as a hexadecimal string.

*request_key: A random request_key value, represented as a hexadecimal string.

*issuer_encap_key_id: The Issuer Encapsulation Key ID computed as in Section 5.3, represented as a hexadecimal string.

*encrypted_token_request: The encrypted InnerTokenRequest, represented as a hexadecimal string.

```
origin_name: 746573742e6578616d706c65
kem_id: 32
kdf_id: 1
aead_id: 1
issuer_encap_key_seed:
d2653816496f400baec656f213f1345092f4406af4f2a63e164956c4c3d240ca
issuer_encap_key: 010020d7b6a2c10e75c4239feb9897e8d23f3f3c377d78e7903611
53167736a24a9c5400010001
token_type: 3
token_key_id: 125
blinded_msg: 89da551a48270b053e53c9eb741badf89e43cb7e66366bb936e11fb2aa0
d30866986a790378bb9fc6a7cf5c32b7b7584d448ffa4ced3be650e354b3136428a52ec0
b27c4103c5855c2b9b4f521ad0713c800d7e6925b6c62e1a6f58b31d13335f468cf509b7
46a16e79b23862d277d0880706c3fb84b127d94faf8d6d2f3e124e681994441b19be084e
c5c159bcd0abab433bbc308d90ea2cabdf4216e1b07155be66a048d686e383ca1e517ab8
0025bb4849d98beb8c3d05d045c1167cb74f4451d8f85695babb604418385464f21f9a81
5fb850ed83fd16a966130427e5637816501f7a79c0010e06adeba55781ceb50f56eae152
ebd06f3cef80dc7ab121d
request_key: 0161d905e4e37f515cb61f863b60e5896aa9e4a17dbe238e752a144c64a
5412e244f0b1f75e010831e185cac023d33cb20
issuer_encap_key_id:
dd2c6de3091f1873643233d229a7a0e9defe0f9fe43f6a7c42ae3a6b16f77837
encrypted_token_request: 82ef7c068506bcabc27d068a51c7ead2cbaf600b76a15e4
d9df99a0da676da5a073fcc8f5ac77b25064d7379037b4e1b186977cface31eceb611978
c73c9aef38c9a0e8ae846881624fa6d454523a0a91d22b02b022891d0469deebd66a912a
a1ab3391b203e92e0a681f0a10c2a2d59b668daf1e5219ed16227d707fa0e8e29188bd58
7ab38b3584564ce9b6538ba82e301cfed4231a2fa4f64a67285a1b9bf648e25f3eb1644c
88d43552bdea6e4bfcbaef0de3ac245e0432be6b019494927fde0743b775f9efe8ca5fef
afbf2048890d54618d408a6001fc8fb276f6828c46f4fe1381e9775eec72ee47593df738
95d18952440d33756d78caea4bd8218950d35afa6c46c535211eda39da277260cb8dab7c
00c6840a745e8150a6ee4893e72b6a51382f877f8c05a15e891a2bde07049760f0f09879
78d78b97e47ecaf90a44996d724dd3720e308abbbf04f672bc5a4db573291986be191b06
03ff521accb6fa081c151c758f3092a89fc6ef591934ff4bc860896c57f83a31b237dd1b
803516c
```

B.2. Anonymous Origin ID Test Vector

The test vector below for the procedure in Section 7 lists the following values:

- *sk_client: Client Secret, serialized and represented as a hexadecimal string.
- *pk_client: Client Key, serialized and represented as a hexadecimal string.
- *sk_origin: Origin Secret, serialized and represented as a hexadecimal string.

*request_blind: The request_blind value computed in Section 7.1.1, represented as a hexadecimal string.

*index_key: The index_key value computed in Section 7.3, represented as a hexadecimal string.

*anon_issuer_origin_id: The anon_issuer_origin_id value computed in Section 7.4, represented as a hexadecimal string.

```
sk_sign: f6e6a0c9de38663ca539ff2e6a04e4fca11dc569794dc405e2d17439d6ce4f6
7abb2b81a1852e0db993b6a0452eb60d6
pk_sign: 032db7483c710673e6999a5fb2a2c6eac1d891f89bbf58d985ff168d182ad51
605c4369280efabb7692f661162e683f03c
sk_origin: 85de5fbbd787da5093da0adb240eba0cc6ea90d72032fc4b6925dd7d0ab1d
a1e5ae0be27fe9f59e9ec7e1f1b15b28696
request_blind: 0698a149fb9d16bcb0a856062f74f9191e82b35e91224a57abce60f5b
79f03a669c6b5e093d57e647865f9fd4305b5a9
request_key: 0287b0ce6b957111263d8c6126af96d400bd5a9d0b0f62ade15ab789446
06c209470ced7086d3c418dd32bf9245fd42678
index_key: 03188bec3dc02d2382b5251b6b4fd729d0472bbddf008c5e93b7c12270d9f
57dde111c861c13be53822a1cebb604946066
anon_issuer_origin_id: 9b0f980e5c1142fddb4401e5cd2107a87d22b73753b0d5dc9
3f9a8f5ed2ee7db78163c6a93cc41ae8158d562381c51ee
```

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