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P. van der Stok
Consultant
P. Kampanakis
Cisco Systems
M. Richardson
SSW
S. Raza
RISE SICS
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EST over secure CoAP (EST-coaps)
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Abstract

Enrollment over Secure Transport (EST) is used as a certificate provisioning protocol over HTTPS. Low-resource devices often use the lightweight Constrained Application Protocol (CoAP) for message exchanges. This document defines how to transport EST payloads over secure CoAP (EST-coaps), which allows constrained devices to use existing EST functionality for provisioning certificates.

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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This Internet-Draft will expire on July 9, 2020.

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Updates to address Yaron S.'s Secdir review.

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Updates to addressed Ben's AD follow up feedback.

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Nits and some clarifications for Esko's new review from 5/21/2019.

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Updated Server-side keygen to simplify motivation and added paragraphs in Security considerations to point out that random numbers are still needed (feedback from Hannes).

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More consistent request format in the examples.

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added application/pkix-cert Content-Format TBD287.

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Removed text on ct negotiation in connection to multipart-core

removed text that duplicates or contradicts RFC7252 (thanks Klaus)

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Added second URI /skc for server-side key gen and a simple cert (not PKCS#7)

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Updated authors.

Added CoAP RST as a MAY for an equivalent to an HTTP 204 message.

Added serialization example of the /skg CBOR response.

Added text regarding expired IDevIDs and persistent DTLS connection that will start using the Explicit TA Database in the new DTLS connection.

Nits and fixes

Removed CBOR envelop for binary data

Replaced TBD8 with 62.

Added RFC8174 reference and text.

Clarified MTI for server-side key generation and Content-Formats. Defined the /skg MTI (PKCS#8) and the cases where CMS encryption will be used.

Moved Fragmentation section up because it was referenced in sections above it.

-06:

clarified discovery section, by specifying that no discovery may be needed for /.well-known/est URI.

added resource type values for IANA

added list of compulsory to implement and optional functions.

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-04:

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-03:

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-02:

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-01:

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Redefinition of proxy to Registrar in Section 6. Explained better the role of https-coaps Registrar, instead of "proxy"

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extended block message example.

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Broke down details for DTLS 1.3

New Media-Type uses CBOR array for multiple Content-Format payloads

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copied from vanderstok-ace-coap-04

2. Introduction

"Classical" Enrollment over Secure Transport (EST) [RFC7030] is used for authenticated/authorized endpoint certificate enrollment (and optionally key provisioning) through a Certificate Authority (CA) or Registration Authority (RA). EST transports messages over HTTPS.

This document defines a new transport for EST based on the Constrained Application Protocol (CoAP) since some Internet of Things (IoT) devices use CoAP instead of HTTP. Therefore, this specification utilizes DTLS [RFC6347] and CoAP [RFC7252] instead of TLS [RFC8446] and HTTP [RFC7230].

EST responses can be relatively large and for this reason this specification also uses CoAP Block-Wise Transfer [RFC7959] to offer a fragmentation mechanism of EST messages at the CoAP layer.

This document also profiles the use of EST to only support certificate-based client authentication. HTTP Basic or Digest authentication (as described in Section 3.2.3 of [RFC7030]) are not supported.

3. 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.

Many of the concepts in this document are taken from [RFC7030]. Consequently, much text is directly traceable to [RFC7030].

4. DTLS and conformance to RFC7925 profiles

This section describes how EST-coaps conforms to the profiles of low-resource devices described in [RFC7925]. EST-coaps can transport certificates and private keys. Certificates are responses to (re-)enrollment requests or requests for a trusted certificate list. Private keys can be transported as responses to a server-side key generation request as described in Section 4.4 of [RFC7030] (and subsections) and discussed in Section 5.8 of this document.

EST-coaps depends on a secure transport mechanism that secures the exchanged CoAP messages. DTLS is one such secure protocol. No other changes are necessary regarding the secure transport of EST messages.

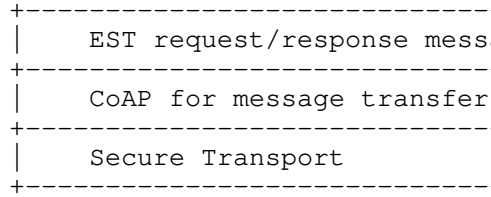

Figure 1: EST-coaps protocol layers

In accordance with sections 3.3 and 4.4 of [RFC7925], the mandatory cipher suite for DTLS in EST-coaps is TLS_ECDHE_ECDSA_WITH_AES_128_CCM_8 [RFC7251]. Curve secp256r1 MUST be supported [RFC8422]; this curve is equivalent to the NIST P-256 curve. After the publication of [RFC7748], support for Curve25519 will likely be required in the future by (D)TLS Profiles for the Internet of Things [RFC7925].

DTLS 1.2 implementations must use the Supported Elliptic Curves and Supported Point Formats Extensions in [RFC8422]. Uncompressed point format must also be supported. DTLS 1.3 [I-D.ietf-tls-dtls13] implementations differ from DTLS 1.2 because they do not support point format negotiation in favor of a single point format for each curve. Thus, support for DTLS 1.3 does not mandate point format extensions and negotiation. In addition, in DTLS 1.3 the Supported Elliptic Curves extension has been renamed to Supported Groups.

CoAP was designed to avoid IP fragmentation. DTLS is used to secure CoAP messages. However, fragmentation is still possible at the DTLS layer during the DTLS handshake when using ECC ciphersuites. If fragmentation is necessary, "DTLS provides a mechanism for fragmenting a handshake message over several records, each of which can be transmitted separately, thus avoiding IP fragmentation" [RFC6347].

The authentication of the EST-coaps server by the EST-coaps client is based on certificate authentication in the DTLS handshake. The EST-coaps client MUST be configured with at least an Implicit TA database which will enable the authentication of the server the first time before updating its trust anchor (Explicit TA) [RFC7030].

The authentication of the EST-coaps client MUST be with a client certificate in the DTLS handshake. This can either be

- a previously issued client certificate (e.g., an existing certificate issued by the EST CA); this could be a common case for simple re-enrollment of clients.

- a previously installed certificate (e.g., manufacturer IDevID [ieee802.1ar] or a certificate issued by some other party). IDevID's are expected to have a very long life, as long as the device, but under some conditions could expire. In that case, the server MAY authenticate a client certificate against its trust store although the certificate is expired (Section 10).

EST-coaps supports the certificate types and Trust Anchors (TA) that are specified for EST in Section 3 of [RFC7030].

As described in Section 2.1 of [RFC5272] proof-of-identity refers to a value that can be used to prove that an end-entity or client is in the possession of and can use the private key corresponding to the certified public key. Additionally, channel-binding information can link proof-of-identity with an established connection. Connection-based proof-of-possession is OPTIONAL for EST-coaps clients and servers. When proof-of-possession is desired, a set of actions are required regarding the use of tls-unique, described in Section 3.5 in [RFC7030]. The tls-unique information consists of the contents of the first "Finished" message in the (D)TLS handshake between server and client [RFC5929]. The client adds the "Finished" message as a ChallengePassword in the attributes section of the PKCS#10 Request [RFC5967] to prove that the client is indeed in control of the private key at the time of the (D)TLS session establishment.

In the case of handshake message fragmentation, if proof-of-possession is desired, the Finished message added as the ChallengePassword in the CSR is calculated as specified by the DTLS standards. We summarize it here for convenience. For DTLS 1.2, in the event of handshake message fragmentation, the Hash of the handshake messages used in the MAC calculation of the Finished message must be computed on each reassembled message, as if each message had not been fragmented (Section 4.2.6 of [RFC6347]). The Finished message is calculated as shown in Section 7.4.9 of [RFC5246]. Similarly, for DTLS 1.3, the Finished message must be computed as if each handshake message had been sent as a single fragment (Section 5.8 of [I-D.ietf-tls-dtls13]) following the algorithm described in 4.4.4 of [RFC8446].

In a constrained CoAP environment, endpoints can't always afford to establish a DTLS connection for every EST transaction. An EST-coaps DTLS connection MAY remain open for sequential EST transactions, which was not the case with [RFC7030]. For example, if a /crts request is followed by a /sen request, both can use the same

authenticated DTLS connection. However, when a /crts request is included in the set of sequential EST transactions, some additional security considerations apply regarding the use of the Implicit and Explicit TA database as explained in Section 10.1.

Given that after a successful enrollment, it is more likely that a new EST transaction will not take place for a significant amount of time, the DTLS connections SHOULD only be kept alive for EST messages that are relatively close to each other. These could include a /sen immediatelly following a /crts when a device is getting bootstrapped. In some cases, like NAT rebinding, keeping the state of a connection is not possible when devices sleep for extended periods of time. In such occasions, [I-D.ietf-tls-dtls-connection-id] negotiates a connection ID that can eliminate the need for new handshake and its additional cost; or DTLS session resumption provides a less costly alternative than re-doing a full DTLS handshake.

5. Protocol Design

EST-coaps uses CoAP to transfer EST messages, aided by Block-Wise Transfer [RFC7959] to avoid IP fragmentation. The use of Blocks for the transfer of larger EST messages is specified in Section 5.6. Figure 1 shows the layered EST-coaps architecture.

The EST-coaps protocol design follows closely the EST design. The supported message types in EST-coaps are:

- CA certificate retrieval needed to receive the complete set of CA certificates.
- Simple enroll and re-enroll for a CA to sign client identity public key.
- Certificate Signing Request (CSR) attribute messages that informs the client of the fields to include in a CSR.
- Server-side key generation messages to provide a client identity private key when the client chooses so.

While [RFC7030] permits a number of the EST functions to be used without authentication, this specification requires that the client MUST be authenticated for all functions.

5.1. Discovery and URIs

EST-coaps is targeted for low-resource networks with small packets. Two types of installations are possible: (1) rigid ones, where the address and the supported functions of the EST server(s) are known,

and (2) a flexible one, where the EST server and its supported functions need to be discovered.

For both types of installations, saving header space is important and short EST-coaps URIs are specified in this document. These URIs are shorter than the ones in [RFC7030]. Two example EST-coaps resource path names are:

coaps://example.com:<port>/.well-known/est/<short-est>
coaps://example.com:<port>/.well-known/est/ArbitraryLabel/<short-est>

The short-est strings are defined in Table 1. Arbitrary Labels are usually defined and used by EST CAs in order to route client requests to the appropriate certificate profile. Implementers should consider using short labels to minimize transmission overhead.

The EST-coaps server URIs, obtained through discovery of the EST-coaps resource(s) as shown below, are of the form:

coaps://example.com:<port>/<root-resource>/<short-est>
coaps://example.com:<port>/<root-resource>/ArbitraryLabel/<short-est>

Figure 5 in Section 3.2.2 of [RFC7030] enumerates the operations and corresponding paths which are supported by EST. Table 1 provides the mapping from the EST URI path to the shorter EST-coaps URI path.

EST	EST-coaps
/cacerts	/crts
/simpleenroll	/sen
/simplereenroll	/sren
/serverkeygen	/skg (PKCS#7)
/serverkeygen	/skc (application/pkix-cert)
/csrattrs	/att

Table 1: Short EST-coaps URI path

The /skg message is the EST /serverkeygen equivalent where the client requests a certificate in PKCS#7 format and a private key. If the client prefers a single application/pkix-cert certificate instead of PKCS#7, it will make an /skc request. In both cases (i.e., /skg, /skc) a private key MUST be returned.

Clients and servers MUST support the short resource EST-coaps URIs.

In the context of CoAP, the presence and location of (path to) the EST resources are discovered by sending a GET request to "/.well-known/core" including a resource type (RT) parameter with the value "ace.est*" [RFC6690]. The example below shows the discovery over CoAPS of the presence and location of EST-coaps resources. Linefeeds are included only for readability.

```
  REQ: GET /.well-known/core?rt=ace.est*

  RES: 2.05 Content
</est/crts>;rt="ace.est.crts";ct="281 TBD287",
</est/sen>;rt="ace.est.sen";ct="281 TBD287",
</est/sren>;rt="ace.est.sren";ct="281 TBD287",
</est/att>;rt="ace.est.att";ct=285,
</est/skg>;rt="ace.est.skg";ct=62,
</est/skc>;rt="ace.est.skc";ct=62
```

The first three lines, describing ace.est.crts, ace.est.sen, and ace.est.sren, of the discovery response above MUST be returned if the server supports resource discovery. The last three lines are only included if the corresponding EST functions are implemented (see Table 2). The Content-Formats in the response allow the client to request one that is supported by the server. These are the values that would be sent in the client request with an Accept option.

Discoverable port numbers can be returned in the response payload. An example response payload for non-default CoAPS server port 61617 follows below. Linefeeds are included only for readability.

```
  REQ: GET /.well-known/core?rt=ace.est*

  RES: 2.05 Content
<coaps://[2001:db8:3::123]:61617/est/crts>;rt="ace.est.crts";
               ct="281 TBD287",
<coaps://[2001:db8:3::123]:61617/est/sen>;rt="ace.est.sen";
               ct="281 TBD287",
<coaps://[2001:db8:3::123]:61617/est/sren>;rt="ace.est.sren";
               ct="281 TBD287",
<coaps://[2001:db8:3::123]:61617/est/att>;rt="ace.est.att";
               ct=285,
<coaps://[2001:db8:3::123]:61617/est/skg>;rt="ace.est.skg";
               ct=62,
<coaps://[2001:db8:3::123]:61617/est/skc>;rt="ace.est.skc";
               ct=62
```

The server MUST support the default /.well-known/est root resource. The server SHOULD support resource discovery when it supports non-default URIs (like /est or /est/ArbitraryLabel) or ports. The client

SHOULD use resource discovery when it is unaware of the available EST-coaps resources.

Throughout this document the example root resource of /est is used.

5.2. Mandatory/optional EST Functions

This specification contains a set of required-to-implement functions, optional functions, and not specified functions. The unspecified functions are deemed too expensive for low-resource devices in payload and calculation times.

Table 2 specifies the mandatory-to-implement or optional implementation of the EST-coaps functions. Discovery of the existence of optional functions is described in Section 5.1.

EST Functions	EST-coaps implementation
/cacerts	MUST
/simpleenroll	MUST
/simplereenroll	MUST
/fullcmc	Not specified
/serverkeygen	OPTIONAL
/csrattrs	OPTIONAL

Table 2: List of EST-coaps functions

5.3. Payload formats

EST-coaps is designed for low-resource devices and hence does not need to send Base64-encoded data. Simple binary is more efficient (30% smaller payload for DER-encoded ASN.1) and well supported by CoAP. Thus, the payload for a given Media-Type follows the ASN.1 structure of the Media-Type and is transported in binary format.

The Content-Format (HTTP Content-Type equivalent) of the CoAP message determines which EST message is transported in the CoAP payload. The Media-Types specified in the HTTP Content-Type header field (Section 3.2.2 of [RFC7030]) are specified by the Content-Format Option (12) of CoAP. The combination of URI-Path and Content-Format in EST-coaps MUST map to an allowed combination of URI and Media-Type in EST. The required Content-Formats for these requests and response messages are defined in Section 9.1. The CoAP response codes are defined in Section 5.5.

Content-Format TBD287 can be used in place of 281 to carry a single certificate instead of a PKCS#7 container in a /crts, /sen, /sren or /skg response. Content-Format 281 MUST be supported by EST-coaps servers. Servers MAY also support Content-Format TBD287. It is up to the client to support only Content-Format 281, TBD287 or both. The client will use a COAP Accept Option in the request to express the preferred response Content-Format. If an Accept Option is not included in the request, the client is not expressing any preference and the server SHOULD choose format 281.

Content-Format 286 is used in /sen, /sren and /skg requests and 285 in /att responses.

A representation with Content-Format identifier 62 contains a collection of representations along with their respective Content-Format. The Content-Format identifies the Media-Type application/multipart-core specified in [I-D.ietf-core-multipart-ct]. For example, a collection, containing two representations in response to a EST-coaps server-side key generation /skg request, could include a private key in PKCS#8 [RFC5958] with Content-Format identifier 284 (0x011C) and a single certificate in a PKCS#7 container with Content-Format identifier 281 (0x0119). Such a collection would look like [284,h'0123456789abcdef', 281,h'fedcba9876543210'] in diagnostic CBOR notation. The serialization of such CBOR content would be

```
84                  # array(4)
19 011C             # unsigned(284)
48                  # bytes(8)
   0123456789ABCDEF # "\x01#Eg\x89\xAB\xCD\xEF"
19 0119             # unsigned(281)
48                  # bytes(8)
   FEDCBA9876543210 # "\xFE\xDC\xBA\x98vT2\x10"
```

Multipart /skg response serialization

When the client makes an /skc request the certificate returned with the private key is a single X.509 certificate (not a PKCS#7 container) with Content-Format identifier TBD287 (0x011F) instead of 281. In cases where the private key is encrypted with CMS (as explained in Section 5.8) the Content-Format identifier is 280 (0x0118) instead of 284. The content format used in the response is summarized in Table 3.

Function	Response part 1	Response part 2
/skg	284	281
/skc	280	TBD287

Table 3: response content formats for skg and skc

The key and certificate representations are DER-encoded ASN.1, in its native binary form. An example is shown in Appendix A.3.

5.4. Message Bindings

The general EST-coaps message characteristics are:

- EST-coaps servers sometimes need to provide delayed responses which are preceded by an immediately returned empty ACK or an ACK containing response code 5.03 as explained in Section 5.7. Thus, it is RECOMMENDED for implementers to send EST-coaps requests in confirmable CON CoAP messages.

- The CoAP Options used are Uri-Host, Uri-Path, Uri-Port, Content-Format, Block1, Block2, and Accept. These CoAP Options are used to communicate the HTTP fields specified in the EST REST messages. The Uri-host and Uri-Port Options can be omitted from the COAP message sent on the wire. When omitted, they are logically assumed to be the transport protocol destination address and port respectively. Explicit Uri-Host and Uri-Port Options are typically used when an endpoint hosts multiple virtual servers and uses the Options to route the requests accordingly. Other COAP Options should be handled in accordance with [RFC7252].

- EST URLs are HTTPS based (https://), in CoAP these are assumed to be translated to CoAPS (coaps://)

Table 1 provides the mapping from the EST URI path to the EST-coaps URI path. Appendix A includes some practical examples of EST messages translated to CoAP.

5.5. CoAP response codes

Section 5.9 of [RFC7252] and Section 7 of [RFC8075] specify the mapping of HTTP response codes to CoAP response codes. The success code in response to an EST-coaps GET request (/crts, /att), is 2.05. Similarly, 2.04 is used in successful response to EST-coaps POST requests (/sen, /sren, /skg, /skc).

EST makes use of HTTP 204 or 404 responses when a resource is not available for the client. In EST-coaps 2.04 is used in response to a POST (/sen, /sren, /skg, /skc). 4.04 is used when the resource is not available for the client.

HTTP response code 202 with a Retry-After header field in [RFC7030] has no equivalent in CoAP. HTTP 202 with Retry-After is used in EST for delayed server responses. Section 5.7 specifies how EST-coaps handles delayed messages with 5.03 responses with a Max-Age Option.

Additionally, EST's HTTP 400, 401, 403, 404 and 503 status codes have their equivalent CoAP 4.00, 4.01, 4.03, 4.04 and 5.03 response codes in EST-coaps. Table 4 summarizes the EST-coaps response codes.

operation	EST-coaps response code	Description
/crts, /att	2.05	Success. Certs included in the response payload.
	4.xx / 5.xx	Failure.
/sen, /skg, /sren, /skc	2.04	Success. Cert included in the response payload.
	5.03	Retry in Max-Age Option time.
	4.xx / 5.xx	Failure.

Table 4: EST-coaps response codes

5.6. Message fragmentation

DTLS defines fragmentation only for the handshake and not for secure data exchange (DTLS records). [RFC6347] states that to avoid using IP fragmentation, which involves error-prone datagram reconstitution, invokers of the DTLS record layer should size DTLS records so that they fit within any Path MTU estimates obtained from the record layer. In addition, invokers residing on a 6LoWPAN over IEEE 802.15.4 [ieee802.15.4] network are recommended to size CoAP messages such that each DTLS record will fit within one or two IEEE 802.15.4 frames.

That is not always possible in EST-coaps. Even though ECC certificates are small in size, they can vary greatly based on signature algorithms, key sizes, and Object Identifier (OID) fields used. For 256-bit curves, common ECDSA cert sizes are 500-1000 bytes which could fluctuate further based on the algorithms, OIDs, Subject Alternative Names (SAN) and cert fields. For 384-bit curves, ECDSA certificates increase in size and can sometimes reach 1.5KB.

Additionally, there are times when the EST cacerts response from the server can include multiple certificates that amount to large payloads. Section 4.6 of CoAP [RFC7252] describes the possible payload sizes: "if nothing is known about the size of the headers, good upper bounds are 1152 bytes for the message size and 1024 bytes for the payload size". Section 4.6 of [RFC7252] also suggests that IPv4 implementations may want to limit themselves to more conservative IPv4 datagram sizes such as 576 bytes. Even with ECC, EST-coaps messages can still exceed MTU sizes on the Internet or 6LoWPAN [RFC4919] (Section 2 of [RFC7959]). EST-coaps needs to be able to fragment messages into multiple DTLS datagrams.

To perform fragmentation in CoAP, [RFC7959] specifies the Block1 Option for fragmentation of the request payload and the Block2 Option for fragmentation of the return payload of a CoAP flow. As explained in Section 1 of [RFC7959], block-wise transfers should be used in Confirmable CoAP messages to avoid the exacerbation of lost blocks. EST-coaps servers MUST implement Block1 and Block2. EST-coaps clients MUST implement Block2. EST-coaps clients MUST implement Block1 only if they are expecting to send EST-coaps requests with a packet size that exceeds the Path MTU.

[RFC7959] also defines Size1 and Size2 Options to provide size information about the resource representation in a request and response. EST-client and server MAY support Size1 and Size2 Options.

Examples of fragmented EST-coaps messages are shown in Appendix B.

5.7. Delayed Responses

Server responses can sometimes be delayed. According to Section 5.2.2 of [RFC7252], a slow server can acknowledge the request and respond later with the requested resource representation. In particular, a slow server can respond to an EST-coaps enrollment request with an empty ACK with code 0.00, before sending the certificate to the client after a short delay. If the certificate response is large, the server will need more than one Block2 block to transfer it.

This situation is shown in Figure 2. The client sends an enrollment request that uses N1+1 Block1 blocks. The server uses an empty 0.00 ACK to announce the delayed response which is provided later with 2.04 messages containing N2+1 Block2 Options. The first 2.04 is a confirmable message that is acknowledged by the client. Onwards, the client acknowledges all subsequent Block2 blocks. The notation of Figure 2 is explained in Appendix B.1.

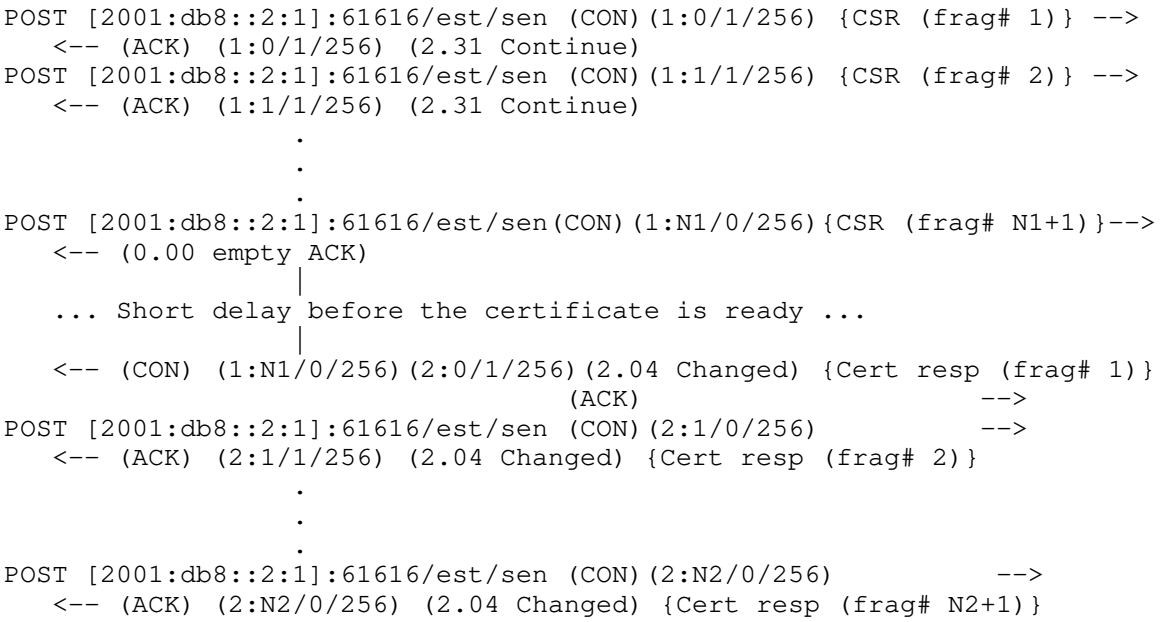

Figure 2: EST-COAP enrollment with short wait

If the server is very slow (for example, manual intervention is required which would take minutes), it SHOULD respond with an ACK containing response code 5.03 (Service unavailable) and a Max-Age Option to indicate the time the client SHOULD wait before sending another request to obtain the content. After a delay of Max-Age, the client SHOULD resend the identical CSR to the server. As long as the server continues to respond with response code 5.03 (Service Unavailable) with a Max-Age Option, the client will continue to delay for Max-Age and then resend the enrollment request until the server responds with the certificate or the client abandons the request for policy or other reasons.

To demonstrate this scenario, Figure 3 shows a client sending an enrollment request that uses N1+1 Block1 blocks to send the CSR to the server. The server needs N2+1 Block2 blocks to respond, but also needs to take a long delay (minutes) to provide the response. Consequently, the server uses a 5.03 ACK response with a Max-Age Option. The client waits for a period of Max-Age as many times as it receives the same 5.03 response and retransmits the enrollment request until it receives a certificate in a fragmented 2.04 response.

```
POST [2001:db8::2:1]:61616/est/sen (CON)(1:0/1/256) {CSR (frag# 1)}  -->
  <-- (ACK) (1:0/1/256) (2.31 Continue)
POST [2001:db8::2:1]:61616/est/sen (CON)(1:1/1/256) {CSR (frag# 2)}  -->
  <-- (ACK) (1:1/1/256) (2.31 Continue)
                    .
                    .
                    .
POST [2001:db8::2:1]:61616/est/sen(CON)(1:N1/0/256){CSR (frag# N1+1)}-->
  <-- (ACK) (1:N1/0/256) (5.03 Service Unavailable) (Max-Age)
                    |
                    |
  ... Client tries again after Max-Age with identical payload ...
                    |
                    |
POST [2001:db8::2:1]:61616/est/sen(CON)(1:0/1/256){CSR (frag# 1)}-->
  <-- (ACK) (1:0/1/256) (2.31 Continue)
POST [2001:db8::2:1]:61616/est/sen (CON)(1:1/1/256) {CSR (frag# 2)}  -->
  <-- (ACK) (1:1/1/256) (2.31 Continue)
                    .
                    .
                    .
POST [2001:db8::2:1]:61616/est/sen(CON)(1:N1/0/256){CSR (frag# N1+1)}-->
                    |
   ... Immediate response when certificate is ready ...
                    |
  <-- (ACK) (1:N1/0/256) (2:0/1/256) (2.04 Changed){Cert resp (frag# 1)}
POST [2001:db8::2:1]:61616/est/sen (CON)(2:1/0/256)           -->
  <-- (ACK) (2:1/1/256) (2.04 Changed) {Cert resp (frag# 2)}
                    .
                    .
                    .
POST [2001:db8::2:1]:61616/est/sen (CON)(2:N2/0/256)          -->
  <-- (ACK) (2:N2/0/256) (2.04 Changed) {Cert resp (frag# N2+1)}
```

Figure 3: EST-COAP enrollment with long wait

5.8. Server-side Key Generation

Private keys can be generated on the server to support scenarios where serer-side key generation is needed. Such scenarios include those where it is considered more secure to generate the long-lived, random private key that identifies the client at the server, or where the resources spent to generate a random private key at the client are considered scarce, or where the security policy requires that the certificate public and corresponding private keys are centrally generated and controlled. As always, it is necessary to use proper random numbers in various protocols such as (D)TLS (Section 10.1).

When requesting server-side key generation, the client asks for the server or proxy to generate the private key and the certificate, which are transferred back to the client in the server-side key generation response. In all respects, the server treats the CSR as it would treat any enroll or re-enroll CSR; the only distinction here is that the server MUST ignore the public key values and signature in the CSR. These are included in the request only to allow re-use of existing codebases for generating and parsing such requests.

The client /skg request is for a certificate in a PKCS#7 container and private key in two application/multipart-core elements. Respectively, an /skc request is for a single application/pkix-cert certificate and a private key. The private key Content-Format requested by the client is indicated in the PKCS#10 CSR request. If the request contains SMIMECapabilities and DecryptKeyIdentifier or AsymmetricDecryptKeyIdentifier the client is expecting Content-Format 280 for the private key. Then this private key is encrypted symmetrically or asymmetrically as per [RFC7030]. The symmetric key or the asymmetric keypair establishment method is out of scope of this specification. A /skg or /skc request with a CSR without SMIMECapabilities expects an application/multipart-core with an unencrypted PKCS#8 private key with Content-Format 284.

The EST-coaps server-side key generation response is returned with Content-Format application/multipart-core [I-D.ietf-core-multipart-ct] containing a CBOR array with four items (Section 5.3). The two representations (each consisting of two CBOR array items) do not have to be in a particular order since each representation is preceded by its Content-Format ID. Depending on the request, the private key can be in unprotected PKCS#8 [RFC5958] format (Content-Format 284) or protected inside of CMS SignedData (Content-Format 280). The SignedData, placed in the outermost container, is signed by the party that generated the private key, which may be the EST server or the EST CA. SignedData placed within the Enveloped Data does not need additional signing as explained in Section 4.4.2 of [RFC7030]. In summary, the symmetrically encrypted key is included in the encryptedKey attribute in a KEKRecipientInfo structure. In the case where the asymmetric encryption key is suitable for transport key operations the generated private key is encrypted with a symmetric key. The symmetric key itself is encrypted by the client-defined (in the CSR) asymmetric public key and is carried in an encryptedKey attribute in a KeyTransRecipientInfo structure. Finally, if the asymmetric encryption key is suitable for key agreement, the generated private key is encrypted with a symmetric key. The symmetric key itself is encrypted by the client defined (in the CSR) asymmetric public key and is carried in an recipientEncryptedKeys attribute in a KeyAgreeRecipientInfo.

[RFC7030] recommends the use of additional encryption of the returned private key. For the context of this specification, clients and servers that choose to support server-side key generation MUST support unprotected (PKCS#8) private keys (Content-Format 284). Symmetric or asymmetric encryption of the private key (CMS EnvelopedData, Content-Format 280) SHOULD be supported for deployments where end-to-end encryption is needed between the client and a server. Such cases could include architectures where an entity between the client and the CA terminates the DTLS connection (Registrar in Figure 4). Although [RFC7030] strongly recommends that clients request the use of CMS encryption on top of the TLS channel's protection, this document does not make such a recommendation; CMS encryption can still be used when mandated by the use-case.

6. HTTPS-CoAPS Registrar

In real-world deployments, the EST server will not always reside within the CoAP boundary. The EST server can exist outside the constrained network in which case it will support TLS/HTTP instead of CoAPS. In such environments EST-coaps is used by the client within the CoAP boundary and TLS is used to transport the EST messages outside the CoAP boundary. A Registrar at the edge is required to operate between the CoAP environment and the external HTTP network as shown in Figure 4.

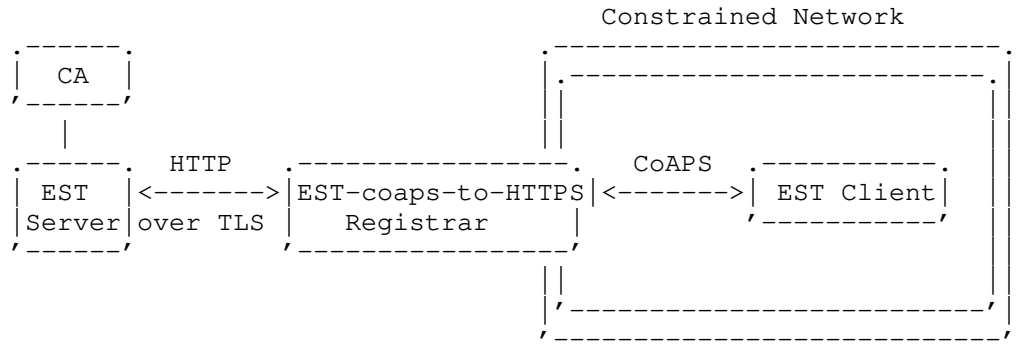

Figure 4: EST-coaps-to-HTTPS Registrar at the CoAP boundary.

The EST-coaps-to-HTTPS Registrar MUST terminate EST-coaps downstream and initiate EST connections over TLS upstream. The Registrar MUST authenticate and optionally authorize the client requests while it MUST be authenticated by the EST server or CA. The trust relationship between the Registrar and the EST server SHOULD be pre-established for the Registrar to proxy these connections on behalf of various clients.

When enforcing Proof-of-Possession (PoP) linking, the DTLS tls-unique value of the (D)TLS session is used to prove that the private key corresponding to the public key is in the possession of the client and was used to establish the connection as explained in Section 4. The PoP linking information is lost between the EST-coaps client and the EST server when a Registrar is present. The EST server becomes aware of the presence of a Registrar from its TLS client certificate that includes id-kp-cmcRA [RFC6402] extended key usage extension (EKU). As explained in Section 3.7 of [RFC7030], the "EST server SHOULD apply an authorization policy consistent with a Registrar client. For example, it could be configured to accept PoP linking information that does not match the current TLS session because the authenticated EST client Registrar has verified this information when acting as an EST server".

Table 1 contains the URI mappings between EST-coaps and EST that the Registrar MUST adhere to. Section 5.5 of this specification and Section 7 of [RFC8075] define the mappings between EST-coaps and HTTP response codes, that determine how the Registrar MUST translate CoAP response codes from/to HTTP status codes. The mapping from CoAP Content-Format to HTTP Content-Type is defined in Section 9.1. Additionally, a conversion from CBOR major type 2 to Base64 encoding MUST take place at the Registrar. If CMS end-to-end encryption is employed for the private key, the encrypted CMS EnvelopedData blob MUST be converted at the Registrar to binary CBOR type 2 downstream to the client. This is a format conversion that does not require decryption of the CMS EnvelopedData.

A deviation from the mappings in Table 1 could take place if clients that leverage server-side key generation preferred for the enrolled keys to be generated by the Registrar in the case the CA does not support server-side key generation. Such a Registrar is responsible for generating a new CSR signed by a new key which will be returned to the client along with the certificate from the CA. In these cases, the Registrar MUST use random number generation with proper entropy.

Due to fragmentation of large messages into blocks, an EST-coaps-to-HTTP Registrar MUST reassemble the BLOCKs before translating the binary content to Base64, and consecutively relay the message upstream.

The EST-coaps-to-HTTP Registrar MUST support resource discovery according to the rules in Section 5.1.

7. Parameters

This section addresses transmission parameters described in sections 4.7 and 4.8 of [RFC7252]. EST does not impose any unique values on the CoAP parameters in [RFC7252], but the setting of the CoAP parameter values may have consequence for the setting of the EST parameter values.

Implementations should follow the default CoAP configuration parameters [RFC7252]. However, depending on the implementation scenario, retransmissions and timeouts can also occur on other networking layers, governed by other configuration parameters. When a change in a server parameter has taken place, the parameter values in the communicating endpoints MUST be adjusted as necessary. Examples of how parameters could be adjusted include higher layer congestion protocols, provisioning agents and configurations included in firmware updates.

Some further comments about some specific parameters, mainly from Table 2 in [RFC7252]:

- NSTART: A parameter that controls the number of simultaneous outstanding interactions that a client maintains to a given server. An EST-coaps client is expected to control at most one interaction with a given server, which is the default NSTART value defined in [RFC7252].

- DEFAULT_LEISURE: This setting is only relevant in multicast scenarios, outside the scope of EST-coaps.

- PROBING_RATE: A parameter which specifies the rate of re-sending non-confirmable messages. In the rare situations that non-confirmable messages are used, the default PROBING_RATE value defined in [RFC7252] applies.

Finally, the Table 3 parameters in [RFC7252] are mainly derived from Table 2. Directly changing parameters on one table would affect parameters on the other.

8. Deployment limitations

Although EST-coaps paves the way for the utilization of EST by constrained devices in constrained networks, some classes of devices [RFC7228] will not have enough resources to handle the payloads that come with EST-coaps. The specification of EST-coaps is intended to ensure that EST works for networks of constrained devices that choose to limit their communications stack to DTLS/CoAP. It is up to the

network designer to decide which devices execute the EST protocol and which do not.

9. IANA Considerations

9.1. Content-Format Registry

Additions to the sub-registry "CoAP Content-Formats", within the "CoRE Parameters" registry [COREparams] are specified in Table 5. These have been registered provisionally in the IETF Review or IESG Approval range (256-9999).

HTTP Content-Type	ID	Reference
application/pkcs7-mime; smime-type=server-generated-key	280	[RFC7030] [I-D.ietf-lamps-rfc5751-bis] [ThisRFC]
application/pkcs7-mime; smime-type=certs-only	281	[I-D.ietf-lamps-rfc5751-bis] [ThisRFC]
application/pkcs8	284	[RFC5958] [I-D.ietf-lamps-rfc5751-bis] [ThisRFC]
application/csrattrs	285	[RFC7030]
application/pkcs10	286	[RFC5967] [I-D.ietf-lamps-rfc5751-bis] [ThisRFC]
application/pkix-cert	TBD287	[RFC2585] [ThisRFC]

Table 5: New CoAP Content-Formats

It is suggested that 287 is allocated to TBD287.

9.2. Resource Type registry

This memo registers new Resource Type (rt=) Link Target Attributes in the "Resource Type (rt=) Link Target Attribute Values" subregistry under the "Constrained RESTful Environments (CoRE) Parameters" registry.

- rt="ace.est.crts". This resource depicts the support of EST get cacerts.
- rt="ace.est.sen". This resource depicts the support of EST simple enroll.
- rt="ace.est.sren". This resource depicts the support of EST simple reenroll.

- rt="ace.est.att". This resource depicts the support of EST get CSR attributes.

- rt="ace.est.skg". This resource depicts the support of EST server-side key generation with the returned certificate in a PKCS#7 container.

- rt="ace.est.skc". This resource depicts the support of EST server-side key generation with the returned certificate in application/pkix-cert format.

9.3. Well-Known URIs Registry

A new additional reference is requested for the est URI in the Well-Known URIs registry:

URI Suffix	Change Controller	References	Status	Related Information	Date Registered	Date Modified
est	IETF	[RFC7030] [THIS RFC]	permanent		2013-08-16	[THIS RFC's publication date]

10. Security Considerations

10.1. EST server considerations

The security considerations of Section 6 of [RFC7030] are only partially valid for the purposes of this document. As HTTP Basic Authentication is not supported, the considerations expressed for using passwords do not apply. The other portions of the security considerations of [RFC7030] continue to apply.

Modern security protocols require random numbers to be available during the protocol run, for example for nonces and ephemeral (EC) Diffie-Hellman key generation. This capability to generate random numbers is also needed when the constrained device generates the private key (that corresponds to the public key enrolled in the CSR). When server-side key generation is used, the constrained device depends on the server to generate the private key randomly, but it still needs locally generated random numbers for use in security protocols, as explained in Section 12 of [RFC7925]. Additionally, the transport of keys generated at the server is inherently risky. For those deploying server-side key generation, analysis SHOULD be

done to establish whether server-side key generation increases or decreases the probability of digital identity theft.

It is important to note that, as pointed out in [PsQs], sources contributing to the randomness pool used to generate random numbers on laptops or desktop PCs, such as mouse movement, timing of keystrokes, or air turbulence on the movement of hard drive heads, are not available on many constrained devices. Other sources have to be used or dedicated hardware has to be added. Selecting hardware for an IoT device that is capable of producing high-quality random numbers is therefore important [RSAfact].

As discussed in Section 6 of [RFC7030], it is "RECOMMENDED that the Implicit Trust Anchor database used for EST server authentication is carefully managed to reduce the chance of a third-party CA with poor certification practices jeopardizing authentication. Disabling the Implicit Trust Anchor database after successfuly receiving the Distribution of CA certificates response (Section 4.1.3) limits any risk to the first TLS exchange". Alternatively, in a case where a /sen request immediately follows a /crts, a client MAY choose to keep the connection authenticated by the Implicit TA open for efficiency reasons (Section 4). A client that interleaves EST-coaps /crts request with other requests in the same DTLS connection SHOULD revalidate the server certificate chain against the updated Explicit TA from the /crts response before proceeding with the subsequent requests. If the server certificate chain does not authenticate against the database, the client SHOULD close the connection without completing the rest of the requests. The updated Explicit TA MUST continue to be used in new DTLS connections.

In cases where the IDevID used to authenticate the client is expired the server MAY still authenticate the client because IDevIDs are expected to live as long as the device itself (Section 4). In such occasions, checking the certificate revocation status or authorizing the client using another method is important for the server to raise its confidence that the client can be trusted.

In accordance with [RFC7030], TLS cipher suites that include "_EXPORT_" and "_DES_" in their names MUST NOT be used. More recommendations for secure use of TLS and DTLS are included in [BCP195].

As described in CMC, Section 6.7 of [RFC5272], "For keys that can be used as signature keys, signing the certification request with the private key serves as a PoP on that key pair". The inclusion of tls-unique in the certificate request links the proof-of-possession to the TLS proof-of-identity. This implies but does not prove that only the authenticated client currently has access to the private key.

What's more, CMC PoP linking uses tls-unique as it is defined in [RFC5929]. The 3SHAKE attack [tripleshake] poses a risk by allowing a man-in-the-middle to leverage session resumption and renegotiation to inject himself between a client and server even when channel binding is in use. Implementers should use the Extended Master Secret Extension in DTLS [RFC7627] to prevent such attacks. In the context of this specification, an attacker could invalidate the purpose of the PoP linking ChallengePassword in the client request by resuming an EST-coaps connection. Even though the practical risk of such an attack to EST-coaps is not devastating, we would rather use a more secure channel binding mechanism. Such a mechanism could include an updated tls-unique value generation like the tls-unique-prf defined in [I-D.josefsson-sasl-tls-cb] by using a TLS exporter [RFC5705] in TLS 1.2 or TLS 1.3's updated exporter (Section 7.5 of [RFC8446]) value in place of the tls-unique value in the CSR. Such mechanism has not been standardized yet. Adopting a channel binding value generated from an exporter would break backwards compatibility for an RA that proxies through to a classic EST server. Thus, in this specification we still depend on the tls-unique mechanism defined in [RFC5929], especially since a 3SHAKE attack does not expose messages exchanged with EST-coaps.

Interpreters of ASN.1 structures should be aware of the use of invalid ASN.1 length fields and should take appropriate measures to guard against buffer overflows, stack overruns in particular, and malicious content in general.

10.2. HTTPS-CoAPS Registrar considerations

The Registrar proposed in Section 6 must be deployed with care, and only when direct client-server connections are not possible. When PoP linking is used the Registrar terminating the DTLS connection establishes a new TLS connection with the upstream CA. Thus, it is impossible for PoP linking to be enforced end-to-end for the EST transaction. The EST server could be configured to accept PoP linking information that does not match the current TLS session because the authenticated EST Registrar is assumed to have verified PoP linking downstream to the client.

The introduction of an EST-coaps-to-HTTP Registrar assumes the client can authenticate the Registrar using its implicit or explicit TA database. It also assumes the Registrar has a trust relationship with the upstream EST server in order to act on behalf of the clients. When a client uses the Implicit TA database for certificate validation, it SHOULD confirm if the server is acting as an RA by the presence of the id-kp-cmcRA EKU [RFC6402] in the server certificate.

In a server-side key generation case, if no end-to-end encryption is used, the Registrar may be able see the private key as it acts as a man-in-the-middle. Thus, the client puts its trust on the Registrar not exposing the private key.

Clients that leverage server-side key generation without end-to-end encryption of the private key (Section 5.8) have no knowledge if the Registrar will be generating the private key and enrolling the certificates with the CA or if the CA will be responsible for generating the key. In such cases, the existence of a Registrar requires the client to put its trust on the registrar when it is generating the private key.

11. Contributors

Martin Furuhed contributed to the EST-coaps specification by providing feedback based on the Nexus EST over CoAPS server implementation that started in 2015. Sandeep Kumar kick-started this specification and was instrumental in drawing attention to the importance of the subject.

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Appendix A. EST messages to EST-coaps

This section shows similar examples to the ones presented in Appendix A of [RFC7030]. The payloads in the examples are the hex encoded binary, generated with 'xxd -p', of the PKI certificates created following [I-D.moskowitz-ecdsa-pki]. Hex is used for visualization purposes because a binary representation cannot be rendered well in text. The hexadecimal representations would not be transported in hex, but in binary. The payloads are shown

unencrypted. In practice the message content would be transferred over an encrypted DTLS channel.

The certificate responses included in the examples contain Content-Format 281 (application/pkcs7). If the client had requested Content-Format TBD287 (application/pkix-cert) by querying /est/skc, the server would respond with a single DER binary certificate in the multipart-core container.

These examples assume a short resource path of "/est". Even though omitted from the examples for brevity, before making the EST-coaps requests, a client would learn about the server supported EST-coaps resources with a GET request for /.well-known/core?rt=ace.est* as explained in Section 5.1.

The corresponding CoAP headers are only shown in Appendix A.1. Creating CoAP headers is assumed to be generally understood.

The message content breakdown is presented in Appendix C.

A.1. cacerts

In EST-coaps, a cacerts message can be:

GET example.com:9085/est/crts
(Accept: 281)

The corresponding CoAP header fields are shown below. The use of block and DTLS are worked out in Appendix B.

```
Ver = 1
T = 0 (CON)
Code = 0x01 (0.01 is GET)
Token = 0x9a (client generated)
Options
Option (Uri-Host)
   Option Delta = 0x3  (option# 3)
   Option Length = 0xB
   Option Value = "example.com"
Option (Uri-Port)
   Option Delta = 0x4  (option# 3+4=7)
   Option Length = 0x2
   Option Value = 9085
 Option (Uri-Path)
   Option Delta = 0x4   (option# 7+4=11)
   Option Length = 0x3
   Option Value = "est"
 Option (Uri-Path)
   Option Delta = 0x0   (option# 11+0=11)
   Option Length = 0x4
   Option Value = "crts"
 Option (Accept)
   Option Delta = 0x6   (option# 11+6=17)
   Option Length = 0x2
   Option Value = 281
Payload = [Empty]
```

As specified in Section 5.10.1 of [RFC7252], the Uri-Host and Uri-Port Options can be omitted if they coincide with the transport protocol destination address and port respectively.

A 2.05 Content response with a cert in EST-coaps will then be

```
2.05 Content (Content-Format: 281)
   {payload with certificate in binary format}
```

with CoAP fields

```
Ver = 1
T = 2 (ACK)
Code = 0x45 (2.05 Content)
Token = 0x9a   (copied from request by server)
Options
  Option (Content-Format)
    Option Delta = 0xC  (option# 12)
    Option Length = 0x2
    Option Value = 281

[ The hexadecimal representation below would NOT be transported
in hex, but in binary. Hex is used because a binary representation
cannot be rendered well in text. ]

Payload =
3082027a06092a864886f70d010702a082026b308202670201013100300b
06092a864886f70d010701a082024d30820249308201efa0030201020208
0b8bb0fe604f6a1e300a06082a8648ce3d0403023067310b300906035504
0613025553310b300906035504080c024341310b300906035504070c024c
413114301206035504a0c0b4578616d706c6520496e6331163014060355
040b0c0d6365727469666963617469 6f6e3110300e06035504030c07526f
6f74204341301e170d313930313331313132373035a170d333930313236
3131323730335a3067310b300906035504061302555310b300906035504
080c024341310b300906035504070c024c413114301206035504a0c0b45
78616d706c6520496e6331163014060355040b0c0d636572746966696361
74696f6e3110300e06035504030c07526f6f74204341305930130607 2a86
48ce3d020106082a8648ce3d030107034200040c1b1e82ba8cc72680973f
97edb8a0c72ab0d405f05d4fe29b997a14ccce89008313d09666b6ce375c
595fcc8e37f8e4354497011be90e56794bd91ad951ab45a3818430818130
1d0603551d0e041604141df1208944d77b5f1d9dcb51ee244a523f3ef5de
301f0603551d23041830168014 1df1208944d77b5f1d9dcb51ee244a523f
3ef5de300f0603551d130101ff040530030101ff300e0603551d0f0101ff
040403020106301e0603551d11041730158113636572746966794065786 1
6d706c652e636f6d300a06082a8648ce3d040302034800304502202b891d
d411d07a6d6f621947635ba4c43165296b3f633726f02e51ecf464bd4002
2100b4be8a80d08675f041fbc719acf3b39dedc85dc92b3035868cb2daa8
f05db196a1003100
```

The breakdown of the payload is shown in Appendix C.1.

A.2. enroll / reenroll

During the (re-)enroll exchange the EST-coaps client uses a CSR (Content-Format 286) request in the POST request payload. The Accept option tells the server that the client is expecting Content-Format 281 (PKCS#7) in the response. As shown in Appendix C.2, the CSR contains a ChallengePassword which is used for PoP linking (Section 4).

```
POST [2001:db8::2:321]:61616/est/sen
(Token: 0x45)
(Accept: 281)
(Content-Format: 286)

[ The hexadecimal representation below would NOT be transported
in hex, but in binary. Hex is used because a binary representation
cannot be rendered well in text. ]

3082018b30820131020100305c310b300906035504061302555310b3009
06035504080c024341310b300906035504070c024c413114301206035504
0a0c0b6578616d706c6520496e63310c300a060355040b0c03496f54310f
300d06035504051306577431323334305930130607 2a8648ce3d02010608
2a8648ce3d03010703420004c8b421f11c25e47e3ac57123bf2d9fdc494f
028bc351cc80c03f150bf50cff958d75419d81a6a245dffae790be95cf75
f602f9152618f816a2b23b5638e59fd9a073303406092a864886f70d0109
0731270c2576437630292a264a4b4a3bc3a2c280c2992f3e3c2e2c3d6b6e
7634332323403d204e787e60303b06092a864886f70d01090e312e302c30
2a0603551d1104233021a01f06082b06010505070804a013301106092b06
010401b43b0a0104040102030430 0a06082a8648ce3d0403020348003045
02210092563a546463bd9ecff170d0fd1f2ef0d3d012160e5ee90cffedab
ec9b9a38920220179f10a3436109051abad17590a09bc87c4dce5453a6fc
1135a1e84eed754377
```

After verification of the CSR by the server, a 2.04 Changed response with the issued certificate will be returned to the client.

```
2.04 Changed
(Token: 0x45)
(Content-Format: 281)

[ The hexadecimal representation below would NOT be transported
in hex, but in binary. Hex is used because a binary representation
cannot be rendered well in text. ]

3082026e06092a864886f70d010702a082025f3082025b0201013100300b
06092a864886f70d010701a08202413082023d308201e2a0030201020208
7e7661d7b54e4632300a06082a8648ce3d040302305d310b300906035504
0613025553310b300906035504080c024341311143012060355040a0c0b45
78616d706c6520496e6331163014060355040b0c0d636572746966696361
74696f6e3113301106035504030c0a3830322e3141522043413020170d31
393031333131313231323931365a180f393939393132333132333353935395a30
5c310b300906035504061302555331 0b300906035504080c024341310b30
0906035504070c024c41311430120603550 40a0c0b6578616d706c652049
6e63310c300a060355040b0c03496f54310f300d06035504051306577431
323334305930130607 2a8648ce3d020106082a8648ce3d03010703420004
c8b421f11c25e47e3ac57123bf2d9fdc494f028bc351cc80c03f150bf50c
ff958d75419d81a6a245dffae790be95cf75f602f9152618f816a2b23b56
38e59fd9a3818a30818730090603551d1304023000301d0603551d0e0416
041496600d8716bf7fd0e752d0ac760777ad665d02a0301f0603551d2304
183016801468d16551f951bfc82a431d0d9f08bc2d205b1160300e060355
1d0f0101ff0404030205a0302a0603551d1104233021a01f06082b060105
05070804a013301106092b06010401b43b0a0104040102030430 0a06082a
8648ce3d040302034900303046022100c0d81996d2507d693f3c48eaa5ee94
91bda6db214099d98117c63b361374cd86022100a774989f4c321a5cf25d
832a4d336a08ad67df20f1506421188a0ade6d349236a1003100
```

The breakdown of the request and response is shown in Appendix C.2.

A.3. serverkeygen

In a serverkeygen exchange the CoAP POST request looks like

```
POST 192.0.2.1:8085/est/skg
(Token: 0xa5)
(Accept: 62)
(Content-Format: 286)

[ The hexadecimal representation below would NOT be transported
in hex, but in binary. Hex is used because a binary representation
cannot be rendered well in text. ]

3081d03078020100301631143012060355040a0c0b736b67206578616d70
6c653059301306072a8648ce3d020106082a8648ce3d03010703420004c8
b421f11c25e47e3ac57123bf2d9fdc494f028bc351cc80c03f150bf50cff
958d75419d81a6a245dffae790be95cf75f602f9152618f816a2b23b5638
e59fd9a000300a06082a8648ce3d040302034800304502207c553981b1fe
349249d8a3f50a0346336b7dfaa099cf74e1ec7a37a0a760485902210084
79295398774b2ff8e7e82abb0c17eaef344a5088fa69fd63ee611850c34b
0a
```

The response would follow [I-D.ietf-core-multipart-ct] and could look like

```
2.04 Changed
(Token: 0xa5)
(Content-Format: 62)

[ The hexadecimal representations below would NOT be transported
in hex, but in binary. Hex is used because a binary representation
cannot be rendered well in text. ]

84                                  # array(4)
19 011C                             # unsigned(284)
58 8A                               # bytes(138)
308187020100301306072a8648ce3d020106082a8648ce3d030107046d30
6b020101042061336a86ac6e7af4a96f632830ad4e6aa0837679206094d7
679a01ca8c6f0c37a14403420004c8b421f11c25e47e3ac57123bf2d9fdc
494f028bc351cc80c03f150bf50cff958d75419d81a6a245dffae790be95
cf75f602f9152618f816a2b23b5638e59fd9
19 0119                             # unsigned(281)
59 01D3                             # bytes(467)
308201cf06092a864886f70d010702a08201c0308201bc0201013100300b
06092a864886f70d010701a08201a23082019e30820144a0030201020209
00b3313e8f3fc9538e300a06082a8648ce3d0403023016311430120603550
040a0c0b736b67206578616d706c65301e170d313930393034303734303
335a170d333930383330303734343033335a3016311430120603550040a0c0b
736b67206578616d706c653059301306072a8648ce3d020106082a8648ce
3d03010703420004c8b421f11c25e47e3ac57123bf2d9fdc494f028bc351
cc80c03f150bf50cff958d75419d81a6a245dffae790be95cf75f602f915
2618f816a2b23b5638e59fd9a37b307930090603551d1304023000302c06
096086480186f842010d041f161d4f70656e53534c2047656e6572617465
64204365727469666963617465301d0603551d0e0416041496600d8716bf
7fd0e752d0ac760777ad665d02a0301f0603551d2304183016801496600d
8716bf7fd0e752d0ac760777ad665d02a0300a06082a8648ce3d04030203
48003045022100e95bfa25a08976652246f2d96143da39fce0dc4c9b26b9
cce1f24164cc2b12b602201351fd8eea65764e3459d324e4345ff5b2a915
38c04976111796b3698bf6379ca1003100
```

The private key in the response above is without CMS EnvelopedData and has no additional encryption beyond DTLS (Section 5.8).

The breakdown of the request and response is shown in Appendix C.3

A.4. csrattrs

Below is a csrattrs exchange

REQ:
GET example.com:61616/est/att

RES:
2.05 Content
(Content-Format: 285)

[The hexadecimal representation below would NOT be transported in hex, but in binary. Hex is used because a binary representation cannot be rendered well in text.]

307c06072b0601010101163022060383701311b131950617273652053455
420617320322e3939392e3120646174610609 2a864886f70d010907302c06
0388370231250603883703060388370413195061727365205345542061732
0322e3939392e3220646174610609 2b240303020801010b06096086480165
03040202

A 2.05 Content response should contain attributes which are relevant for the authenticated client. This example is copied from Section A.2 in [RFC7030], where the base64 representation is replaced with a hexadecimal representation of the equivalent binary format. The EST-coaps server returns attributes that the client can ignore if they are unknown to him.

Appendix B. EST-coaps Block message examples

Two examples are presented in this section:

1. a cacerts exchange shows the use of Block2 and the block headers

2. an enroll exchange shows the Block1 and Block2 size negotiation for request and response payloads.

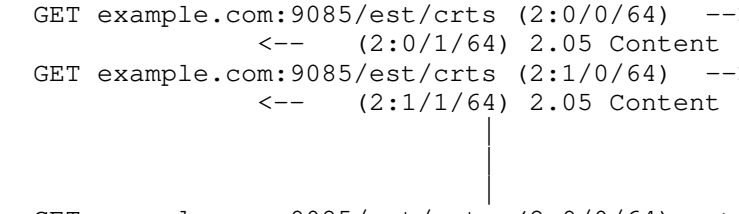
The payloads are shown unencrypted. In practice the message contents would be binary formatted and transferred over an encrypted DTLS tunnel. The corresponding CoAP headers are only shown in Appendix B.1. Creating CoAP headers is assumed to be generally known.

B.1. cacerts

This section provides a detailed example of the messages using DTLS and BLOCK option Block2. The example block length is taken as 64 which gives an SZX value of 2.

The following is an example of a cacerts exchange over DTLS. The content length of the cacerts response in appendix A.1 of [RFC7030] contains 639 bytes in binary in this example. The CoAP message adds

around 10 bytes in this exmple, the DTLS record around 29 bytes. To avoid IP fragmentation, the CoAP Block Option is used and an MTU of 127 is assumed to stay within one IEEE 802.15.4 packet. To stay below the MTU of 127, the payload is split in 9 packets with a payload of 64 bytes each, followed by a last tenth packet of 63 bytes. The client sends an IPv6 packet containing a UDP datagram with DTLS record protection that encapsulates a CoAP request 10 times (one fragment of the request per block). The server returns an IPv6 packet containing a UDP datagram with the DTLS record that encapsulates the CoAP response. The CoAP request-response exchange with block option is shown below. Block Option is shown in a decomposed way (block-option:NUM/M/size) indicating the kind of Block Option (2 in this case) followed by a colon, and then the block number (NUM), the more bit (M = 0 in Block2 response means it is last block), and block size with exponent (2**(SZX+4)) separated by slashes. The Length 64 is used with SZX=2. The CoAP Request is sent confirmable (CON) and the Content-Format of the response, even though not shown, is 281 (application/pkcs7-mime; smime-type=certs-only). The transfer of the 10 blocks with partially filled block NUM=9 is shown below



The header of the GET request looks like

```
Ver = 1
T = 0 (CON)
Code = 0x01 (0.1 GET)
Token = 0x9a    (client generated)
Options
 Option (Uri-Host)
   Option Delta = 0x3  (option# 3)
   Option Length = 0xB
   Option Value = "example.com"
 Option (Uri-Port)
   Option Delta = 0x4   (option# 3+4=7)
   Option Length = 0x2
   Option Value = 9085
 Option (Uri-Path)
   Option Delta = 0x4    (option# 7+4=11)
   Option Length = 0x3
   Option Value = "est"
 Option (Uri-Path)Uri-Path)
   Option Delta = 0x0    (option# 11+0=11)
   Option Length = 0x4
   Option Value = "crts"
 Option (Accept)
   Option Delta = 0x6   (option# 11+6=17)
   Option Length = 0x2
   Option Value = 281
Payload = [Empty]
```

The Uri-Host and Uri-Port Options can be omitted if they coincide with the transport protocol destination address and port respectively. Explicit Uri-Host and Uri-Port Options are typically used when an endpoint hosts multiple virtual servers and uses the Options to route the requests accordingly.

For further detailing the CoAP headers, the first two and the last blocks are written out below. The header of the first Block2 response looks like

```
     Ver = 1
     T = 2 (ACK)
     Code = 0x45 (2.05 Content)
     Token = 0x9a     (copied from request by server)
     Options
       Option
         Option Delta = 0xC  (option# 12 Content-Format)
         Option Length = 0x2
         Option Value = 281
       Option
         Option Delta = 0xB  (option# 12+11=23 Block2)
         Option Length = 0x1
         Option Value = 0x0A (block#=0, M=1, SZX=2)

     [ The hexadecimal representation below would NOT be transported
     in hex, but in binary. Hex is used because a binary representation
     cannot be rendered well in text. ]

     Payload =
   3082027b06092a864886f70d010702a082026c308202680201013100300b
   06092a864886f70d010701a082024e3082024a308201f0a0030201020209
   009189bc
```

The second Block2:

```
     Ver = 1
     T = 2 (means ACK)
     Code = 0x45 (2.05 Content)
     Token = 0x9a     (copied from request by server)
     Options
       Option
         Option Delta = 0xC  (option# 12 Content-Format)
         Option Length = 0x2
         Option Value = 281
       Option
         Option Delta = 0xB  (option 12+11=23 Block2)
         Option Length = 0x1
         Option Value = 0x1A (block#=1, M=1, SZX=2)

     [ The hexadecimal representation below would NOT be transported
     in hex, but in binary. Hex is used because a binary representation
     cannot be rendered well in text. ]

     Payload =
   df9c99244b300a06082a8648ce3d0403023067310b300906035504061302
   5553310b300906035504080c024341310b300906035504070c024c413114
   30120603
```

The 10th and final Block2:

```
  Ver = 1
  T = 2 (means ACK)
  Code = 0x45      (2.05 Content)
  Token = 0x9a     (copied from request by server)
  Options
    Option
      Option Delta = 0xC  (option# 12 Content-Format)
      Option Length = 0x2
      Option Value = 281
    Option
      Option Delta = 0xB  (option# 12+11=23 Block2 )
      Option Length = 0x1
      Option Value = 0x92 (block#=9, M=0, SZX=2)

  [ The hexadecimal representation below would NOT be transported
  in hex, but in binary. Hex is used because a binary representation
  cannot be rendered well in text. ]

  Payload =
2ec0b4af52d46f3b7ecc9687ddf267bcec368f7b7f1353272f022047a28a
e5c7306163b3c3834bab3c103f743070594c089aaa0ac870cd13b902caa1
003100
```

B.2. enroll / reenroll

In this example, the requested Block2 size of 256 bytes, required by the client, is transferred to the server in the very first request message. The block size 256=(2**(SZX+4)) which gives SZX=4. The notation for block numbering is the same as in Appendix B.1. The header fields and the payload are omitted for brevity.

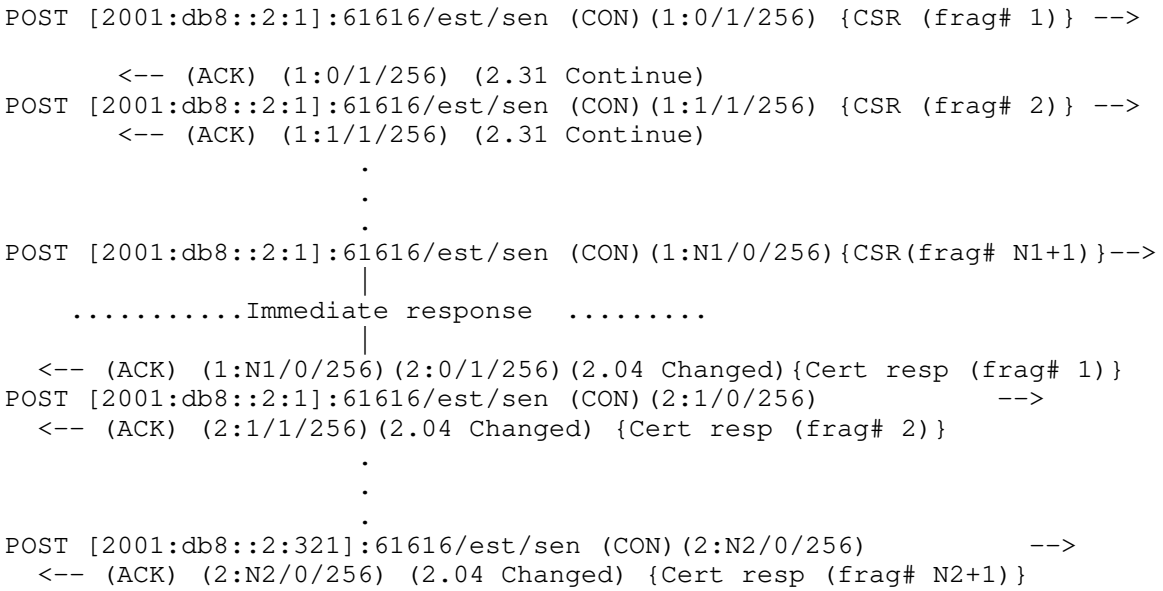


Figure 5: EST-COAP enrollment with multiple blocks

N1+1 blocks have been transferred from client to the server and N2+1 blocks have been transferred from server to client.

Appendix C. Message content breakdown

This appendix presents the breakdown of the hexadecimal dumps of the binary payloads shown in Appendix A.

C.1. cacerts

The breakdown of cacerts response containing one root CA certificate is

```
   Certificate:
       Data:
           Version: 3 (0x2)
           Serial Number: 831953162763987486 (0xb8bb0fe604f6a1e)
       Signature Algorithm: ecdsa-with-SHA256
           Issuer: C=US, ST=CA, L=LA, O=Example Inc,
                     OU=certification, CN=Root CA
           Validity
               Not Before: Jan 31 11:27:03 2019 GMT
               Not After : Jan 26 11:27:03 2039 GMT
           Subject: C=US, ST=CA, L=LA, O=Example Inc,
                       OU=certification, CN=Root CA
           Subject Public Key Info:
               Public Key Algorithm: id-ecPublicKey
                   Public-Key: (256 bit)
                   pub:
                       04:0c:1b:1e:82:ba:8c:c7:26:80:97:3f:97:ed:b8:
                       a0:c7:2a:b0:d4:05:f0:5d:4f:e2:9b:99:7a:14:cc:
                       ce:89:00:83:13:d0:96:66:b6:ce:37:5c:59:5f:cc:
                       8e:37:f8:e4:35:44:97:01:1b:e9:0e:56:79:4b:d9:
                       1a:d9:51:ab:45
                   ASN1 OID: prime256v1
                   NIST CURVE: P-256
           X509v3 extensions:
               X509v3 Subject Key Identifier:
   1D:F1:20:89:44:D7:7B:5F:1D:9D:CB:51:EE:24:4A:52:3F:3E:F5:DE
               X509v3 Authority Key Identifier:
                     keyid:
   1D:F1:20:89:44:D7:7B:5F:1D:9D:CB:51:EE:24:4A:52:3F:3E:F5:DE

               X509v3 Basic Constraints: critical
                   CA:TRUE
               X509v3 Key Usage: critical
                   Certificate Sign, CRL Sign
               X509v3 Subject Alternative Name:
                   email:certify@example.com
       Signature Algorithm: ecdsa-with-SHA256
            30:45:02:20:2b:89:1d:d4:11:d0:7a:6d:6f:62:19:47:63:5b:
            a4:c4:31:65:29:6b:3f:63:37:26:f0:2e:51:ec:f4:64:bd:40:
            02:21:00:b4:be:8a:80:d0:86:75:f0:41:fb:c7:19:ac:f3:b3:
            9d:ed:c8:5d:c9:2b:30:35:86:8c:b2:da:a8:f0:5d:b1:96
```

C.2. enroll / reenroll

The breakdown of the enrollment request is

```
Certificate Request:
    Data:
        Version: 0 (0x0)
        Subject: C=US, ST=CA, L=LA, O=example Inc,
                    OU=IoT/serialNumber=Wt1234
        Subject Public Key Info:
            Public Key Algorithm: id-ecPublicKey
                Public-Key: (256 bit)
                pub:
                    04:c8:b4:21:f1:1c:25:e4:7e:3a:c5:71:23:bf:2d:
                    9f:dc:49:4f:02:8b:c3:51:cc:80:c0:3f:15:0b:f5:
                    0c:ff:95:8d:75:41:9d:81:a6:a2:45:df:fa:e7:90:
                    be:95:cf:75:f6:02:f9:15:26:18:f8:16:a2:b2:3b:
                    56:38:e5:9f:d9
                ASN1 OID: prime256v1
                NIST CURVE: P-256
        Attributes:
            challengePassword:   <256-bit PoP linking value>
        Requested Extensions:
            X509v3 Subject Alternative Name:
                othername:<unsupported>
    Signature Algorithm: ecdsa-with-SHA256
         30:45:02:21:00:92:56:3a:54:64:63:bd:9e:cf:f1:70:d0:fd:
         1f:2e:f0:d3:d0:12:16:0e:5e:e9:0c:ff:ed:ab:ec:9b:9a:38:
         92:02:20:17:9f:10:a3:43:61:09:05:1a:ba:d1:75:90:a0:9b:
         c8:7c:4d:ce:54:53:a6:fc:11:35:a1:e8:4e:ed:75:43:77
```

The CSR contains a ChallengePassword which is used for PoP linking (Section 4). The CSR also contains an id-on-hardwareModuleName hardware identifier to customize the returned certificate to the requesting device (See [RFC7299] and [I-D.moskowitz-ecdsa-pki]).

The breakdown of the issued certificate is

```
   Certificate:
       Data:
           Version: 3 (0x2)
           Serial Number: 9112578475118446130 (0x7e7661d7b54e4632)
       Signature Algorithm: ecdsa-with-SHA256
           Issuer: C=US, ST=CA, O=Example Inc,
                         OU=certification, CN=802.1AR CA
           Validity
               Not Before: Jan 31 11:29:16 2019 GMT
               Not After : Dec 31 23:59:59 9999 GMT
           Subject: C=US, ST=CA, L=LA, O=example Inc,
                   OU=IoT/serialNumber=Wt1234
           Subject Public Key Info:
               Public Key Algorithm: id-ecPublicKey
                   Public-Key: (256 bit)
                   pub:
                       04:c8:b4:21:f1:1c:25:e4:7e:3a:c5:71:23:bf:2d:
                       9f:dc:49:4f:02:8b:c3:51:cc:80:c0:3f:15:0b:f5:
                       0c:ff:95:8d:75:41:9d:81:a6:a2:45:df:fa:e7:90:
                       be:95:cf:75:f6:02:f9:15:26:18:f8:16:a2:b2:3b:
                       56:38:e5:9f:d9
                   ASN1 OID: prime256v1
                   NIST CURVE: P-256
           X509v3 extensions:
               X509v3 Basic Constraints:
                   CA:FALSE
               X509v3 Subject Key Identifier:
   96:60:0D:87:16:BF:7F:D0:E7:52:D0:AC:76:07:77:AD:66:5D:02:A0
               X509v3 Authority Key Identifier:
                   keyid:
   68:D1:65:51:F9:51:BF:C8:2A:43:1D:0D:9F:08:BC:2D:20:5B:11:60

               X509v3 Key Usage: critical
                   Digital Signature, Key Encipherment
               X509v3 Subject Alternative Name:
                   othername:<unsupported>
       Signature Algorithm: ecdsa-with-SHA256
            30:46:02:21:00:c0:d8:19:96:d2:50:7d:69:3f:3c:48:ea:a5:
            ee:94:91:bd:a6:db:21:40:99:d9:81:17:c6:3b:36:13:74:cd:
            86:02:21:00:a7:74:98:9f:4c:32:1a:5c:f2:5d:83:2a:4d:33:
            6a:08:ad:67:df:20:f1:50:64:21:18:8a:0a:de:6d:34:92:36
```

C.3. serverkeygen

The following is the breakdown of the server-side key generation request.

```
Certificate Request:
    Data:
        Version: 0 (0x0)
        Subject: O=skg example
        Subject Public Key Info:
            Public Key Algorithm: id-ecPublicKey
                Public-Key: (256 bit)
                pub:
                    04:c8:b4:21:f1:1c:25:e4:7e:3a:c5:71:23:bf:2d:
                    9f:dc:49:4f:02:8b:c3:51:cc:80:c0:3f:15:0b:f5:
                    0c:ff:95:8d:75:41:9d:81:a6:a2:45:df:fa:e7:90:
                    be:95:cf:75:f6:02:f9:15:26:18:f8:16:a2:b2:3b:
                    56:38:e5:9f:d9
                ASN1 OID: prime256v1
                NIST CURVE: P-256
        Attributes:
            a0:00
    Signature Algorithm: ecdsa-with-SHA256
         30:45:02:20:7c:55:39:81:b1:fe:34:92:49:d8:a3:f5:0a:03:
         46:33:6b:7d:fa:a0:99:cf:74:e1:ec:7a:37:a0:a7:60:48:59:
         02:21:00:84:79:29:53:98:77:4b:2f:f8:e7:e8:2a:bb:0c:17:
         ea:ef:34:4a:50:88:fa:69:fd:63:ee:61:18:50:c3:4b:0a
```

Following is the breakdown of the private key content of the server-side key generation response.

```
Private-Key: (256 bit)
priv:
    61:33:6a:86:ac:6e:7a:f4:a9:6f:63:28:30:ad:4e:
    6a:a0:83:76:79:20:60:94:d7:67:9a:01:ca:8c:6f:
    0c:37
pub:
    04:c8:b4:21:f1:1c:25:e4:7e:3a:c5:71:23:bf:2d:
    9f:dc:49:4f:02:8b:c3:51:cc:80:c0:3f:15:0b:f5:
    0c:ff:95:8d:75:41:9d:81:a6:a2:45:df:fa:e7:90:
    be:95:cf:75:f6:02:f9:15:26:18:f8:16:a2:b2:3b:
    56:38:e5:9f:d9
ASN1 OID: prime256v1
NIST CURVE: P-256
```

The following is the breakdown of the certificate in the server-side key generation response payload.

```
   Certificate:
       Data:
           Version: 3 (0x2)
           Serial Number:
               b3:31:3e:8f:3f:c9:53:8e
       Signature Algorithm: ecdsa-with-SHA256
           Issuer: O=skg example
           Validity
               Not Before: Sep  4 07:44:03 2019 GMT
               Not After : Aug 30 07:44:03 2039 GMT
           Subject: O=skg example
           Subject Public Key Info:
               Public Key Algorithm: id-ecPublicKey
                   Public-Key: (256 bit)
                   pub:
                       04:c8:b4:21:f1:1c:25:e4:7e:3a:c5:71:23:bf:2d:
                       9f:dc:49:4f:02:8b:c3:51:cc:80:c0:3f:15:0b:f5:
                       0c:ff:95:8d:75:41:9d:81:a6:a2:45:df:fa:e7:90:
                       be:95:cf:75:f6:02:f9:15:26:18:f8:16:a2:b2:3b:
                       56:38:e5:9f:d9
                   ASN1 OID: prime256v1
                   NIST CURVE: P-256
           X509v3 extensions:
               X509v3 Basic Constraints:
                   CA:FALSE
               Netscape Comment:
                   OpenSSL Generated Certificate
               X509v3 Subject Key Identifier:
   96:60:0D:87:16:BF:7F:D0:E7:52:D0:AC:76:07:77:AD:66:5D:02:A0
               X509v3 Authority Key Identifier:
                   keyid:
   96:60:0D:87:16:BF:7F:D0:E7:52:D0:AC:76:07:77:AD:66:5D:02:A0

       Signature Algorithm: ecdsa-with-SHA256
            30:45:02:21:00:e9:5b:fa:25:a0:89:76:65:22:46:f2:d9:61:
            43:da:39:fc:e0:dc:4c:9b:26:b9:cc:e1:f2:41:64:cc:2b:12:
            b6:02:20:13:51:fd:8e:ea:65:76:4e:34:59:d3:24:e4:34:5f:
            f5:b2:a9:15:38:c0:49:76:11:17:96:b3:69:8b:f6:37:9c
```

Authors' Addresses

Peter van der Stok
Consultant

Email: consultancy@vanderstok.org

Panos Kampanakis
Cisco Systems

Email: pkampana@cisco.com

Michael C. Richardson
Sandelman Software Works

Email: mcr+ietf@sandelman.ca
URI: http://www.sandelman.ca/

Shahid Raza
RISE SICS
Isafjordsgatan 22
Kista, Stockholm 16440
SE

Email: shahid@sics.se

ACE
Internet-Draft
Intended status: Standards Track
Expires: May 3, 2020

M. Jones
Microsoft
L. Seitz
RISE SICS
G. Selander
Ericsson AB
S. Erdtman
Spotify
H. Tschofenig
Arm Ltd.

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Proof-of-Possession Key Semantics for CBOR Web Tokens (CWTs)
draft-ietf-ace-cwt-proof-of-possession-11

Abstract

This specification describes how to declare in a CBOR Web Token (CWT) (which is defined by RFC 8392) that the presenter of the CWT possesses a particular proof-of-possession key. Being able to prove possession of a key is also sometimes described as being the holder-of-key. This specification provides equivalent functionality to "Proof-of-Possession Key Semantics for JSON Web Tokens (JWTs)" (RFC 7800) but using Concise Binary Object Representation (CBOR) and CWTs rather than JavaScript Object Notation (JSON) and JSON Web Tokens (JWTs).

Table of Contents

1. Introduction

This specification describes how a CBOR Web Token (CWT) [RFC8392] can declare that the presenter of the CWT possesses a particular proof-of-possession (PoP) key. Proof of possession of a key is also sometimes described as being the holder-of-key. This specification

provides equivalent functionality to "Proof-of-Possession Key Semantics for JSON Web Tokens (JWTs)" [RFC7800] but using Concise Binary Object Representation (CBOR) [RFC7049] and CWTs [RFC8392] rather than JavaScript Object Notation (JSON) [RFC8259] and JSON Web Tokens (JWTs) [JWT].

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.

This specification uses terms defined in the CBOR Web Token (CWT) [RFC8392], CBOR Object Signing and Encryption (COSE) [RFC8152], and Concise Binary Object Representation (CBOR) [RFC7049] specifications.

These terms are defined by this specification:

Issuer
: Party that creates the CWT and binds the claims about the subject to the proof-of-possession key.

Presenter
: Party that proves possession of a private key (for asymmetric key cryptography) or secret key (for symmetric key cryptography) to a recipient of a CWT.
In the context of OAuth, this party is also called the OAuth Client.

Recipient
: Party that receives the CWT containing the proof-of-possession key information from the presenter.
In the context of OAuth, this party is also called the OAuth Resource Server.

This specification provides examples in CBOR extended diagnostic notation, as defined in Appendix G of [RFC8610]. The examples include line breaks for readability.

3. Representations for Proof-of-Possession Keys

By including a "cnf" (confirmation) claim in a CWT, the issuer of the CWT declares that the presenter possesses a particular key and that the recipient can cryptographically confirm that the presenter has possession of that key. The value of the "cnf" claim is a CBOR map

(which is defined in Section 2.1 of [RFC7049]) and the members of that map identify the proof-of-possession key.

The presenter can be identified in one of several ways by the CWT, depending upon the application requirements. For instance, some applications may use the CWT "sub" (subject) claim [RFC8392], to identify the presenter. Other applications may use the "iss" (issuer) claim [RFC8392] to identify the presenter. In some applications, the subject identifier might be relative to the issuer identified by the "iss" claim. The actual mechanism used is dependent upon the application. The case in which the presenter is the subject of the CWT is analogous to Security Assertion Markup Language (SAML) 2.0 [OASIS.saml-core-2.0-os] SubjectConfirmation usage.

3.1. Confirmation Claim

The "cnf" claim in the CWT is used to carry confirmation methods. Some of them use proof-of-possession keys while others do not. This design is analogous to the SAML 2.0 [OASIS.saml-core-2.0-os] SubjectConfirmation element in which a number of different subject confirmation methods can be included (including proof-of-possession key information).

The set of confirmation members that a CWT must contain to be considered valid is context dependent and is outside the scope of this specification. Specific applications of CWTs will require implementations to understand and process some confirmation members in particular ways. However, in the absence of such requirements, all confirmation members that are not understood by implementations MUST be ignored.

This specification establishes the IANA "CWT Confirmation Methods" registry for these members in Section 7.2 and registers the members defined by this specification. Other specifications can register other members used for confirmation, including other members for conveying proof-of-possession keys using different key representations.

The "cnf" claim value MUST represent only a single proof-of-possession key. At most one of the "COSE_Key" and "Encrypted_COSE_Key" confirmation values defined in Figure 1 may be present. Note that if an application needs to represent multiple proof-of-possession keys in the same CWT, one way for it to achieve this is to use other claim names, in addition to "cnf", to hold the additional proof-of-possession key information. These claims could use the same syntax and semantics as the "cnf" claim. Those claims would be defined by applications or other specifications and could be

registered in the IANA "CBOR Web Token Claims" registry [IANA.CWT.Claims].

Name	Key	Value type
COSE_Key	1	COSE_Key
Encrypted_COSE_Key	2	COSE_Encrypt or COSE_Encrypt0
kid	3	binary string

Figure 1: Summary of the cnf names, keys, and value types

3.2. Representation of an Asymmetric Proof-of-Possession Key

When the key held by the presenter is an asymmetric private key, the "COSE_Key" member is a COSE_Key [RFC8152] representing the corresponding asymmetric public key. The following example demonstrates such a declaration in the CWT Claims Set of a CWT:

```
  {
  /iss/ 1 : "coaps://server.example.com",
  /aud/ 3 : "coaps://client.example.org",
  /exp/ 4 : 1879067471,
  /cnf/ 8 :{
    /COSE_Key/ 1 :{
      /kty/ 1 : /EC2/ 2,
      /crv/ -1 : /P-256/ 1,
      /x/ -2 : h'd7cc072de2205bdc1537a543d53c60a6acb62eccd890c7fa27c9
                 e354089bbe13',
      /y/ -3 : h'f95e1d4b851a2cc80fff87d8e23f22afb725d535e515d020731e
                 79a3b4e47120'
     }
   }
 }
```

The COSE_Key MUST contain the required key members for a COSE_Key of that key type and MAY contain other COSE_Key members, including the "kid" (Key ID) member.

The "COSE_Key" member MAY also be used for a COSE_Key representing a symmetric key, provided that the CWT is encrypted so that the key is not revealed to unintended parties. The means of encrypting a CWT is explained in [RFC8392]. If the CWT is not encrypted, the symmetric key MUST be encrypted as described in Section 3.3. This procedure is equivalent to the one defined in section 3.3 of [RFC7800].

3.3. Representation of an Encrypted Symmetric Proof-of-Possession Key

When the key held by the presenter is a symmetric key, the "Encrypted_COSE_Key" member is an encrypted COSE_Key [RFC8152] representing the symmetric key encrypted to a key known to the recipient using COSE_Encrypt or COSE_Encrypt0.

The following example illustrates a symmetric key that could subsequently be encrypted for use in the "Encrypted_COSE_Key" member:

```
  {
   /kty/ 1 : /Symmetric/ 4,
   /alg/ 3 : /HMAC 256-256/ 5,
   /k/ -1 : h'6684523ab17337f173500e5728c628547cb37df
             e68449c65f885d1b73b49eae1'
  }
```

The COSE_Key representation is used as the plaintext when encrypting the key.

The following example CWT Claims Set of a CWT illustrates the use of an encrypted symmetric key as the "Encrypted_COSE_Key" member value:

```
{
 /iss/ 1 : "coaps://server.example.com",
 /sub/ 2 : "24400320",
 /aud/ 3: "s6BhdRkqt3",
 /exp/ 4 : 1311281970,
 /iat/ 5 : 1311280970,
 /cnf/ 8 : {
 /Encrypted_COSE_Key/ 2 : [
     /protected header/ h'A1010A' /{ \alg\ 1:10 \AES-CCM-16-64-128\}/,
     /unprotected header/ { / iv / 5: h'636898994FF0EC7BFCF6D3F95B'},
     /ciphertext/  h'0573318A3573EB983E55A7C2F06CADD0796C9E584F1D0E3E
                    A8C5B052592A8B2694BE9654F0431F38D5BBC8049FA7F13F'
   ]
  }
}
```

The example above was generated with the key:

```
          h'616263040506070809 0a0b0c0d0e0f10'
```

3.4. Representation of a Key ID for a Proof-of-Possession Key

The proof-of-possession key can also be identified using a Key ID instead of communicating the actual key, provided the recipient is able to obtain the identified key using the Key ID. In this case, the issuer of a CWT declares that the presenter possesses a particular key and that the recipient can cryptographically confirm proof of possession of the key by the presenter by including a "cnf" claim in the CWT whose value is a CBOR map with the CBOR map containing a "kid" member identifying the key.

The following example demonstrates such a declaration in the CWT Claims Set of a CWT:

```
{
 /iss/ 1 : "coaps://as.example.com",
 /aud/ 3 : "coaps://resource.example.org",
 /exp/ 4 : 1361398824,
 /cnf/ 8 : {
   /kid/ 3 : h'dfd1aa976d8d4575a0fe34b96de2bfad'
  }
}
```

The content of the "kid" value is application specific. For instance, some applications may choose to use a cryptographic hash of the public key value as the "kid" value.

Note that the use of a Key ID to identify a proof-of-possession key needs to be carefully circumscribed, as described below and in Section 6. In cases where the Key ID is not a cryptographic value derived from the key or where not all of the parties involved are validating the cryptographic derivation, implementers should expect collisions, where different keys are assigned the same Key ID. Recipients of a CWT with a PoP key linked through only a Key ID should be prepared to handle such situations.

In the world of constrained Internet of Things (IoT) devices, there is frequently a restriction on the size of Key IDs, either because of table constraints or a desire to keep message sizes small.

Note that the value of a Key ID for a specific key is not necessarily the same for different parties. When sending a COSE encrypted message with a shared key, the Key ID may be different on both sides of the conversation, with the appropriate one being included in the message based on the recipient of the message.

3.5. Specifics Intentionally Not Specified

Proof of possession is often demonstrated by having the presenter sign a value determined by the recipient using the key possessed by the presenter. This value is sometimes called a "nonce" or a "challenge". There are, however, also other means to demonstrate freshness of the exchange and to link the proof-of-possession key to the participating parties, as demonstrated by various authentication and key exchange protocols.

The means of communicating the nonce and the nature of its contents are intentionally not described in this specification, as different protocols will communicate this information in different ways. Likewise, the means of communicating the signed nonce is also not specified, as this is also protocol specific.

Note that other means of proving possession of the key exist, which could be used in conjunction with a CWT's confirmation key. Applications making use of such alternate means are encouraged to register them in the IANA "CWT Confirmation Methods" registry established in Section 7.2.

4. Security Considerations

All the security considerations that are discussed in [RFC8392] also apply here. In addition, proof of possession introduces its own unique security issues. Possessing a key is only valuable if it is kept secret. Appropriate means must be used to ensure that unintended parties do not learn private key or symmetric key values.

Applications utilizing proof of possession SHOULD also utilize audience restriction, as described in Section 3.1.3 of [RFC8392], as it provides additional protections. Audience restriction can be used by recipients to reject messages intended for different recipients. (Of course, applications not using proof of possession can also benefit from using audience restriction to reject messages intended for different recipients.)

CBOR Web Tokens with proof-of-possession keys are used in context of an architecture, such as the ACE OAuth Framework [I-D.ietf-ace-oauth-authz], in which protocols are used by a presenter to request these tokens and to subsequently use them with recipients. Proof of possession only provides the intended security gains when the proof is known to be current and not subject to replay attacks; security protocols using mechanisms such as nonces and timestamps can be used to avoid the risk of replay when performing proof of possession for a token. Note that a discussion of the

architecture or specific protocols that CWT proof-of-possession tokens are used with is beyond the scope of this specification.

As is the case with other information included in a CWT, it is necessary to apply data origin authentication and integrity protection (via a keyed message digest or a digital signature). Data origin authentication ensures that the recipient of the CWT learns about the entity that created the CWT since this will be important for any policy decisions. Integrity protection prevents an adversary from changing any elements conveyed within the CWT payload. Special care has to be applied when carrying symmetric keys inside the CWT since those not only require integrity protection but also confidentiality protection.

As described in Section 6 (Key Identification) and Appendix D (Notes on Key Selection) of [JWS], it is important to make explicit trust decisions about the keys. Proof-of-possession signatures made with keys not meeting the application's trust criteria MUST NOT be relied upon.

5. Privacy Considerations

A proof-of-possession key can be used as a correlation handle if the same key is used on multiple occasions. Thus, for privacy reasons, it is recommended that different proof-of-possession keys be used when interacting with different parties.

6. Operational Considerations

The use of CWTs with proof-of-possession keys requires additional information to be shared between the involved parties in order to ensure correct processing. The recipient needs to be able to use credentials to verify the authenticity and integrity of the CWT. Furthermore, the recipient may need to be able to decrypt either the whole CWT or the encrypted parts thereof (see Section 3.3). This requires the recipient to know information about the issuer. Likewise, there needs to be agreement between the issuer and the recipient about the claims being used (which is also true of CWTs in general).

When an issuer creates a CWT containing a Key ID claim, it needs to make sure that it does not issue another CWT with different claims containing the same Key ID within the lifetime of the CWTs, unless intentionally desired. Failure to do so may allow one party to impersonate another party, with the potential to gain additional privileges. A case where such reuse of a Key ID would be intentional is when a presenter obtains a CWT with different claims (e.g., extended scope) for the same recipient, but wants to continue using

an existing security association (e.g., a DTLS session) bound to the key identified by the Key ID. Likewise, if PoP keys are used for multiple different kinds of CWTs in an application and the PoP keys are identified by Key IDs, care must be taken to keep the keys for the different kinds of CWTs segregated so that an attacker cannot cause the wrong PoP key to be used by using a valid Key ID for the wrong kind of CWT. Using an audience restriction for the CWT would be one strategy to mitigate this risk.

7. IANA Considerations

The following registration procedure is used for all the registries established by this specification.

Values are registered on a Specification Required [RFC8126] basis after a three-week review period on the cwt-reg-review@ietf.org mailing list, on the advice of one or more Designated Experts. However, to allow for the allocation of values prior to publication, the Designated Experts may approve registration once they are satisfied that such a specification will be published. [[Note to the RFC Editor: The name of the mailing list should be determined in consultation with the IESG and IANA. Suggested name: cwt-reg-review@ietf.org.]]

Registration requests sent to the mailing list for review should use an appropriate subject (e.g., "Request to Register CWT Confirmation Method: example"). Registration requests that are undetermined for a period longer than 21 days can be brought directly to IANA's attention (using the iana@iana.org mailing list) for resolution.

Designated Experts should determine whether a registration request contains enough information for the registry to be populated with the new values and whether the proposed new functionality already exists. In the case of an incomplete registration or an attempt to register already existing functionality, the Designated Experts should ask for corrections or reject the registration.

It is suggested that multiple Designated Experts be appointed who are able to represent the perspectives of different applications using this specification in order to enable broadly informed review of registration decisions. In cases where a registration decision could be perceived as creating a conflict of interest for a particular Expert, that Expert should defer to the judgment of the other Experts.

7.1. CBOR Web Token Claims Registration

This specification registers the "cnf" claim in the IANA "CBOR Web Token Claims" registry [IANA.CWT.Claims] established by [RFC8392].

7.1.1. Registry Contents

- Claim Name: "cnf"
- Claim Description: Confirmation
- JWT Claim Name: "cnf"
- Claim Key: TBD (maybe 8)
- Claim Value Type(s): map
- Change Controller: IESG
- Specification Document(s): Section 3.1 of [[this document]]

7.2. CWT Confirmation Methods Registry

This specification establishes the IANA "CWT Confirmation Methods" registry for CWT "cnf" member values. The registry records the confirmation method member and a reference to the specification that defines it.

7.2.1. Registration Template

Confirmation Method Name:
: The human-readable name requested (e.g., "kid").

Confirmation Method Description:
: Brief description of the confirmation method (e.g., "Key Identifier").

JWT Confirmation Method Name:
: Claim Name of the equivalent JWT confirmation method value, as registered in [IANA.JWT.Claims]. CWT claims should normally have a corresponding JWT claim. If a corresponding JWT claim would not make sense, the Designated Experts can choose to accept registrations for which the JWT Claim Name is listed as "N/A".

Confirmation Key:
: CBOR map key value for the confirmation method.

Confirmation Value Type(s):
: CBOR types that can be used for the confirmation method value.

Change Controller:
: For Standards Track RFCs, list the "IESG". For others, give the name of the responsible party.

Specification Document(s):
Reference to the document or documents that specify the parameter, preferably including URIs that can be used to retrieve copies of the documents. An indication of the relevant sections may also be included but is not required. Note that the Designated Experts and IANA must be able to obtain copies of the specification document(s) to perform their work.

7.2.2. Initial Registry Contents

- Confirmation Method Name: "COSE_Key"
- Confirmation Method Description: COSE_Key Representing Public Key
- JWT Confirmation Method Name: "jwk"
- Confirmation Key: 1
- Confirmation Value Type(s): COSE_Key structure
- Change Controller: IESG
- Specification Document(s): Section 3.2 of [[this document]]

- Confirmation Method Name: "Encrypted_COSE_Key"
- Confirmation Method Description: Encrypted COSE_Key
- JWT Confirmation Method Name: "jwe"
- Confirmation Key: 2
- Confirmation Value Type(s): COSE_Encrypt or COSE_Encrypt0 structure (with an optional corresponding COSE_Encrypt or COSE_Encrypt0 tag)
- Change Controller: IESG
- Specification Document(s): Section 3.3 of [[this document]]

- Confirmation Method Name: "kid"
- Confirmation Method Description: Key Identifier
- JWT Confirmation Method Name: "kid"
- Confirmation Key: 3
- Confirmation Value Type(s): binary string
- Change Controller: IESG
- Specification Document(s): Section 3.4 of [[this document]]

8. References

8.1. Normative References

[IANA.CWT.Claims]
IANA, "CBOR Web Token Claims", <http://www.iana.org/assignments/cwt>.

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-11

- Addressed remaining IESG review comment by Mirja Kuehlewind.

-10

- Addressed IESG review comments by Adam Roach and Eric Vyncke.

-09

- Addressed Gen-ART review comments by Christer Holmberg and SecDir review comments by Yoav Nir.

-08

- Addressed remaining Area Director review comments by Benjamin Kaduk.

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-06

- Corrected nits identified by Roman Danyliw.

-05

- Added text suggested by Jim Schaad describing considerations when using the Key ID confirmation method.

-04

- Addressed additional WGLC comments by Jim Schaad and Roman Danyliw.

-03

- Addressed review comments by Jim Schaad, see https://www.ietf.org/mail-archive/web/ace/current/msg02798.html
- Removed unnecessary sentence in the introduction regarding the use any strings that could be case-sensitive.
- Clarified the terms Presenter and Recipient.
- Clarified text about the confirmation claim.

-02

- Changed "typically" to "often" when describing ways of performing proof of possession.
- Changed b64 to hex encoding in an example.
- Changed to using the RFC 8174 boilerplate instead of the RFC 2119 boilerplate.

-01

- Now uses CBOR diagnostic notation for the examples.
- Added a table summarizing the "cnf" names, keys, and value types.
- Addressed some of Jim Schaad's feedback on -00.

-00

- Created the initial working group draft from draft-jones-ace-cwt-proof-of-possession-01.

Authors' Addresses

Michael B. Jones
Microsoft

Email: mbj@microsoft.com
URI: http://self-issued.info/

Ludwig Seitz
RISE SICS
Scheelevaegen 17
Lund 223 70
Sweden

Email: ludwig@ri.se

Goeran Selander
Ericsson AB
Faeroegatan 6
Kista 164 80
Sweden

Email: goran.selander@ericsson.com

Samuel Erdtman
Spotify

Email: erdtman@spotify.com

Hannes Tschofenig
Arm Ltd.
Hall in Tirol 6060
Austria

Email: Hannes.Tschofenig@arm.com

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S. Gerdes
O. Bergmann
C. Bormann
Universitaet Bremen TZI
G. Selander
Ericsson AB
L. Seitz
Combitech

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Datagram Transport Layer Security (DTLS) Profile for Authentication and Authorization for Constrained Environments (ACE) draft-ietf-ace-dtls-authorize-14

Abstract

This specification defines a profile of the ACE framework that allows constrained servers to delegate client authentication and authorization. The protocol relies on DTLS version 1.2 for communication security between entities in a constrained network using either raw public keys or pre-shared keys. A resource-constrained server can use this protocol to delegate management of authorization information to a trusted host with less severe limitations regarding processing power and memory.

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

This specification defines a profile of the ACE framework [I-D.ietf-ace-oauth-authz]. In this profile, a client and a resource server use CoAP [RFC7252] over DTLS version 1.2 [RFC6347] to communicate. The client obtains an access token, bound to a key (the proof-of-possession key), from an authorization server to prove its authorization to access protected resources hosted by the resource

server. Also, the client and the resource server are provided by the authorization server with the necessary keying material to establish a DTLS session. The communication between client and authorization server may also be secured with DTLS. This specification supports DTLS with Raw Public Keys (RPK) [RFC7250] and with Pre-Shared Keys (PSK) [RFC4279].

The ACE framework requires that client and server mutually authenticate each other before any application data is exchanged. DTLS enables mutual authentication if both client and server prove their ability to use certain keying material in the DTLS handshake. The authorization server assists in this process on the server side by incorporating keying material (or information about keying material) into the access token, which is considered a "proof of possession" token.

In the RPK mode, the client proves that it can use the RPK bound to the token and the server shows that it can use a certain RPK.

The resource server needs access to the token in order to complete this exchange. For the RPK mode, the client must upload the access token to the resource server before initiating the handshake, as described in Section 5.8.1 of the ACE framework [I-D.ietf-ace-oauth-authz].

In the PSK mode, client and server show with the DTLS handshake that they can use the keying material that is bound to the access token. To transfer the access token from the client to the resource server, the "psk_identity" parameter in the DTLS PSK handshake may be used instead of uploading the token prior to the handshake.

As recommended in Section 5.8 of [I-D.ietf-ace-oauth-authz], this specification uses CBOR web tokens to convey claims within an access token issued by the server. While other formats could be used as well, those are out of scope for this document.

1.1. 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.

Readers are expected to be familiar with the terms and concepts described in [I-D.ietf-ace-oauth-authz] and in [I-D.ietf-ace-oauth-params].

The authorization information (authz-info) resource refers to the authorization information endpoint as specified in [I-D.ietf-ace-oauth-authz]. The term "claim" is used in this document with the same semantics as in [I-D.ietf-ace-oauth-authz], i.e., it denotes information carried in the access token or returned from introspection.

2. Protocol Overview

The CoAP-DTLS profile for ACE specifies the transfer of authentication information and, if necessary, authorization information between the client (C) and the resource server (RS) during setup of a DTLS session for CoAP messaging. It also specifies how the client can use CoAP over DTLS to retrieve an access token from the authorization server (AS) for a protected resource hosted on the resource server. As specified in Section 6.7 of [I-D.ietf-ace-oauth-authz], use of DTLS for one or both of these interactions is completely independent

This profile requires the client to retrieve an access token for protected resource(s) it wants to access on the resource server as specified in [I-D.ietf-ace-oauth-authz]. Figure 1 shows the typical message flow in this scenario (messages in square brackets are optional):

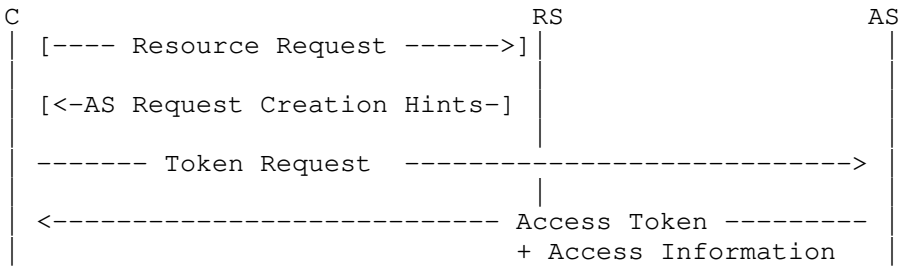

Figure 1: Retrieving an Access Token

To determine the authorization server in charge of a resource hosted at the resource server, the client can send an initial Unauthorized Resource Request message to the resource server. The resource server then denies the request and sends an AS Request Creation Hints message containing the address of its authorization server back to the client as specified in Section 5.1.2 of [I-D.ietf-ace-oauth-authz].

Once the client knows the authorization server's address, it can send an access token request to the token endpoint at the authorization

server as specified in [I-D.ietf-ace-oauth-authz]. As the access token request as well as the response may contain confidential data, the communication between the client and the authorization server must be confidentiality-protected and ensure authenticity. The client may have been registered at the authorization server via the OAuth 2.0 client registration mechanism as outlined in Section 5.3 of [I-D.ietf-ace-oauth-authz].

The access token returned by the authorization server can then be used by the client to establish a new DTLS session with the resource server. When the client intends to use an asymmetric proof-of-possession key in the DTLS handshake with the resource server, the client MUST upload the access token to the authz-info resource, i.e. the authz-info endpoint, on the resource server before starting the DTLS handshake, as described in Section 5.8.1 of [I-D.ietf-ace-oauth-authz]. In case the client uses a symmetric proof-of-possession key in the DTLS handshake, the procedure as above MAY be used, or alternatively, the access token MAY instead be transferred in the DTLS ClientKeyExchange message (see Section 3.3.2). In any case, DTLS MUST be used in a mode that provides replay protection.

Figure 2 depicts the common protocol flow for the DTLS profile after the client has retrieved the access token from the authorization server, AS.

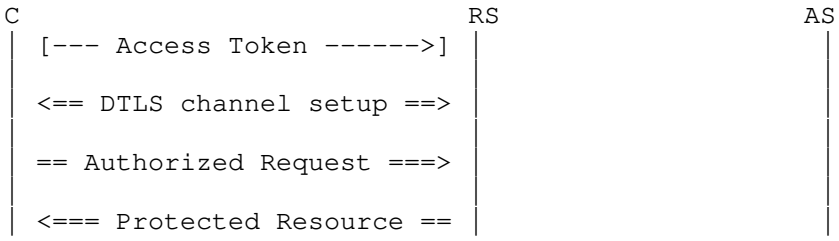

Figure 2: Protocol overview

3. Protocol Flow

The following sections specify how CoAP is used to interchange access-related data between the resource server, the client and the authorization server so that the authorization server can provide the client and the resource server with sufficient information to establish a secure channel, and convey authorization information specific for this communication relationship to the resource server.

Section 3.1 describes how the communication between the client (C) and the authorization server (AS) must be secured. Depending on the used CoAP security mode (see also Section 9 of [RFC7252], the Client-to-AS request, AS-to-Client response (see Section 5.6 of [I-D.ietf-ace-oauth-authz]) and DTLS session establishment carry slightly different information. Section 3.2 addresses the use of raw public keys while Section 3.3 defines how pre-shared keys are used in this profile.

3.1. Communication Between the Client and the Authorization Server

To retrieve an access token for the resource that the client wants to access, the client requests an access token from the authorization server. Before the client can request the access token, the client and the authorization server MUST establish a secure communication channel. This profile assumes that the keying material to secure this communication channel has securely been obtained either by manual configuration or in an automated provisioning process. The following requirements in alignment with Section 6.5 of [I-D.ietf-ace-oauth-authz] therefore must be met:

- The client MUST securely have obtained keying material to communicate with the authorization server.

- Furthermore, the client MUST verify that the authorization server is authorized to provide access tokens (including authorization information) about the resource server to the client, and that this authorization information about the authorization server is still valid.

- Also, the authorization server MUST securely have obtained keying material for the client, and obtained authorization rules approved by the resource owner (RO) concerning the client and the resource server that relate to this keying material.

The client and the authorization server MUST use their respective keying material for all exchanged messages. How the security association between the client and the authorization server is bootstrapped is not part of this document. The client and the authorization server must ensure the confidentiality, integrity and authenticity of all exchanged messages within the ACE protocol.

Section 6 specifies how communication with the authorization server is secured.

3.2. RawPublicKey Mode

When the client uses RawPublicKey authentication, the procedure is as described in the following.

3.2.1. Access Token Retrieval from the Authorization Server

After the client and the authorization server mutually authenticated each other and validated each other's authorization, the client sends a token request to the authorization server's token endpoint. The client MUST add a "req_cnf" object carrying either its raw public key or a unique identifier for a public key that it has previously made known to the authorization server. It is RECOMMENDED that the client uses DTLS with the same keying material to secure the communication with the authorization server, proving possession of the key as part of the token request. Other mechanisms for proving possession of the key may be defined in the future.

An example access token request from the client to the authorization server is depicted in Figure 3.

```
POST coaps://as.example.com/token
Content-Format: application/ace+cbor
Payload:
{
  grant_type : client_credentials,
  req_aud    : "tempSensor4711",
  req_cnf    : {
    COSE_Key : {
      kty : EC2,
      crv : P-256,
      x   : h'e866c35f4c3c81bb96a1...',
      y   : h'2e25556be097c8778a20...'
    }
  }
}
```

Figure 3: Access Token Request Example for RPK Mode

The example shows an access token request for the resource identified by the string "tempSensor4711" on the authorization server using a raw public key.

The authorization server MUST check if the client that it communicates with is associated with the RPK in the "req_cnf" parameter before issuing an access token to it. If the authorization server determines that the request is to be authorized according to the respective authorization rules, it generates an access token

response for the client. The access token MUST be bound to the RPK of the client by means of the "cnf" claim.

The response MAY contain a "profile" parameter with the value "coap_dtls" to indicate that this profile MUST be used for communication between the client and the resource server. The "profile" may be specified out-of-band, in which case it does not have to be sent. The response also contains an access token with information for the resource server about the client's public key. The authorization server MUST return in its response the parameter "rs_cnf" unless it is certain that the client already knows the public key of the resource server. The authorization server MUST ascertain that the RPK specified in "rs_cnf" belongs to the resource server that the client wants to communicate with. The authorization server MUST protect the integrity of the access token such that the resource server can detect unauthorized changes. If the access token contains confidential data, the authorization server MUST also protect the confidentiality of the access token.

The client MUST ascertain that the access token response belongs to a certain previously sent access token request, as the request may specify the resource server with which the client wants to communicate.

An example access token response from the authorization server to the client is depicted in Figure 4. Here, the contents of the "access_token" claim have been truncated to improve readability. Caching proxies process the Max-Age option in the CoAP response which has a default value of 60 seconds (Section 5.6.1 of [RFC7252]). The authorization server SHOULD adjust the Max-Age option such that it does not exceed the "expires_in" parameter to avoid stale responses.

```
2.01 Created
Content-Format: application/ace+cbor
Max-Age: 3560
Payload:
{
  access_token : b64'SlAV32hkKG...
   (remainder of CWT omitted for brevity;
   CWT contains the client's RPK in the cnf claim)',
  expires_in : 3600,
  rs_cnf     : {
    COSE_Key : {
      kty : EC2,
      crv : P-256,
      x   : h'd7cc072de2205bdc1537...',
      y   : h'f95e1d4b851a2cc80fff...'
    }
  }
}
```

Figure 4: Access Token Response Example for RPK Mode

3.2.2. DTLS Channel Setup Between Client and Resource Server

Before the client initiates the DTLS handshake with the resource server, the client MUST send a "POST" request containing the obtained access token to the authz-info resource hosted by the resource server. After the client receives a confirmation that the resource server has accepted the access token, it SHOULD proceed to establish a new DTLS channel with the resource server. The client MUST use its correct public key in the DTLS handshake. If the authorization server has specified a "cnf" field in the access token response, the client MUST use this key. Otherwise, the client MUST use the public key that it specified in the "req_cnf" of the access token request. The client MUST specify this public key in the SubjectPublicKeyInfo structure of the DTLS handshake as described in [RFC7250].

To be consistent with [RFC7252] which allows for shortened MAC tags in constrained environments, an implementation that supports the RPK mode of this profile MUST at least support the ciphersuite TLS_ECDHE_ECDSA_WITH_AES_128_CCM_8 [RFC7251]. As discussed in [RFC7748], new ECC curves have been defined recently that are considered superior to the so-called NIST curves. This specification therefore mandates implementation support for curve25519 (cf. [RFC8032], [RFC8422]) as this curve said to be efficient and less dangerous regarding implementation errors than the secp256r1 curve mandated in [RFC7252].

The resource server MUST check if the access token is still valid, if the resource server is the intended destination (i.e., the audience) of the token, and if the token was issued by an authorized authorization server. The access token is constructed by the authorization server such that the resource server can associate the access token with the Client's public key. The "cnf" claim MUST contain either the client's RPK or, if the key is already known by the resource server (e.g., from previous communication), a reference to this key. If the authorization server has no certain knowledge that the Client's key is already known to the resource server, the Client's public key MUST be included in the access token's "cnf" parameter. If CBOR web tokens [RFC8392] are used (as recommended in [I-D.ietf-ace-oauth-authz]), keys MUST be encoded as specified in [RFC8747]. A resource server MUST have the capacity to store one access token for every proof-of-possession key of every authorized client.

The raw public key used in the DTLS handshake with the client MUST belong to the resource server. If the resource server has several raw public keys, it needs to determine which key to use. The authorization server can help with this decision by including a "cnf" parameter in the access token that is associated with this communication. In this case, the resource server MUST use the information from the "cnf" field to select the proper keying material.

Thus, the handshake only finishes if the client and the resource server are able to use their respective keying material.

3.3. PreSharedKey Mode

When the client uses pre-shared key authentication, the procedure is as described in the following.

3.3.1. Access Token Retrieval from the Authorization Server

To retrieve an access token for the resource that the client wants to access, the client MAY include a "cnf" object carrying an identifier for a symmetric key in its access token request to the authorization server. This identifier can be used by the authorization server to determine the shared secret to construct the proof-of-possession token. The authorization server MUST check if the identifier refers to a symmetric key that was previously generated by the authorization server as a shared secret for the communication between this client and the resource server. If no such symmetric key was found, the authorization server MUST generate a new symmetric key that is returned in its response to the client.

The authorization server MUST determine the authorization rules for the client it communicates with as defined by the resource owner and generate the access token accordingly. If the authorization server authorizes the client, it returns an AS-to-Client response. If the profile parameter is present, it is set to "coap_dtls". The authorization server MUST ascertain that the access token is generated for the resource server that the client wants to communicate with. Also, the authorization server MUST protect the integrity of the access token to ensure that the resource server can detect unauthorized changes. If the token contains confidential data such as the symmetric key, the confidentiality of the token MUST also be protected. Depending on the requested token type and algorithm in the access token request, the authorization server adds access Information to the response that provides the client with sufficient information to setup a DTLS channel with the resource server. The authorization server adds a "cnf" parameter to the access information carrying a "COSE_Key" object that informs the client about the shared secret that is to be used between the client and the resource server. To convey the same secret to the resource server, the authorization server can include it directly in the access token by means of the "cnf" claim or provide sufficient information to enable the resource server to derive the shared secret from the access token. As an alternative, the resource server MAY use token introspection to retrieve the keying material for this access token directly from the authorization server.

An example access token request for an access token with a symmetric proof-of-possession key is illustrated in Figure 5.

```
POST coaps://as.example.com/token
Content-Format: application/ace+cbor
Payload:
{
  audience    : "smokeSensor1807",
}
```

Figure 5: Example Access Token Request, (implicit) symmetric PoP-key

A corresponding example access token response is illustrated in Figure 6. In this example, the authorization server returns a 2.01 response containing a new access token (truncated to improve readability) and information for the client, including the symmetric key in the cnf claim. The information is transferred as a CBOR data structure as specified in [I-D.ietf-ace-oauth-authz].

```
2.01 Created
Content-Format: application/ace+cbor
Max-Age: 85800
Payload:
{
   access_token : h'd08343a10...
   (remainder of CWT omitted for brevity)
   token_type : PoP,
   expires_in : 86400,
   profile    : coap_dtls,
   cnf        : {
     COSE_Key : {
       kty : symmetric,
       kid : h'3d027833fc6267ce',
       k   : h'73657373696f6e6b6579'
     }
   }
}
```

Figure 6: Example Access Token Response, symmetric PoP-key

The access token also comprises a "cnf" claim. This claim usually contains a "COSE_Key" object that carries either the symmetric key itself or a key identifier that can be used by the resource server to determine the secret key it shares with the client. If the access token carries a symmetric key, the access token MUST be encrypted using a "COSE_Encrypt0" structure. The authorization server MUST use the keying material shared with the resource server to encrypt the token.

The "cnf" structure in the access token is provided in Figure 7.

```
cnf : {
  COSE_Key : {
    kty : symmetric,
    kid : h'3d027833fc6267ce'
  }
}
```

Figure 7: Access Token without Keying Material

A response that declines any operation on the requested resource is constructed according to Section 5.2 of [RFC6749], (cf. Section 5.6.3. of [I-D.ietf-ace-oauth-authz]). Figure 8 shows an example for a request that has been rejected due to invalid request parameters.

```
4.00 Bad Request
Content-Format: application/ace+cbor
Payload:
{
  error : invalid_request
}
```

Figure 8: Example Access Token Response With Reject

The method for how the resource server determines the symmetric key from an access token containing only a key identifier is application-specific; the remainder of this section provides one example.

The authorization server and the resource server are assumed to share a key derivation key used to derive the symmetric key shared with the client from the key identifier in the access token. The key derivation key may be derived from some other secret key shared between the authorization server and the resource server. This key needs to be securely stored and processed in the same way as the key used to protect the communication between the authorization server and the resource server.

Knowledge of the symmetric key shared with the client must not reveal any information about the key derivation key or other secret keys shared between the authorization server and resource server.

In order to generate a new symmetric key to be used by client and resource server, the authorization server generates a new key identifier which MUST be unique among all key identifiers used by the authorization server for this resource server. The authorization server then uses the key derivation key shared with the resource server to derive the symmetric key as specified below. Instead of providing the keying material in the access token, the authorization server includes the key identifier in the "kid" parameter, see Figure 7. This key identifier enables the resource server to calculate the symmetric key used for the communication with the client using the key derivation key and a KDF to be defined by the application, for example HKDF-SHA-256. The key identifier picked by the authorization server MUST be unique for each access token where a unique symmetric key is required.

In this example, HKDF consists of the composition of the HKDF-Extract and HKDF-Expand steps [RFC5869]. The symmetric key is derived from the key identifier, the key derivation key and other data:

OKM = HKDF(salt, IKM, info, L),

where:

- OKM, the output keying material, is the derived symmetric key
- salt is the empty byte string
- IKM, the input keying material, is the key derivation key as defined above
- info is the serialization of a CBOR array consisting of ([RFC8610]):

```
info = [
  type : tstr,
  L : uint,
  access_token: bytes
]
```

where:

- type is set to the constant text string "ACE-CoAP-DTLS-key-derivation",
- L is the size of the symmetric key in bytes,
- access_token is the content of the "access_token" field as transferred from the authorization server to the resource server.

All CBOR data types are encoded in CBOR using preferred serialization and deterministic encoding as specified in Section 4 of [I-D.ietf-cbor-7049bis]. This implies in particular that the "type" and "L" components use the minimum length encoding. The content of the "access_token" field is treated as opaque data for the purpose of key derivation.

Use of a unique (per resource server) "kid" and the use of a key derivation IKM that MUST be unique per authorization server/resource server pair as specified above will ensure that the derived key is not shared across multiple clients. However, to additionally provide variation in the derived key across different tokens used by the same client, it is additionally RECOMMENDED to include the "iat" claim and either the "exp" or "exi" claims in the access token.

3.3.2. DTLS Channel Setup Between Client and Resource Server

When a client receives an access token response from an authorization server, the client MUST check if the access token response is bound to a certain previously sent access token request, as the request may specify the resource server with which the client wants to communicate.

The client checks if the payload of the access token response contains an "access_token" parameter and a "cnf" parameter. With this information the client can initiate the establishment of a new DTLS channel with a resource server. To use DTLS with pre-shared keys, the client follows the PSK key exchange algorithm specified in Section 2 of [RFC4279] using the key conveyed in the "cnf" parameter of the AS response as PSK when constructing the premaster secret. To be consistent with the recommendations in [RFC7252] a client is expected to offer at least the ciphersuite TLS_PSK_WITH_AES_128_CCM_8 [RFC6655] to the resource server.

In PreSharedKey mode, the knowledge of the shared secret by the client and the resource server is used for mutual authentication between both peers. Therefore, the resource server must be able to determine the shared secret from the access token. Following the general ACE authorization framework, the client can upload the access token to the resource server's authz-info resource before starting the DTLS handshake. The client then needs to indicate during the DTLS handshake which previously uploaded access token it intends to use. To do so, it MUST create a "COSE_Key" structure with the "kid" that was conveyed in the "rs_cnf" claim in the token response from the authorization server and the key type "symmetric". This structure then is included as the only element in the "cnf" structure that is used as value for "psk_identity" as shown in Figure 9.

```
{ cnf : {
   COSE_Key : {
      kty: symmetric,
      kid : h'3d027833fc6267ce'
    }
  }
}
```

Figure 9: Access token containing a single kid parameter

As an alternative to the access token upload, the client can provide the most recent access token in the "psk_identity" field of the ClientKeyExchange message. To do so, the client MUST treat the contents of the "access_token" field from the AS-to-Client response as opaque data as specified in Section 4.2 of [RFC7925] and not perform any re-coding. This allows the resource server to retrieve the shared secret directly from the "cnf" claim of the access token.

If a resource server receives a ClientKeyExchange message that contains a "psk_identity" with a length greater than zero, it MUST parse the contents of the "psk_identity" field as CBOR data structure and process the contents as following:

- If the data contains a "cnf" field with a "COSE_Key" structure with a "kid", the resource server continues the DTLS handshake with the associated key that corresponds to this kid.

- If the data comprises additional CWT information, this information must be stored as an access token for this DTLS association before continuing with the DTLS handshake.

If the contents of the "psk_identity" do not yield sufficient information to select a valid access token for the requesting client, the resource server aborts the DTLS handshake with an "illegal_parameter" alert.

When the resource server receives an access token, it MUST check if the access token is still valid, if the resource server is the intended destination (i.e., the audience of the token), and if the token was issued by an authorized authorization server. This specification implements access tokens as proof-of-possession tokens. Therefore, the access token is bound to a symmetric PoP key that is used as shared secret between the client and the resource server. A resource server MUST have the capacity to store one access token for every proof-of-possession key of every authorized client. The resource server may use token introspection [RFC7662] on the access token to retrieve more information about the specific token. The use of introspection is out of scope for this specification.

While the client can retrieve the shared secret from the contents of the "cnf" parameter in the AS-to-Client response, the resource server uses the information contained in the "cnf" claim of the access token to determine the actual secret when no explicit "kid" was provided in the "psk_identity" field. If key derivation is used, the resource server uses the "COSE_KDF_Context" information as described above.

3.4. Resource Access

Once a DTLS channel has been established as described in Section 3.2 or Section 3.3, respectively, the client is authorized to access resources covered by the access token it has uploaded to the authz-info resource hosted by the resource server.

With the successful establishment of the DTLS channel, the client and the resource server have proven that they can use their respective keying material. An access token that is bound to the client's keying material is associated with the channel. According to Section 5.8.1 of [I-D.ietf-ace-oauth-authz], there should be only one access token for each client. New access tokens issued by the authorization server SHOULD replace previously issued access tokens for the respective client. The resource server therefore needs a

common understanding with the authorization server how access tokens are ordered. The authorization server may, e.g., specify a "cti" claim for the access token (see Section 5.8.3 of [I-D.ietf-ace-oauth-authz]) to employ a strict order.

Any request that the resource server receives on a DTLS channel that is tied to an access token via its keying material MUST be checked against the authorization rules that can be determined with the access token. The resource server MUST check for every request if the access token is still valid. If the token has expired, the resource server MUST remove it. Incoming CoAP requests that are not authorized with respect to any access token that is associated with the client MUST be rejected by the resource server with 4.01 response. The response SHOULD include AS Request Creation Hints as described in Section 5.1.1 of [I-D.ietf-ace-oauth-authz].

The resource server MUST only accept an incoming CoAP request as authorized if the following holds:

1. The message was received on a secure channel that has been established using the procedure defined in this document.

2. The authorization information tied to the sending client is valid.

3. The request is destined for the resource server.

4. The resource URI specified in the request is covered by the authorization information.

5. The request method is an authorized action on the resource with respect to the authorization information.

Incoming CoAP requests received on a secure DTLS channel that are not thus authorized MUST be rejected according to Section 5.8.2 of [I-D.ietf-ace-oauth-authz]

1. with response code 4.03 (Forbidden) when the resource URI specified in the request is not covered by the authorization information, and

2. with response code 4.05 (Method Not Allowed) when the resource URI specified in the request covered by the authorization information but not the requested action.

The client MUST ascertain that its keying material is still valid before sending a request or processing a response. If the client recently has updated the access token (see Section 4), it must be

prepared that its request is still handled according to the previous authorization rules as there is no strict ordering between access token uploads and resource access messages. See also Section 7.2 for a discussion of access token processing.

If the client gets an error response containing AS Request Creation Hints (cf. Section 5.1.2 of [I-D.ietf-ace-oauth-authz] as response to its requests, it SHOULD request a new access token from the authorization server in order to continue communication with the resource server.

Unauthorized requests that have been received over a DTLS session SHOULD be treated as non-fatal by the resource server, i.e., the DTLS session SHOULD be kept alive until the associated access token has expired.

4. Dynamic Update of Authorization Information

Resource servers must only use a new access token to update the authorization information for a DTLS session if the keying material that is bound to the token is the same that was used in the DTLS handshake. By associating the access tokens with the identifier of an existing DTLS session, the authorization information can be updated without changing the cryptographic keys for the DTLS communication between the client and the resource server, i.e. an existing session can be used with updated permissions.

The client can therefore update the authorization information stored at the resource server at any time without changing an established DTLS session. To do so, the client requests a new access token from the authorization server for the intended action on the respective resource and uploads this access token to the authz-info resource on the resource server.

Figure 10 depicts the message flow where the client requests a new access token after a security association between the client and the resource server has been established using this protocol. If the client wants to update the authorization information, the token request MUST specify the key identifier of the proof-of-possession key used for the existing DTLS channel between the client and the resource server in the "kid" parameter of the Client-to-AS request. The authorization server MUST verify that the specified "kid" denotes a valid verifier for a proof-of-possession token that has previously been issued to the requesting client. Otherwise, the Client-to-AS request MUST be declined with the error code "unsupported_pop_key" as defined in Section 5.6.3 of [I-D.ietf-ace-oauth-authz].

When the authorization server issues a new access token to update existing authorization information, it MUST include the specified "kid" parameter in this access token. A resource server MUST replace the authorization information of any existing DTLS session that is identified by this key identifier with the updated authorization information.

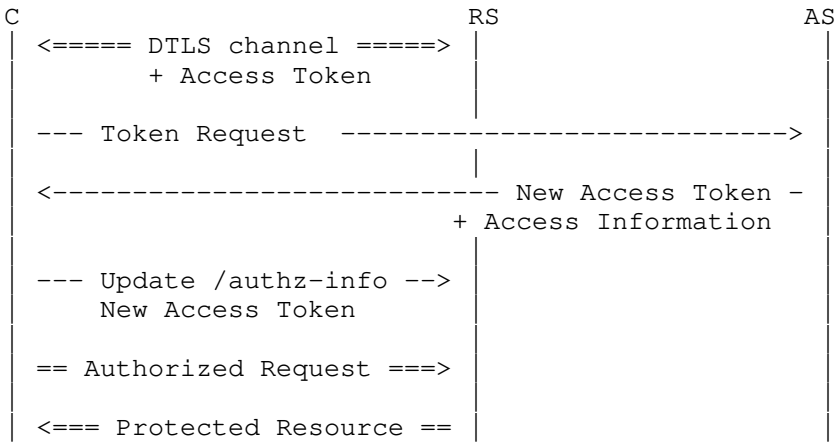

Figure 10: Overview of Dynamic Update Operation

5. Token Expiration

The resource server MUST delete access tokens that are no longer valid. DTLS associations that have been setup in accordance with this profile are always tied to specific tokens (which may be exchanged with a dynamic update as described in Section 4). As tokens may become invalid at any time (e.g., because they have expired), the association may become useless at some point. A resource server therefore MUST terminate existing DTLS association after the last access token associated with this association has expired.

As specified in Section 5.8.3 of [I-D.ietf-ace-oauth-authz], the resource server MUST notify the client with an error response with code 4.01 (Unauthorized) for any long running request before terminating the association.

6. Secure Communication with an Authorization Server

As specified in the ACE framework (Sections 5.6 and 5.7 of [I-D.ietf-ace-oauth-authz]), the requesting entity (the resource server and/or the client) and the authorization server communicate

via the token endpoint or introspection endpoint. The use of CoAP and DTLS for this communication is RECOMMENDED in this profile, other protocols (such as HTTP and TLS, or CoAP and OSCORE [RFC8613]) MAY be used instead.

How credentials (e.g., PSK, RPK, X.509 cert) for using DTLS with the authorization server are established is out of scope for this profile.

If other means of securing the communication with the authorization server are used, the communication security requirements from Section 6.2 of [I-D.ietf-ace-oauth-authz] remain applicable.

7. Security Considerations

This document specifies a profile for the Authentication and Authorization for Constrained Environments (ACE) framework [I-D.ietf-ace-oauth-authz]. As it follows this framework's general approach, the general security considerations from Section 6 of [I-D.ietf-ace-oauth-authz] also apply to this profile.

The authorization server must ascertain that the keying material for the client that it provides to the resource server actually is associated with this client. Malicious clients may hand over access tokens containing their own access permissions to other entities. This problem cannot be completely eliminated. Nevertheless, in RPK mode it should not be possible for clients to request access tokens for arbitrary public keys: if the client can cause the authorization server to issue a token for a public key without proving possession of the corresponding private key, this allows for identity misbinding attacks where the issued token is usable by an entity other than the intended one. The authorization server therefore at some point needs to validate that the client can actually use the private key corresponding to the client's public key.

When using pre-shared keys provisioned by the authorization server, the security level depends on the randomness of PSK, and the security of the TLS cipher suite and key exchange algorithm. As this specification targets at constrained environments, message payloads exchanged between the client and the resource server are expected to be small and rare. CoAP [RFC7252] mandates the implementation of cipher suites with abbreviated, 8-byte tags for message integrity protection. For consistency, this profile requires implementation of the same cipher suites. For application scenarios where the cost of full-width authentication tags is low compared to the overall amount of data being transmitted, the use of cipher suites with 16-byte integrity protection tags is preferred.

The PSK mode of this profile offers a distribution mechanism to convey authorization tokens together with a shared secret to a client and a server. As this specification aims at constrained devices and uses CoAP [RFC7252] as transfer protocol, at least the ciphersuite TLS_PSK_WITH_AES_128_CCM_8 [RFC6655] should be supported. The access tokens and the corresponding shared secrets generated by the authorization server are expected to be sufficiently short-lived to provide similar forward-secrecy properties to using ephemeral Diffie-Hellman (DHE) key exchange mechanisms. For longer-lived access tokens, DHE ciphersuites should be used.

Constrained devices that use DTLS [RFC6347] are inherently vulnerable to Denial of Service (DoS) attacks as the handshake protocol requires creation of internal state within the device. This is specifically of concern where an adversary is able to intercept the initial cookie exchange and interject forged messages with a valid cookie to continue with the handshake. A similar issue exists with the unprotected authorization information endpoint when the resource server needs to keep valid access tokens for a long time. Adversaries could fill up the constrained resource server's internal storage for a very long time with interjected or otherwise retrieved valid access tokens. To mitigate against this, the resource server should set a time boundary until an access token that has not been used until then will be deleted.

The protection of access tokens that are stored in the authorization information endpoint depends on the keying material that is used between the authorization server and the resource server: The resource server must ensure that it processes only access tokens that are (encrypted and) integrity-protected by an authorization server that is authorized to provide access tokens for the resource server.

7.1. Reuse of Existing Sessions

To avoid the overhead of a repeated DTLS handshake, [RFC7925] recommends session resumption [RFC5077] to reuse session state from an earlier DTLS association and thus requires client side implementation. In this specification, the DTLS session is subject to the authorization rules denoted by the access token that was used for the initial setup of the DTLS association. Enabling session resumption would require the server to transfer the authorization information with the session state in an encrypted SessionTicket to the client. Assuming that the server uses long-lived keying material, this could open up attacks due to the lack of forward secrecy. Moreover, using this mechanism, a client can resume a DTLS session without proving the possession of the PoP key again. Therefore, the use of session resumption is NOT RECOMMENDED for resource servers.

Since renegotiation of DTLS associations is prone to attacks as well, [RFC7925] requires clients to decline any renogiation attempt. A server that wants to initiate re-keying therefore SHOULD periodically force a full handshake.

7.2. Multiple Access Tokens

The use of multiple access tokens for a single client increases the strain on the resource server as it must consider every access token and calculate the actual permissions of the client. Also, tokens may contradict each other which may lead the server to enforce wrong permissions. If one of the access tokens expires earlier than others, the resulting permissions may offer insufficient protection. Developers SHOULD avoid using multiple access tokens for a client.

Even when a single access token per client is used, an attacker could compromise the dynamic update mechanism for existing DTLS connections by delaying or reordering packets destined for the authz-info endpoint. Thus, the order in which operations occur at the resource server (and thus which authorization info is used to process a given client request) cannot be guaranteed. Especially in the presence of later-issued access tokens that reduce the client's permissions from the initial access token, it is impossible to guarantee that the reduction in authorization will take effect prior to the expiration of the original token.

7.3. Out-of-Band Configuration

To communicate securely, the authorization server, the client and the resource server require certain information that must be exchanged outside the protocol flow described in this document. The authorization server must have obtained authorization information concerning the client and the resource server that is approved by the resource owner as well as corresponding keying material. The resource server must have received authorization information approved by the resource owner concerning its authorization managers and the respective keying material. The client must have obtained authorization information concerning the authorization server approved by its owner as well as the corresponding keying material. Also, the client's owner must have approved of the client's communication with the resource server. The client and the authorization server must have obtained a common understanding how this resource server is identified to ensure that the client obtains access token and keying material for the correct resource server. If the client is provided with a raw public key for the resource server, it must be ascertained to which resource server (which identifier and authorization information) the key is associated. All authorization information and keying material must be kept up to date.

8. Privacy Considerations

This privacy considerations from Section 7 of the [I-D.ietf-ace-oauth-authz] apply also to this profile.

An unprotected response to an unauthorized request may disclose information about the resource server and/or its existing relationship with the client. It is advisable to include as little information as possible in an unencrypted response. When a DTLS session between an authenticated client and the resource server already exists, more detailed information MAY be included with an error response to provide the client with sufficient information to react on that particular error.

Also, unprotected requests to the resource server may reveal information about the client, e.g., which resources the client attempts to request or the data that the client wants to provide to the resource server. The client SHOULD NOT send confidential data in an unprotected request.

Note that some information might still leak after DTLS session is established, due to observable message sizes, the source, and the destination addresses.

9. IANA Considerations

The following registrations are done for the ACE OAuth Profile Registry following the procedure specified in [I-D.ietf-ace-oauth-authz].

Note to RFC Editor: Please replace all occurrences of "[RFC-XXXX]" with the RFC number of this specification and delete this paragraph.

Profile name: coap_dtls

Profile Description: Profile for delegating client authentication and authorization in a constrained environment by establishing a Datagram Transport Layer Security (DTLS) channel between resource-constrained nodes.

Profile ID: TBD (suggested: 1)

Change Controller: IESG

Reference: [RFC-XXXX]

10. Acknowledgments

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Authors' Addresses

Stefanie Gerdes
Universitaet Bremen TZI
Postfach 330440
Bremen D-28359
Germany

Phone: +49-421-218-63906
Email: gerdes@tzi.org

Olaf Bergmann
Universitaet Bremen TZI
Postfach 330440
Bremen D-28359
Germany

Phone: +49-421-218-63904
Email: bergmann@tzi.org

Carsten Bormann
Universitaet Bremen TZI
Postfach 330440
Bremen D-28359
Germany

Phone: +49-421-218-63921
Email: cabo@tzi.org

Goeran Selander
Ericsson AB

Email: goran.selander@ericsson.com

Ludwig Seitz
Combitech
Djaeknegatan 31
Malmoe 211 35
Sweden

Email: ludwig.seitz@combitech.se

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L. Seitz
Combitech
G. Selander
Ericsson
E. Wahlstroem

S. Erdtman
Spotify AB
H. Tschofenig
Arm Ltd.

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Authentication and Authorization for Constrained Environments (ACE) using the OAuth 2.0 Framework (ACE-OAuth) draft-ietf-ace-oauth-authz-36

Abstract

This specification defines a framework for authentication and authorization in Internet of Things (IoT) environments called ACE-OAuth. The framework is based on a set of building blocks including OAuth 2.0 and the Constrained Application Protocol (CoAP), thus transforming a well-known and widely used authorization solution into a form suitable for IoT devices. Existing specifications are used where possible, but extensions are added and profiles are defined to better serve the IoT use cases.

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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This Internet-Draft will expire on May 21, 2021.

Table of Contents

1. Introduction

Authorization is the process for granting approval to an entity to access a generic resource [RFC4949]. The authorization task itself can best be described as granting access to a requesting client, for a resource hosted on a device, the resource server (RS). This exchange is mediated by one or multiple authorization servers (AS). Managing authorization for a large number of devices and users can be a complex task.

While prior work on authorization solutions for the Web and for the mobile environment also applies to the Internet of Things (IoT) environment, many IoT devices are constrained, for example, in terms of processing capabilities, available memory, etc. For web applications on constrained nodes, this specification RECOMMENDS the use of the Constrained Application Protocol (CoAP) [RFC7252] as replacement for HTTP.

Appendix A gives an overview of the constraints considered in this design, and a more detailed treatment of constraints can be found in [RFC7228]. This design aims to accommodate different IoT deployments and thus a continuous range of device and network capabilities.

Taking energy consumption as an example: At one end there are energy-harvesting or battery powered devices which have a tight power budget, on the other end there are mains-powered devices, and all levels in between.

Hence, IoT devices may be very different in terms of available processing and message exchange capabilities and there is a need to support many different authorization use cases [RFC7744].

This specification describes a framework for authentication and authorization in constrained environments (ACE) built on re-use of OAuth 2.0 [RFC6749], thereby extending authorization to Internet of Things devices. This specification contains the necessary building blocks for adjusting OAuth 2.0 to IoT environments.

More detailed, interoperable specifications can be found in separate profile specifications. Implementations may claim conformance with a specific profile, whereby implementations utilizing the same profile interoperate while implementations of different profiles are not expected to be interoperable. Some devices, such as mobile phones and tablets, may implement multiple profiles and will therefore be able to interact with a wider range of low end devices. Requirements on profiles are described at contextually appropriate places throughout this specification, and also summarized in Appendix C.

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.

Certain security-related terms such as "authentication", "authorization", "confidentiality", "(data) integrity", "message authentication code", and "verify" are taken from [RFC4949].

Since exchanges in this specification are described as RESTful protocol interactions, HTTP [RFC7231] offers useful terminology.

Terminology for entities in the architecture is defined in OAuth 2.0 [RFC6749] such as client (C), resource server (RS), and authorization server (AS).

Note that the term "endpoint" is used here following its OAuth definition, which is to denote resources such as token and introspection at the AS and authz-info at the RS (see Section 5.10.1 for a definition of the authz-info endpoint). The CoAP [RFC7252]

definition, which is "An entity participating in the CoAP protocol" is not used in this specification.

The specifications in this document is called the "framework" or "ACE framework". When referring to "profiles of this framework" it refers to additional specifications that define the use of this specification with concrete transport and communication security protocols (e.g., CoAP over DTLS).

We use the term "Access Information" for parameters other than the access token provided to the client by the AS to enable it to access the RS (e.g. public key of the RS, profile supported by RS).

We use the term "Authorization Information" to denote all information, including the claims of relevant access tokens, that an RS uses to determine whether an access request should be granted.

3. Overview

This specification defines the ACE framework for authorization in the Internet of Things environment. It consists of a set of building blocks.

The basic block is the OAuth 2.0 [RFC6749] framework, which enjoys widespread deployment. Many IoT devices can support OAuth 2.0 without any additional extensions, but for certain constrained settings additional profiling is needed.

Another building block is the lightweight web transfer protocol CoAP [RFC7252], for those communication environments where HTTP is not appropriate. CoAP typically runs on top of UDP, which further reduces overhead and message exchanges. While this specification defines extensions for the use of OAuth over CoAP, other underlying protocols are not prohibited from being supported in the future, such as HTTP/2 [RFC7540], Message Queuing Telemetry Transport (MQTT) [MQTT5.0], Bluetooth Low Energy (BLE) [BLE] and QUIC [I-D.ietf-quic-transport]. Note that this document specifies protocol exchanges in terms of RESTful verbs such as GET and POST. Future profiles using protocols that do not support these verbs MUST specify how the corresponding protocol messages are transmitted instead.

A third building block is the Concise Binary Object Representation (CBOR) [RFC7049], for encodings where JSON [RFC8259] is not sufficiently compact. CBOR is a binary encoding designed for small code and message size, which may be used for encoding of self contained tokens, and also for encoding payloads transferred in protocol messages.

A fourth building block is CBOR Object Signing and Encryption (COSE) [RFC8152], which enables object-level layer security as an alternative or complement to transport layer security (DTLS [RFC6347] or TLS [RFC8446]). COSE is used to secure self-contained tokens such as proof-of-possession (PoP) tokens, which are an extension to the OAuth bearer tokens. The default token format is defined in CBOR web token (CWT) [RFC8392]. Application layer security for CoAP using COSE can be provided with OSCORE [RFC8613].

With the building blocks listed above, solutions satisfying various IoT device and network constraints are possible. A list of constraints is described in detail in [RFC7228] and a description of how the building blocks mentioned above relate to the various constraints can be found in Appendix A.

Luckily, not every IoT device suffers from all constraints. The ACE framework nevertheless takes all these aspects into account and allows several different deployment variants to co-exist, rather than mandating a one-size-fits-all solution. It is important to cover the wide range of possible interworking use cases and the different requirements from a security point of view. Once IoT deployments mature, popular deployment variants will be documented in the form of ACE profiles.

3.1. OAuth 2.0

The OAuth 2.0 authorization framework enables a client to obtain scoped access to a resource with the permission of a resource owner. Authorization information, or references to it, is passed between the nodes using access tokens. These access tokens are issued to clients by an authorization server with the approval of the resource owner. The client uses the access token to access the protected resources hosted by the resource server.

A number of OAuth 2.0 terms are used within this specification:

The token and introspection Endpoints:
: The AS hosts the token endpoint that allows a client to request access tokens. The client makes a POST request to the token endpoint on the AS and receives the access token in the response (if the request was successful).
: In some deployments, a token introspection endpoint is provided by the AS, which can be used by the RS if it needs to request additional information regarding a received access token. The RS makes a POST request to the introspection endpoint on the AS and receives information about the access token in the response. (See "Introspection" below.)

Access Tokens:
: Access tokens are credentials needed to access protected resources. An access token is a data structure representing authorization permissions issued by the AS to the client. Access tokens are generated by the AS and consumed by the RS. The access token content is opaque to the client.

  Access tokens can have different formats, and various methods of utilization e.g., cryptographic properties) based on the security requirements of the given deployment.

Refresh Tokens:
: Refresh tokens are credentials used to obtain access tokens. Refresh tokens are issued to the client by the authorization server and are used to obtain a new access token when the current access token becomes invalid or expires, or to obtain additional access tokens with identical or narrower scope (such access tokens may have a shorter lifetime and fewer permissions than authorized by the resource owner). Issuing a refresh token is optional at the discretion of the authorization server. If the authorization server issues a refresh token, it is included when issuing an access token (i.e., step (B) in Figure 1).

  A refresh token in OAuth 2.0 is a string representing the authorization granted to the client by the resource owner. The string is usually opaque to the client. The token denotes an identifier used to retrieve the authorization information. Unlike access tokens, refresh tokens are intended for use only with authorization servers and are never sent to resource servers. In this framework, refresh tokens are encoded in binary instead of strings, if used.

Proof of Possession Tokens:
: A token may be bound to a cryptographic key, which is then used to bind the token to a request authorized by the token. Such tokens are called proof-of-possession tokens (or PoP tokens).

  The proof-of-possession (PoP) security concept used here assumes that the AS acts as a trusted third party that binds keys to tokens. In the case of access tokens, these so called PoP keys are then used by the client to demonstrate the possession of the secret to the RS when accessing the resource. The RS, when receiving an access token, needs to verify that the key used by the client matches the one bound to the access token. When this

specification uses the term "access token" it is assumed to be a PoP access token token unless specifically stated otherwise.

The key bound to the token (the PoP key) may use either symmetric or asymmetric cryptography. The appropriate choice of the kind of cryptography depends on the constraints of the IoT devices as well as on the security requirements of the use case.

Symmetric PoP key:
: The AS generates a random symmetric PoP key. The key is either stored to be returned on introspection calls or encrypted and included in the token. The PoP key is also encrypted for the token recipient and sent to the recipient together with the token.

Asymmetric PoP key:
: An asymmetric key pair is generated on the token's recipient and the public key is sent to the AS (if it does not already have knowledge of the recipient's public key). Information about the public key, which is the PoP key in this case, is either stored to be returned on introspection calls or included inside the token and sent back to the requesting party. The consumer of the token can identify the public key from the information in the token, which allows the recipient of the token to use the corresponding private key for the proof of possession.

The token is either a simple reference, or a structured information object (e.g., CWT [RFC8392]) protected by a cryptographic wrapper (e.g., COSE [RFC8152]). The choice of PoP key does not necessarily imply a specific credential type for the integrity protection of the token.

Scopes and Permissions:
: In OAuth 2.0, the client specifies the type of permissions it is seeking to obtain (via the scope parameter) in the access token request. In turn, the AS may use the scope response parameter to inform the client of the scope of the access token issued. As the client could be a constrained device as well, this specification defines the use of CBOR encoding, see Section 5, for such requests and responses.

The values of the scope parameter in OAuth 2.0 are expressed as a list of space-delimited, case-sensitive strings, with a semantic that is well-known to the AS and the RS. More details about the concept of scopes is found under Section 3.3 in [RFC6749].

Claims:
Information carried in the access token or returned from introspection, called claims, is in the form of name-value pairs. An access token may, for example, include a claim identifying the AS that issued the token (via the "iss" claim) and what audience the access token is intended for (via the "aud" claim). The audience of an access token can be a specific resource or one or many resource servers. The resource owner policies influence what claims are put into the access token by the authorization server.

While the structure and encoding of the access token varies throughout deployments, a standardized format has been defined with the JSON Web Token (JWT) [RFC7519] where claims are encoded as a JSON object. In [RFC8392], an equivalent format using CBOR encoding (CWT) has been defined.

Introspection:
Introspection is a method for a resource server to query the authorization server for the active state and content of a received access token. This is particularly useful in those cases where the authorization decisions are very dynamic and/or where the received access token itself is an opaque reference rather than a self-contained token. More information about introspection in OAuth 2.0 can be found in [RFC7662].

3.2. CoAP

CoAP is an application layer protocol similar to HTTP, but specifically designed for constrained environments. CoAP typically uses datagram-oriented transport, such as UDP, where reordering and loss of packets can occur. A security solution needs to take the latter aspects into account.

While HTTP uses headers and query strings to convey additional information about a request, CoAP encodes such information into header parameters called 'options'.

CoAP supports application-layer fragmentation of the CoAP payloads through blockwise transfers [RFC7959]. However, blockwise transfer

does not increase the size limits of CoAP options, therefore data encoded in options has to be kept small.

Transport layer security for CoAP can be provided by DTLS or TLS [RFC6347][RFC8446] [I-D.ietf-tls-dtls13]. CoAP defines a number of proxy operations that require transport layer security to be terminated at the proxy. One approach for protecting CoAP communication end-to-end through proxies, and also to support security for CoAP over a different transport in a uniform way, is to provide security at the application layer using an object-based security mechanism such as COSE [RFC8152].

One application of COSE is OSCORE [RFC8613], which provides end-to-end confidentiality, integrity and replay protection, and a secure binding between CoAP request and response messages. In OSCORE, the CoAP messages are wrapped in COSE objects and sent using CoAP.

This framework RECOMMENDS the use of CoAP as replacement for HTTP for use in constrained environments. For communication security this framework does not make an explicit protocol recommendation, since the choice depends on the requirements of the specific application. DTLS [RFC6347], [I-D.ietf-tls-dtls13] and OSCORE [RFC8613] are mentioned as examples, other protocols fulfilling the requirements from Section 6.5 are also applicable.

4. Protocol Interactions

The ACE framework is based on the OAuth 2.0 protocol interactions using the token endpoint and optionally the introspection endpoint. A client obtains an access token, and optionally a refresh token, from an AS using the token endpoint and subsequently presents the access token to an RS to gain access to a protected resource. In most deployments the RS can process the access token locally, however in some cases the RS may present it to the AS via the introspection endpoint to get fresh information. These interactions are shown in Figure 1. An overview of various OAuth concepts is provided in Section 3.1.

The OAuth 2.0 framework defines a number of "protocol flows" via grant types, which have been extended further with extensions to OAuth 2.0 (such as [RFC7521] and [RFC8628]). What grant types works best depends on the usage scenario and [RFC7744] describes many different IoT use cases but there are two preferred grant types, namely the Authorization Code Grant (described in Section 4.1 of [RFC7521]) and the Client Credentials Grant (described in Section 4.4 of [RFC7521]). The Authorization Code Grant is a good fit for use with apps running on smart phones and tablets that request access to IoT devices, a common scenario in the smart home environment, where

users need to go through an authentication and authorization phase (at least during the initial setup phase). The native apps guidelines described in [RFC8252] are applicable to this use case. The Client Credential Grant is a good fit for use with IoT devices where the OAuth client itself is constrained. In such a case, the resource owner has pre-arranged access rights for the client with the authorization server, which is often accomplished using a commissioning tool.

The consent of the resource owner, for giving a client access to a protected resource, can be provided dynamically as in the traditional OAuth flows, or it could be pre-configured by the resource owner as authorization policies at the AS, which the AS evaluates when a token request arrives. The resource owner and the requesting party (i.e., client owner) are not shown in Figure 1.

This framework supports a wide variety of communication security mechanisms between the ACE entities, such as client, AS, and RS. It is assumed that the client has been registered (also called enrolled or onboarded) to an AS using a mechanism defined outside the scope of this document. In practice, various techniques for onboarding have been used, such as factory-based provisioning or the use of commissioning tools. Regardless of the onboarding technique, this provisioning procedure implies that the client and the AS exchange credentials and configuration parameters. These credentials are used to mutually authenticate each other and to protect messages exchanged between the client and the AS.

It is also assumed that the RS has been registered with the AS, potentially in a similar way as the client has been registered with the AS. Established keying material between the AS and the RS allows the AS to apply cryptographic protection to the access token to ensure that its content cannot be modified, and if needed, that the content is confidentiality protected.

The keying material necessary for establishing communication security between C and RS is dynamically established as part of the protocol described in this document.

At the start of the protocol, there is an optional discovery step where the client discovers the resource server and the resources this server hosts. In this step, the client might also determine what permissions are needed to access the protected resource. A generic procedure is described in Section 5.1; profiles MAY define other procedures for discovery.

In Bluetooth Low Energy, for example, advertisements are broadcasted by a peripheral, including information about the primary services.

In CoAP, as a second example, a client can make a request to "/.well-known/core" to obtain information about available resources, which are returned in a standardized format as described in [RFC6690].

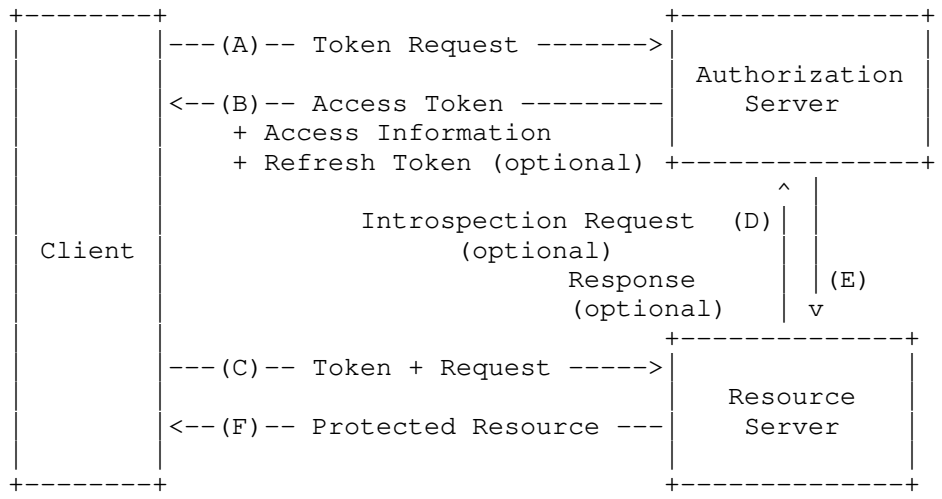

Figure 1: Basic Protocol Flow.

Requesting an Access Token (A):
The client makes an access token request to the token endpoint at the AS. This framework assumes the use of PoP access tokens (see Section 3.1 for a short description) wherein the AS binds a key to an access token. The client may include permissions it seeks to obtain, and information about the credentials it wants to use (e.g., symmetric/asymmetric cryptography or a reference to a specific credential).

Access Token Response (B):
If the AS successfully processes the request from the client, it returns an access token and optionally a refresh token (note that only certain grant types support refresh tokens). It can also return additional parameters, referred to as "Access Information". In addition to the response parameters defined by OAuth 2.0 and the PoP access token extension, this framework defines parameters that can be used to inform the client about capabilities of the RS, e.g. the profiles the RS supports. More information about these parameters can be found in Section 5.8.4.

Resource Request (C):
The client interacts with the RS to request access to the protected resource and provides the access token. The protocol to use between the client and the RS is not restricted to CoAP. HTTP, HTTP/2, QUIC, MQTT, Bluetooth Low Energy, etc., are also viable candidates.

Depending on the device limitations and the selected protocol, this exchange may be split up into two parts:

(1) the client sends the access token containing, or referencing, the authorization information to the RS, that may be used for subsequent resource requests by the client, and

(2) the client makes the resource access request, using the communication security protocol and other Access Information obtained from the AS.

The Client and the RS mutually authenticate using the security protocol specified in the profile (see step B) and the keys obtained in the access token or the Access Information. The RS verifies that the token is integrity protected and originated by the AS. It then compares the claims contained in the access token with the resource request. If the RS is online, validation can be handed over to the AS using token introspection (see messages D and E) over HTTP or CoAP.

Token Introspection Request (D):
A resource server may be configured to introspect the access token by including it in a request to the introspection endpoint at that AS. Token introspection over CoAP is defined in Section 5.9 and for HTTP in [RFC7662].

Note that token introspection is an optional step and can be omitted if the token is self-contained and the resource server is prepared to perform the token validation on its own.

Token Introspection Response (E):
The AS validates the token and returns the most recent parameters, such as scope, audience, validity etc. associated with it back to the RS. The RS then uses the received parameters to process the request to either accept or to deny it.

Protected Resource (F):
: If the request from the client is authorized, the RS fulfills the request and returns a response with the appropriate response code. The RS uses the dynamically established keys to protect the response, according to the communication security protocol used.

5. Framework

The following sections detail the profiling and extensions of OAuth 2.0 for constrained environments, which constitutes the ACE framework.

Credential Provisioning
: For IoT, it cannot be assumed that the client and RS are part of a common key infrastructure, so the AS provisions credentials or associated information to allow mutual authentication between client and RS. The resulting security association between client and RS may then also be used to bind these credentials to the access tokens the client uses.

Proof-of-Possession
: The ACE framework, by default, implements proof-of-possession for access tokens, i.e., that the token holder can prove being a holder of the key bound to the token. The binding is provided by the "cnf" claim [RFC8747] indicating what key is used for proof-of-possession. If a client needs to submit a new access token, e.g., to obtain additional access rights, they can request that the AS binds this token to the same key as the previous one.

ACE Profiles
: The client or RS may be limited in the encodings or protocols it supports. To support a variety of different deployment settings, specific interactions between client and RS are defined in an ACE profile. In ACE framework the AS is expected to manage the matching of compatible profile choices between a client and an RS. The AS informs the client of the selected profile using the "ace_profile" parameter in the token response.

OAuth 2.0 requires the use of TLS both to protect the communication between AS and client when requesting an access token; between client and RS when accessing a resource and between AS and RS if introspection is used. In constrained settings TLS is not always feasible, or desirable. Nevertheless it is REQUIRED that the communications named above are encrypted, integrity protected and

protected against message replay. It is also REQUIRED that the communicating endpoints perform mutual authentication. Furthermore it MUST be assured that responses are bound to the requests in the sense that the receiver of a response can be certain that the response actually belongs to a certain request. Note that setting up such a secure communication may require some unprotected messages to be exchanged first (e.g. sending the token from the client to the RS).

Profiles MUST specify a communication security protocol that provides the features required above.

In OAuth 2.0 the communication with the Token and the Introspection endpoints at the AS is assumed to be via HTTP and may use Uri-query parameters. When profiles of this framework use CoAP instead, it is REQUIRED to use of the following alternative instead of Uri-query parameters: The sender (client or RS) encodes the parameters of its request as a CBOR map and submits that map as the payload of the POST request.

Profiles that use CBOR encoding of protocol message parameters at the outermost encoding layer MUST use the media format 'application/ ace+cbor'. If CoAP is used for communication, the Content-Format MUST be abbreviated with the ID: 19 (see Section 8.16).

The OAuth 2.0 AS uses a JSON structure in the payload of its responses both to client and RS. If CoAP is used, it is REQUIRED to use CBOR [RFC7049] instead of JSON. Depending on the profile, the CBOR payload MAY be enclosed in a non-CBOR cryptographic wrapper.

5.1. Discovering Authorization Servers

C must discover the AS in charge of RS to determine where to request the access token. To do so, C must 1. find out the AS URI to which the token request message must be sent and 2. MUST validate that the AS with this URI is authorized to provide access tokens for this RS.

In order to determine the AS URI, C MAY send an initial Unauthorized Resource Request message to RS. RS then denies the request and sends the address of its AS back to C (see Section 5.2). How C validates the AS authorization is not in scope for this document. C may, e.g., ask it's owner if this AS is authorized for this RS. C may also use a mechanism that addresses both problems at once.

5.2. Unauthorized Resource Request Message

An Unauthorized Resource Request message is a request for any resource hosted by RS for which the client does not have authorization granted. RSes MUST treat any request for a protected resource as an Unauthorized Resource Request message when any of the following hold:

- The request has been received on an unprotected channel.
- The RS has no valid access token for the sender of the request regarding the requested action on that resource.
- The RS has a valid access token for the sender of the request, but that token does not authorize the requested action on the requested resource.

Note: These conditions ensure that the RS can handle requests autonomously once access was granted and a secure channel has been established between C and RS. The authz-info endpoint, as part of the process for authorizing to protected resources, is not itself a protected resource and MUST NOT be protected as specified above (cf. Section 5.10.1).

Unauthorized Resource Request messages MUST be denied with an "unauthorized_client" error response. In this response, the Resource Server SHOULD provide proper AS Request Creation Hints to enable the Client to request an access token from RS's AS as described in Section 5.3.

The handling of all client requests (including unauthorized ones) by the RS is described in Section 5.10.2.

5.3. AS Request Creation Hints

The AS Request Creation Hints message is sent by an RS as a response to an Unauthorized Resource Request message (see Section 5.2) to help the sender of the Unauthorized Resource Request message acquire a valid access token. The AS Request Creation Hints message is a CBOR map, with an OPTIONAL element "AS" specifying an absolute URI (see Section 4.3 of [RFC3986]) that identifies the appropriate AS for the RS.

The message can also contain the following OPTIONAL parameters:

- A "audience" element containing a suggested audience that the client should request at the AS.

- A "kid" element containing the key identifier of a key used in an existing security association between the client and the RS. The RS expects the client to request an access token bound to this key, in order to avoid having to re-establish the security association.

- A "cnonce" element containing a client-nonce. See Section 5.3.1.

- A "scope" element containing the suggested scope that the client should request towards the AS.

Figure 2 summarizes the parameters that may be part of the AS Request Creation Hints.

Name	CBOR Key	Value Type
AS	1	text string
kid	2	byte string
audience	5	text string
scope	9	text or byte string
cnonce	39	byte string

Figure 2: AS Request Creation Hints

Note that the schema part of the AS parameter may need to be adapted to the security protocol that is used between the client and the AS. Thus the example AS value "coap://as.example.com/token" might need to be transformed to "coaps://as.example.com/token". It is assumed that the client can determine the correct schema part on its own depending on the way it communicates with the AS.

Figure 3 shows an example for an AS Request Creation Hints message payload using CBOR [RFC7049] diagnostic notation, using the parameter names instead of the CBOR keys for better human readability.

```
4.01 Unauthorized
Content-Format: application/ace+cbor
Payload :
{
 "AS" : "coaps://as.example.com/token",
 "audience" : "coaps://rs.example.com"
 "scope" : "rTempC",
 "cnonce" : h'e0a156bb3f'
}
```

Figure 3: AS Request Creation Hints payload example

In the example above, the response parameter "AS" points the receiver of this message to the URI "coaps://as.example.com/token" to request access tokens. The RS sending this response (i.e., RS) uses an internal clock that is only loosely synchronized with the clock of the AS. Therefore it can not reliably verify the expiration time of access tokens it receives. To ensure a certain level of access token freshness nevetheless, the RS has included a "cnonce" parameter (see Section 5.3.1) in the response.

Figure 4 illustrates the mandatory to use binary encoding of the message payload shown in Figure 3.

```
a4                                  # map(4)
   01                               # unsigned(1) (=AS)
   78 1c                            # text(28)
      636f6170733a2f2f61732e657861
      6d706c652e636f6d2f746f6b656e  # "coaps://as.example.com/token"
   05                               # unsigned(5) (=audience)
   76                               # text(22)
      636f6170733a2f2f72732e657861
      6d706c652e636f6d              # "coaps://rs.example.com"
   09                               # unsigned(9) (=scope)
   66                               # text(6)
      7254656d7043                  # "rTempC"
   18 27                            # unsigned(39) (=cnonce)
   45                               # bytes(5)
      e0a156bb3f                    #
```

Figure 4: AS Request Creation Hints example encoded in CBOR

5.3.1. The Client-Nonce Parameter

If the RS does not synchronize its clock with the AS, it could be tricked into accepting old access tokens, that are either expired or have been compromised. In order to ensure some level of token freshness in that case, the RS can use the "cnonce" (client-nonce) parameter. The processing requirements for this parameter are as follows:

- An RS sending a "cnonce" parameter in an AS Request Creation Hints message MUST store information to validate that a given cnonce is fresh. How this is implemented internally is out of scope for this specification. Expiration of client-nonces should be based roughly on the time it would take a client to obtain an access token after receiving the AS Request Creation Hints message, with some allowance for unexpected delays.

- A client receiving a "cnonce" parameter in an AS Request Creation Hints message MUST include this in the parameters when requesting an access token at the AS, using the "cnonce" parameter from Section 5.8.4.4.

- If an AS grants an access token request containing a "cnonce" parameter, it MUST include this value in the access token, using the "cnonce" claim specified in Section 5.10.

- An RS that is using the client-nonce mechanism and that receives an access token MUST verify that this token contains a cnonce claim, with a client-nonce value that is fresh according to the information stored at the first step above. If the cnonce claim is not present or if the cnonce claim value is not fresh, the RS MUST discard the access token. If this was an interaction with the authz-info endpoint the RS MUST also respond with an error message using a response code equivalent to the CoAP code 4.01 (Unauthorized).

5.4. Authorization Grants

To request an access token, the client obtains authorization from the resource owner or uses its client credentials as a grant. The authorization is expressed in the form of an authorization grant.

The OAuth framework [RFC6749] defines four grant types. The grant types can be split up into two groups, those granted on behalf of the resource owner (password, authorization code, implicit) and those for the client (client credentials). Further grant types have been added later, such as [RFC7521] defining an assertion-based authorization grant.

The grant type is selected depending on the use case. In cases where the client acts on behalf of the resource owner, the authorization code grant is recommended. If the client acts on behalf of the resource owner, but does not have any display or has very limited interaction possibilities, it is recommended to use the device code grant defined in [RFC8628]. In cases where the client acts autonomously the client credentials grant is recommended.

For details on the different grant types, see section 1.3 of [RFC6749]. The OAuth 2.0 framework provides an extension mechanism for defining additional grant types, so profiles of this framework MAY define additional grant types, if needed.

5.5. Client Credentials

Authentication of the client is mandatory independent of the grant type when requesting an access token from the token endpoint. In the case of the client credentials grant type, the authentication and grant coincide.

Client registration and provisioning of client credentials to the client is out of scope for this specification.

The OAuth framework defines one client credential type in section 2.3.1 of [RFC6749]: client id and client secret. [I-D.erdtman-ace-rpcc] adds raw-public-key and pre-shared-key to the client credentials types. Profiles of this framework MAY extend with an additional client credentials type using client certificates.

5.6. AS Authentication

The client credential grant does not, by default, authenticate the AS that the client connects to. In classic OAuth, the AS is authenticated with a TLS server certificate.

Profiles of this framework MUST specify how clients authenticate the AS and how communication security is implemented. By default, server side TLS certificates, as defined by OAuth 2.0, are required.

5.7. The Authorization Endpoint

The OAuth 2.0 authorization endpoint is used to interact with the resource owner and obtain an authorization grant, in certain grant flows. The primary use case for the ACE-OAuth framework is for machine-to-machine interactions that do not involve the resource owner in the authorization flow; therefore, this endpoint is out of scope here. Future profiles may define constrained adaptation mechanisms for this endpoint as well. Non-constrained clients interacting with constrained resource servers can use the specification in section 3.1 of [RFC6749] and the attack countermeasures suggested in section 4.2 of [RFC6819].

5.8. The Token Endpoint

In standard OAuth 2.0, the AS provides the token endpoint for submitting access token requests. This framework extends the functionality of the token endpoint, giving the AS the possibility to help the client and RS to establish shared keys or to exchange their public keys. Furthermore, this framework defines encodings using CBOR, as a substitute for JSON.

The endpoint may, however, be exposed over HTTPS as in classical OAuth or even other transports. A profile MUST define the details of the mapping between the fields described below, and these transports. If HTTPS is used, JSON or CBOR payloads may be supported. If JSON payloads are used, the semantics of Section 4 of the OAuth 2.0 specification MUST be followed (with additions as described below). If CBOR payload is supported, the semantics described below MUST be followed.

For the AS to be able to issue a token, the client MUST be authenticated and present a valid grant for the scopes requested. Profiles of this framework MUST specify how the AS authenticates the client and how the communication between client and AS is protected, fulfilling the requirements specified in Section 5.

The default name of this endpoint in an url-path is '/token', however implementations are not required to use this name and can define their own instead.

The figures of this section use CBOR diagnostic notation without the integer abbreviations for the parameters or their values for illustrative purposes. Note that implementations MUST use the integer abbreviations and the binary CBOR encoding, if the CBOR encoding is used.

5.8.1. Client-to-AS Request

The client sends a POST request to the token endpoint at the AS. The profile MUST specify how the communication is protected. The content of the request consists of the parameters specified in the relevant subsection of section 4 of the OAuth 2.0 specification [RFC6749], depending on the grant type, with the following exceptions and additions:

- The parameter "grant_type" is OPTIONAL in the context of this framework (as opposed to REQUIRED in RFC6749). If that parameter is missing, the default value "client_credentials" is implied.

- The "audience" parameter from [RFC8693] is OPTIONAL to request an access token bound to a specific audience.

- The "cnonce" parameter defined in Section 5.8.4.4 is REQUIRED if the RS provided a client-nonce in the "AS Request Creation Hints" message Section 5.3

- The "scope" parameter MAY be encoded as a byte string instead of the string encoding specified in section 3.3 of [RFC6749], in order allow compact encoding of complex scopes. The syntax of

such a binary encoding is explicitly not specified here and left to profiles or applications, specifically note that a binary encoded scope does not necessarily use the space character '0x20' to delimit scope-tokens.

- The client can send an empty (null value) "ace_profile" parameter to indicate that it wants the AS to include the "ace_profile" parameter in the response. See Section 5.8.4.3.

- A client MUST be able to use the parameters from [I-D.ietf-ace-oauth-params] in an access token request to the token endpoint and the AS MUST be able to process these additional parameters.

The default behavior, is that the AS generates a symmetric proof-of-possession key for the client. In order to use an asymmetric key pair or to re-use a key previously established with the RS, the client is supposed to use the "req_cnf" parameter from [I-D.ietf-ace-oauth-params].

If CBOR is used then these parameters MUST be provided as a CBOR map.

When HTTP is used as a transport then the client makes a request to the token endpoint by sending the parameters using the "application/x-www-form-urlencoded" format with a character encoding of UTF-8 in the HTTP request entity-body, as defined in section 3.2 of [RFC6749].

The following examples illustrate different types of requests for proof-of-possession tokens.

Figure 5 shows a request for a token with a symmetric proof-of-possession key. The content is displayed in CBOR diagnostic notation, without abbreviations for better readability.

```
Header: POST (Code=0.02)
Uri-Host: "as.example.com"
Uri-Path: "token"
Content-Format: "application/ace+cbor"
Payload:
{
  "client_id" : "myclient",
  "audience" : "tempSensor4711"
 }
```

Figure 5: Example request for an access token bound to a symmetric key.

Figure 6 shows a request for a token with an asymmetric proof-of-possession key. Note that in this example OSCORE [RFC8613] is used to provide object-security, therefore the Content-Format is "application/oscore" wrapping the "application/ace+cbor" type content. The OSCORE option has a decoded interpretation appended in parentheses for the reader's convenience. Also note that in this example the audience is implicitly known by both client and AS. Furthermore note that this example uses the "req_cnf" parameter from [I-D.ietf-ace-oauth-params].

```
Header: POST (Code=0.02)
Uri-Host: "as.example.com"
Uri-Path: "token"
OSCORE: 0x09, 0x05, 0x44, 0x6C
  (h=0, k=1, n=001, partialIV= 0x05, kid=[0x44, 0x6C])
Content-Format: "application/oscore"
Payload:
  0x44025d1 ... (full payload omitted for brevity) ... 68b3825e

Decrypted payload:
{
  "client_id" : "myclient",
  "req_cnf" : {
    "COSE_Key" : {
      "kty" : "EC",
      "kid" : h'11',
      "crv" : "P-256",
      "x" : b64'usWxHK2PmfnHKwXPS54m0kTcGJ90UiglWiGahtagnv8',
      "y" : b64'IBOL+C3BttVivg+lSreASjpkttcsz+1rb7btKLv8EX4'
    }
  }
}
```

Figure 6: Example token request bound to an asymmetric key.

Figure 7 shows a request for a token where a previously communicated proof-of-possession key is only referenced using the "req_cnf" parameter from [I-D.ietf-ace-oauth-params].

```
Header: POST (Code=0.02)
Uri-Host: "as.example.com"
Uri-Path: "token"
Content-Format: "application/ace+cbor"
Payload:
{
  "client_id" : "myclient",
  "audience" : "valve424",
  "scope" : "read",
  "req_cnf" : {
    "kid" : b64'6kg0dXJM13U'
  }
}W
```

Figure 7: Example request for an access token bound to a key reference.

Refresh tokens are typically not stored as securely as proof-of-possession keys in requesting clients. Proof-of-possession based refresh token requests MUST NOT request different proof-of-possession keys or different audiences in token requests. Refresh token requests can only use to request access tokens bound to the same proof-of-possession key and the same audience as access tokens issued in the initial token request.

5.8.2. AS-to-Client Response

If the access token request has been successfully verified by the AS and the client is authorized to obtain an access token corresponding to its access token request, the AS sends a response with the response code equivalent to the CoAP response code 2.01 (Created). If client request was invalid, or not authorized, the AS returns an error response as described in Section 5.8.3.

Note that the AS decides which token type and profile to use when issuing a successful response. It is assumed that the AS has prior knowledge of the capabilities of the client and the RS (see Appendix D). This prior knowledge may, for example, be set by the use of a dynamic client registration protocol exchange [RFC7591]. If the client has requested a specific proof-of-possession key using the "req_cnf" parameter from [I-D.ietf-ace-oauth-params], this may also influence which profile the AS selects, as it needs to support the use of the key type requested the client.

The content of the successful reply is the Access Information. When using CBOR payloads, the content MUST be encoded as a CBOR map, containing parameters as specified in Section 5.1 of [RFC6749], with the following additions and changes:

ace_profile:
OPTIONAL unless the request included an empty ace_profile parameter in which case it is MANDATORY. This indicates the profile that the client MUST use towards the RS. See Section 5.8.4.3 for the formatting of this parameter. If this parameter is absent, the AS assumes that the client implicitly knows which profile to use towards the RS.

token_type:
This parameter is OPTIONAL, as opposed to 'required' in [RFC6749]. By default implementations of this framework SHOULD assume that the token_type is "PoP". If a specific use case requires another token_type (e.g., "Bearer") to be used then this parameter is REQUIRED.

Furthermore [I-D.ietf-ace-oauth-params] defines additional parameters that the AS MUST be able to use when responding to a request to the token endpoint.

Figure 8 summarizes the parameters that can currently be part of the Access Information. Future extensions may define additional parameters.

Parameter name	Specified in
access_token	RFC 6749
token_type	RFC 6749
expires_in	RFC 6749
refresh_token	RFC 6749
scope	RFC 6749
state	RFC 6749
error	RFC 6749
error_description	RFC 6749
error_uri	RFC 6749
ace_profile	[this document]
cnf	[I-D.ietf-ace-oauth-params]
rs_cnf	[I-D.ietf-ace-oauth-params]

Figure 8: Access Information parameters

Figure 9 shows a response containing a token and a "cnf" parameter with a symmetric proof-of-possession key, which is defined in [I-D.ietf-ace-oauth-params]. Note that the key identifier 'kid' is only used to simplify indexing and retrieving the key, and no assumptions should be made that it is unique in the domains of either the client or the RS.

```
Header: Created (Code=2.01)
Content-Format: "application/ace+cbor"
Payload:
{
  "access_token" : b64'SlAV32hkKG ...
   (remainder of CWT omitted for brevity;
   CWT contains COSE_Key in the "cnf" claim)',
  "ace_profile" : "coap_dtls",
  "expires_in" : "3600",
  "cnf" : {
    "COSE_Key" : {
      "kty" : "Symmetric",
      "kid" : b64'39Gqlw',
      "k" : b64'hJtXhkV8FJG+Onbc6mxCcQh'
    }
  }
}
```

Figure 9: Example AS response with an access token bound to a symmetric key.

5.8.3. Error Response

The error responses for CoAP-based interactions with the AS are generally equivalent to the ones for HTTP-based interactions as defined in Section 5.2 of [RFC6749], with the following exceptions:

- When using CBOR the raw payload before being processed by the communication security protocol MUST be encoded as a CBOR map.
- A response code equivalent to the CoAP code 4.00 (Bad Request) MUST be used for all error responses, except for invalid_client where a response code equivalent to the CoAP code 4.01 (Unauthorized) MAY be used under the same conditions as specified in Section 5.2 of [RFC6749].
- The Content-Format (for CoAP-based interactions) or media type (for HTTP-based interactions) "application/ace+cbor" MUST be used for the error response.
- The parameters "error", "error_description" and "error_uri" MUST be abbreviated using the codes specified in Figure 12, when a CBOR encoding is used.
- The error code (i.e., value of the "error" parameter) MUST be abbreviated as specified in Figure 10, when a CBOR encoding is used.

Name	CBOR Values
invalid_request	1
invalid_client	2
invalid_grant	3
unauthorized_client	4
unsupported_grant_type	5
invalid_scope	6
unsupported_pop_key	7
incompatible_ace_profiles	8

Figure 10: CBOR abbreviations for common error codes

In addition to the error responses defined in OAuth 2.0, the following behavior MUST be implemented by the AS:

- If the client submits an asymmetric key in the token request that the RS cannot process, the AS MUST reject that request with a response code equivalent to the CoAP code 4.00 (Bad Request) including the error code "unsupported_pop_key" defined in Figure 10.

- If the client and the RS it has requested an access token for do not share a common profile, the AS MUST reject that request with a response code equivalent to the CoAP code 4.00 (Bad Request) including the error code "incompatible_ace_profiles" defined in Figure 10.

5.8.4. Request and Response Parameters

This section provides more detail about the new parameters that can be used in access token requests and responses, as well as abbreviations for more compact encoding of existing parameters and common parameter values.

5.8.4.1. Grant Type

The abbreviations specified in the registry defined in Section 8.5 MUST be used in CBOR encodings instead of the string values defined in [RFC6749], if CBOR payloads are used.

Name	CBOR Value	Original Specification
password	0	[RFC6749]
authorization_code	1	[RFC6749]
client_credentials	2	[RFC6749]
refresh_token	3	[RFC6749]

Figure 11: CBOR abbreviations for common grant types

5.8.4.2. Token Type

The "token_type" parameter, defined in section 5.1 of [RFC6749], allows the AS to indicate to the client which type of access token it is receiving (e.g., a bearer token).

This document registers the new value "PoP" for the OAuth Access Token Types registry, specifying a proof-of-possession token. How the proof-of-possession by the client to the RS is performed MUST be specified by the profiles.

The values in the "token_type" parameter MUST use the CBOR abbreviations defined in the registry specified by Section 8.7, if a CBOR encoding is used.

In this framework the "pop" value for the "token_type" parameter is the default. The AS may, however, provide a different value.

5.8.4.3. Profile

Profiles of this framework MUST define the communication protocol and the communication security protocol between the client and the RS. The security protocol MUST provide encryption, integrity and replay protection. It MUST also provide a binding between requests and responses. Furthermore profiles MUST define a list of allowed proof-of-possession methods, if they support proof-of-possession tokens.

A profile MUST specify an identifier that MUST be used to uniquely identify itself in the "ace_profile" parameter. The textual representation of the profile identifier is intended for human readability and for JSON-based interactions, it MUST NOT be used for CBOR-based interactions. Profiles MUST register their identifier in the registry defined in Section 8.8.

Profiles MAY define additional parameters for both the token request and the Access Information in the access token response in order to support negotiation or signaling of profile specific parameters.

Clients that want the AS to provide them with the "ace_profile" parameter in the access token response can indicate that by sending a ace_profile parameter with a null value (for CBOR-based interactions) or an empty string (for JSON based interactions) in the access token request.

5.8.4.4. Client-Nonce

This parameter MUST be sent from the client to the AS, if it previously received a "cnonce" parameter in the AS Request Creation Hints Section 5.3. The parameter is encoded as a byte string for CBOR-based interactions, and as a string (Base64 encoded binary) for JSON-based interactions. It MUST copy the value from the cnonce parameter in the AS Request Creation Hints.

5.8.5. Mapping Parameters to CBOR

If CBOR encoding is used, all OAuth parameters in access token requests and responses MUST be mapped to CBOR types as specified in the registry defined by Section 8.10, using the given integer abbreviation for the map keys.

Note that we have aligned the abbreviations corresponding to claims with the abbreviations defined in [RFC8392].

Note also that abbreviations from -24 to 23 have a 1 byte encoding size in CBOR. We have thus chosen to assign abbreviations in that range to parameters we expect to be used most frequently in constrained scenarios.

Name	CBOR Key	Value Type
access_token	1	byte string
expires_in	2	unsigned integer
audience	5	text string
scope	9	text or byte string
client_id	24	text string
client_secret	25	byte string
response_type	26	text string
redirect_uri	27	text string
state	28	text string
code	29	byte string
error	30	integer
error_description	31	text string
error_uri	32	text string
grant_type	33	unsigned integer
token_type	34	integer
username	35	text string
password	36	text string
refresh_token	37	byte string
ace_profile	38	integer
cnonce	39	byte string

Figure 12: CBOR mappings used in token requests and responses

5.9. The Introspection Endpoint

Token introspection [RFC7662] can be OPTIONALLY provided by the AS, and is then used by the RS and potentially the client to query the AS for metadata about a given token, e.g., validity or scope. Analogous to the protocol defined in [RFC7662] for HTTP and JSON, this section defines adaptations to more constrained environments using CBOR and leaving the choice of the application protocol to the profile.

Communication between the requesting entity and the introspection endpoint at the AS MUST be integrity protected and encrypted. The communication security protocol MUST also provide a binding between requests and responses. Furthermore the two interacting parties MUST perform mutual authentication. Finally the AS SHOULD verify that the requesting entity has the right to access introspection information about the provided token. Profiles of this framework that support introspection MUST specify how authentication and communication security between the requesting entity and the AS is implemented.

The default name of this endpoint in an url-path is '/introspect', however implementations are not required to use this name and can define their own instead.

The figures of this section uses CBOR diagnostic notation without the integer abbreviations for the parameters or their values for better readability.

Note that supporting introspection is OPTIONAL for implementations of this framework.

5.9.1. Introspection Request

The requesting entity sends a POST request to the introspection endpoint at the AS. The profile MUST specify how the communication is protected. If CBOR is used, the payload MUST be encoded as a CBOR map with a "token" entry containing the access token. Further optional parameters representing additional context that is known by the requesting entity to aid the AS in its response MAY be included.

For CoAP-based interaction, all messages MUST use the content type "application/ace+cbor", while for HTTP-based interactions the equivalent media type "application/ace+cbor" MUST be used.

The same parameters are required and optional as in Section 2.1 of [RFC7662].

For example, Figure 13 shows an RS calling the token introspection endpoint at the AS to query about an OAuth 2.0 proof-of-possession token. Note that object security based on OSCORE [RFC8613] is assumed in this example, therefore the Content-Format is "application/oscore". Figure 14 shows the decoded payload.

```
Header: POST (Code=0.02)
Uri-Host: "as.example.com"
Uri-Path: "introspect"
OSCORE: 0x09, 0x05, 0x25
Content-Format: "application/oscore"
Payload:
... COSE content ...
```

Figure 13: Example introspection request.

```
{
  "token" : b64'7gj0dXJQ43U',
  "token_type_hint" : "PoP"
}
```

Figure 14: Decoded payload.

5.9.2. Introspection Response

If the introspection request is authorized and successfully processed, the AS sends a response with the response code equivalent to the CoAP code 2.01 (Created). If the introspection request was invalid, not authorized or couldn't be processed the AS returns an error response as described in Section 5.9.3.

In a successful response, the AS encodes the response parameters in a map including with the same required and optional parameters as in Section 2.2 of [RFC7662] with the following addition:

ace_profile OPTIONAL. This indicates the profile that the RS MUST use with the client. See Section 5.8.4.3 for more details on the formatting of this parameter.

cnonce OPTIONAL. A client-nonce provided to the AS by the client. The RS MUST verify that this corresponds to the client-nonce previously provided to the client in the AS Request Creation Hints. See Section 5.3 and Section 5.8.4.4.

exi OPTIONAL. The "expires-in" claim associated to this access token. See Section 5.10.3.

Furthermore [I-D.ietf-ace-oauth-params] defines more parameters that the AS MUST be able to use when responding to a request to the introspection endpoint.

For example, Figure 15 shows an AS response to the introspection request in Figure 13. Note that this example contains the "cnf" parameter defined in [I-D.ietf-ace-oauth-params].

```
Header: Created (Code=2.01)
Content-Format: "application/ace+cbor"
Payload:
{
  "active" : true,
  "scope" : "read",
  "ace_profile" : "coap_dtls",
  "cnf" : {
    "COSE_Key" : {
      "kty" : "Symmetric",
      "kid" : b64'39Gqlw',
      "k" : b64'hJtXhkV8FJG+Onbc6mxCcQh'
    }
  }
}
```

Figure 15: Example introspection response.

5.9.3. Error Response

The error responses for CoAP-based interactions with the AS are equivalent to the ones for HTTP-based interactions as defined in Section 2.3 of [RFC7662], with the following differences:

- If content is sent and CBOR is used the payload MUST be encoded as a CBOR map and the Content-Format "application/ace+cbor" MUST be used.

- If the credentials used by the requesting entity (usually the RS) are invalid the AS MUST respond with the response code equivalent to the CoAP code 4.01 (Unauthorized) and use the required and optional parameters from Section 5.2 in [RFC6749].

- If the requesting entity does not have the right to perform this introspection request, the AS MUST respond with a response code equivalent to the CoAP code 4.03 (Forbidden). In this case no payload is returned.

- The parameters "error", "error_description" and "error_uri" MUST be abbreviated using the codes specified in Figure 12.

- The error codes MUST be abbreviated using the codes specified in the registry defined by Section 8.4.

Note that a properly formed and authorized query for an inactive or otherwise invalid token does not warrant an error response by this specification. In these cases, the authorization server MUST instead

respond with an introspection response with the "active" field set to "false".

5.9.4. Mapping Introspection parameters to CBOR

If CBOR is used, the introspection request and response parameters MUST be mapped to CBOR types as specified in the registry defined by Section 8.12, using the given integer abbreviation for the map key.

Note that we have aligned abbreviations that correspond to a claim with the abbreviations defined in [RFC8392] and the abbreviations of parameters with the same name from Section 5.8.5.

Parameter name	CBOR Key	Value Type
iss	1	text string
sub	2	text string
aud	3	text string
exp	4	integer or floating-point number
nbf	5	integer or floating-point number
iat	6	integer or floating-point number
cti	7	byte string
scope	9	text or byte string
active	10	True or False
token	11	byte string
client_id	24	text string
error	30	integer
error_description	31	text string
error_uri	32	text string
token_type_hint	33	text string
token_type	34	integer
username	35	text string
ace_profile	38	integer
cnonce	39	byte string
exi	40	unsigned integer

Figure 16: CBOR Mappings to Token Introspection Parameters.

5.10. The Access Token

This framework RECOMMENDS the use of CBOR web token (CWT) as specified in [RFC8392].

In order to facilitate offline processing of access tokens, this document uses the "cnf" claim from [RFC8747] and the "scope" claim from [RFC8693] for JWT- and CWT-encoded tokens. In addition to string encoding specified for the "scope" claim, a binary encoding MAY be used. The syntax of such an encoding is explicitly not specified here and left to profiles or applications, specifically note that a binary encoded scope does not necessarily use the space character '0x20' to delimit scope-tokens.

If the AS needs to convey a hint to the RS about which profile it should use to communicate with the client, the AS MAY include an "ace_profile" claim in the access token, with the same syntax and semantics as defined in Section 5.8.4.3.

If the client submitted a client-nonce parameter in the access token request Section 5.8.4.4, the AS MUST include the value of this parameter in the "cnonce" claim specified here. The "cnonce" claim uses binary encoding.

5.10.1. The Authorization Information Endpoint

The access token, containing authorization information and information about the proof-of-possession method used by the client, needs to be transported to the RS so that the RS can authenticate and authorize the client request.

This section defines a method for transporting the access token to the RS using a RESTful protocol such as CoAP. Profiles of this framework MAY define other methods for token transport.

The method consists of an authz-info endpoint, implemented by the RS. A client using this method MUST make a POST request to the authz-info endpoint at the RS with the access token in the payload. The RS receiving the token MUST verify the validity of the token. If the token is valid, the RS MUST respond to the POST request with 2.01 (Created). Section Section 5.10.1.1 outlines how an RS MUST proceed to verify the validity of an access token.

The RS MUST be prepared to store at least one access token for future use. This is a difference to how access tokens are handled in OAuth 2.0, where the access token is typically sent along with each request, and therefore not stored at the RS.

This specification RECOMMENDS that an RS stores only one token per proof-of-possession key, meaning that an additional token linked to the same key will overwrite any existing token at the RS. The reason is that this greatly simplifies (constrained) implementations, with

respect to required storage and resolving a request to the applicable token.

If the payload sent to the authz-info endpoint does not parse to a token, the RS MUST respond with a response code equivalent to the CoAP code 4.00 (Bad Request).

The RS MAY make an introspection request to validate the token before responding to the POST request to the authz-info endpoint, e.g. if the token is an opaque reference. Some transport protocols may provide a way to indicate that the RS is busy and the client should retry after an interval; this type of status update would be appropriate while the RS is waiting for an introspection response.

Profiles MUST specify whether the authz-info endpoint is protected, including whether error responses from this endpoint are protected. Note that since the token contains information that allow the client and the RS to establish a security context in the first place, mutual authentication may not be possible at this point.

The default name of this endpoint in an url-path is '/authz-info', however implementations are not required to use this name and can define their own instead.

5.10.1.1. Verifying an Access Token

When an RS receives an access token, it MUST verify it before storing it. The details of token verification depends on various aspects, including the token encoding, the type of token, the security protection applied to the token, and the claims. The token encoding matters since the security wrapper differs between the token encodings. For example, a CWT token uses COSE while a JWT token uses JOSE. The type of token also has an influence on the verification procedure since tokens may be self-contained whereby token verification may happen locally at the RS while a token-by-reference requires further interaction with the authorization server, for example using token introspection, to obtain the claims associated with the token reference. Self-contained tokens MUST, at a minimum, be integrity protected but they MAY also be encrypted.

For self-contained tokens the RS MUST process the security protection of the token first, as specified by the respective token format. For CWT the description can be found in [RFC8392] and for JWT the relevant specification is [RFC7519]. This MUST include a verification that security protection (and thus the token) was generated by an AS that has the right to issue access tokens for this RS.

In case the token is communicated by reference the RS needs to obtain the claims first. When the RS uses token introspection the relevant specification is [RFC7662] with CoAP transport specified in Section 5.9.

Errors may happen during this initial processing stage:

- If token or claim verification fails, the RS MUST discard the token and, if this was an interaction with authz-info, return an error message with a response code equivalent to the CoAP code 4.01 (Unauthorized).

- If the claims cannot be obtained the RS MUST discard the token and, in case of an interaction via the authz-info endpoint, return an error message with a response code equivalent to the CoAP code 4.00 (Bad Request).

Next, the RS MUST verify claims, if present, contained in the access token. Errors are returned when claim checks fail, in the order of priority of this list:

iss The issuer claim must identify an AS that has the authority to issue access tokens for the receiving RS. If that is not the case the RS MUST discard the token. If this was an interaction with authz-info, the RS MUST also respond with a response code equivalent to the CoAP code 4.01 (Unauthorized).

exp The expiration date must be in the future. If that is not the case the RS MUST discard the token. If this was an interaction with authz-info the RS MUST also respond with a response code equivalent to the CoAP code 4.01 (Unauthorized). Note that the RS has to terminate access rights to the protected resources at the time when the tokens expire.

aud The audience claim must refer to an audience that the RS identifies with. If that is not the case the RS MUST discard the token. If this was an interaction with authz-info, the RS MUST also respond with a response code equivalent to the CoAP code 4.03 (Forbidden).

scope The RS must recognize value of the scope claim. If that is not the case the RS MUST discard the token. If this was an interaction with authz-info, the RS MUST also respond with a response code equivalent to the CoAP code 4.00 (Bad Request). The RS MAY provide additional information in the error response, to clarify what went wrong.

Additional processing may be needed for other claims in a way specific to a profile or the underlying application.

Note that the Subject (sub) claim cannot always be verified when the token is submitted to the RS since the client may not have authenticated yet. Also note that a counter for the expires_in (exi) claim MUST be initialized when the RS first verifies this token.

Also note that profiles of this framework may define access token transport mechanisms that do not allow for error responses. Therefore the error messages specified here only apply if the token was sent to the authz-info endpoint.

When sending error responses, the RS MAY use the error codes from Section 3.1 of [RFC6750], to provide additional details to the client.

5.10.1.2. Protecting the Authorization Information Endpoint

As this framework can be used in RESTful environments, it is important to make sure that attackers cannot perform unauthorized requests on the authz-info endpoints, other than submitting access tokens.

Specifically it SHOULD NOT be possible to perform GET, DELETE or PUT on the authz-info endpoint and on it's children (if any).

The POST method SHOULD NOT be allowed on children of the authz-info endpoint.

The RS SHOULD implement rate limiting measures to mitigate attacks aiming to overload the processing capacity of the RS by repeatedly submitting tokens. For CoAP-based communication the RS could use the mechanisms from [RFC8516] to indicate that it is overloaded.

5.10.2. Client Requests to the RS

Before sending a request to an RS, the client MUST verify that the keys used to protect this communication are still valid. See Section 5.10.4 for details on how the client determines the validity of the keys used.

If an RS receives a request from a client, and the target resource requires authorization, the RS MUST first verify that it has an access token that authorizes this request, and that the client has performed the proof-of-possession binding that token to the request.

The response code MUST be 4.01 (Unauthorized) in case the client has not performed the proof-of-possession, or if RS has no valid access token for the client. If RS has an access token for the client but the token does not authorize access for the resource that was requested, RS MUST reject the request with a 4.03 (Forbidden). If RS has an access token for the client but it does not cover the action that was requested on the resource, RS MUST reject the request with a 4.05 (Method Not Allowed).

Note: The use of the response codes 4.03 and 4.05 is intended to prevent infinite loops where a dumb Client optimistically tries to access a requested resource with any access token received from AS. As malicious clients could pretend to be C to determine C's privileges, these detailed response codes must be used only when a certain level of security is already available which can be achieved only when the Client is authenticated.

Note: The RS MAY use introspection for timely validation of an access token, at the time when a request is presented.

Note: Matching the claims of the access token (e.g., scope) to a specific request is application specific.

If the request matches a valid token and the client has performed the proof-of-possession for that token, the RS continues to process the request as specified by the underlying application.

5.10.3. Token Expiration

Depending on the capabilities of the RS, there are various ways in which it can verify the expiration of a received access token. Here follows a list of the possibilities including what functionality they require of the RS.

- The token is a CWT and includes an "exp" claim and possibly the "nbf" claim. The RS verifies these by comparing them to values from its internal clock as defined in [RFC7519]. In this case the RS's internal clock must reflect the current date and time, or at least be synchronized with the AS's clock. How this clock synchronization would be performed is out of scope for this specification.

- The RS verifies the validity of the token by performing an introspection request as specified in Section 5.9. This requires the RS to have a reliable network connection to the AS and to be able to handle two secure sessions in parallel (C to RS and RS to AS).

- In order to support token expiration for devices that have no reliable way of synchronizing their internal clocks, this specification defines the following approach: The claim "exi" ("expires in") can be used, to provide the RS with the lifetime of the token in seconds from the time the RS first receives the token. For CBOR-based interaction this parameter is encoded as unsigned integer, while JSON-based interactions encode this as JSON number.

- Processing this claim requires that the RS does the following:

  * For each token the RS receives, that contains an "exi" claim: Keep track of the time it received that token and revisit that list regularly to expunge expired tokens.

  * Keep track of the identifiers of tokens containing the "exi" claim that have expired (in order to avoid accepting them again). In order to avoid an unbounded memory usage growth, this MUST be implemented in the following way when the "exi" claim is used:

    + When creating the token, the AS MUST add a 'cti' claim (or 'jti' for JWTs) to the access token. The value of this claim MUST be created as the binary representation of the concatenation of the identifier of the RS with a sequence number counting the tokens containing an 'exi' claim, issued by this AS for the RS.

    + The RS MUST store the highest sequence number of an expired token containing the "exi" claim that it has seen, and treat tokens with lower sequence numbers as expired.

If a token that authorizes a long running request such as a CoAP Observe [RFC7641] expires, the RS MUST send an error response with the response code equivalent to the CoAP code 4.01 (Unauthorized) to the client and then terminate processing the long running request.

5.10.4. Key Expiration

The AS provides the client with key material that the RS uses. This can either be a common symmetric PoP-key, or an asymmetric key used by the RS to authenticate towards the client. Since there is currently no expiration metadata associated to those keys, the client has no way of knowing if these keys are still valid. This may lead to situations where the client sends requests containing sensitive information to the RS using a key that is expired and possibly in the hands of an attacker, or accepts responses from the RS that are not

properly protected and could possibly have been forged by an attacker.

In order to prevent this, the client must assume that those keys are only valid as long as the related access token is. Since the access token is opaque to the client, one of the following methods MUST be used to inform the client about the validity of an access token:

- The client knows a default validity time for all tokens it is using (i.e. how long a token is valid after being issued). This information could be provisioned to the client when it is registered at the AS, or published by the AS in a way that the client can query.

- The AS informs the client about the token validity using the "expires_in" parameter in the Access Information.

A client that is not able to obtain information about the expiration of a token MUST NOT use this token.

6. Security Considerations

Security considerations applicable to authentication and authorization in RESTful environments provided in OAuth 2.0 [RFC6749] apply to this work. Furthermore [RFC6819] provides additional security considerations for OAuth which apply to IoT deployments as well. If the introspection endpoint is used, the security considerations from [RFC7662] also apply.

The following subsections address issues specific to this document and it's use in constrained environments.

6.1. Protecting Tokens

A large range of threats can be mitigated by protecting the contents of the access token by using a digital signature or a keyed message digest (MAC) or an Authenticated Encryption with Associated Data (AEAD) algorithm. Consequently, the token integrity protection MUST be applied to prevent the token from being modified, particularly since it contains a reference to the symmetric key or the asymmetric key used for proof-of-possession. If the access token contains the symmetric key, this symmetric key MUST be encrypted by the authorization server so that only the resource server can decrypt it. Note that using an AEAD algorithm is preferable over using a MAC unless the token needs to be publicly readable.

If the token is intended for multiple recipients (i.e. an audience that is a group), integrity protection of the token with a symmetric

key, shared between the AS and the recipients, is not sufficient, since any of the recipients could modify the token undetected by the other recipients. Therefore a token with a multi-recipient audience MUST be protected with an asymmetric signature.

It is important for the authorization server to include the identity of the intended recipient (the audience), typically a single resource server (or a list of resource servers), in the token. The same shared secret MUST NOT be used as proof-of-possession key with multiple resource servers since the benefit from using the proof-of-possession concept is then significantly reduced.

If clients are capable of doing so, they should frequently request fresh access tokens, as this allows the AS to keep the lifetime of the tokens short. This allows the AS to use shorter proof-of-possession key sizes, which translate to a performance benefit for the client and for the resource server. Shorter keys also lead to shorter messages (particularly with asymmetric keying material).

When authorization servers bind symmetric keys to access tokens, they SHOULD scope these access tokens to a specific permission.

In certain situations it may be necessary to revoke an access token that is still valid. Client-initiated revocation is specified in [RFC7009] for OAuth 2.0. Other revocation mechanisms are currently not specified, as the underlying assumption in OAuth is that access tokens are issued with a relatively short lifetime. This may not hold true for disconnected constrained devices, needing access tokens with relatively long lifetimes, and would therefore necessitate further standardization work that is out of scope for this document.

6.2. Communication Security

Communication with the authorization server MUST use confidentiality protection. This step is extremely important since the client or the RS may obtain the proof-of-possession key from the authorization server for use with a specific access token. Not using confidentiality protection exposes this secret (and the access token) to an eavesdropper thereby completely negating proof-of-possession security. Profiles MUST specify how communication security according to the requirements in Section 5 is provided.

Additional protection for the access token can be applied by encrypting it, for example encryption of CWTs is specified in Section 5.1 of [RFC8392]. Such additional protection can be necessary if the token is later transferred over an insecure connection (e.g. when it is sent to the authz-info endpoint).

Developers MUST ensure that the ephemeral credentials (i.e., the private key or the session key) are not leaked to third parties. An adversary in possession of the ephemeral credentials bound to the access token will be able to impersonate the client. Be aware that this is a real risk with many constrained environments, since adversaries can often easily get physical access to the devices. This risk can also be mitigated to some extent by making sure that keys are refreshed more frequently.

6.3. Long-Term Credentials

Both clients and RSs have long-term credentials that are used to secure communications, and authenticate to the AS. These credentials need to be protected against unauthorized access. In constrained devices, deployed in publicly accessible places, such protection can be difficult to achieve without specialized hardware (e.g. secure key storage memory).

If credentials are lost or compromised, the operator of the affected devices needs to have procedures to invalidate any access these credentials give and to revoke tokens linked to such credentials. The loss of a credential linked to a specific device MUST NOT lead to a compromise of other credentials not linked to that device, therefore secret keys used for authentication MUST NOT be shared between more than two parties.

Operators of clients or RS SHOULD have procedures in place to replace credentials that are suspected to have been compromised or that have been lost.

Operators also SHOULD have procedures for decommissioning devices, that include securely erasing credentials and other security critical material in the devices being decommissioned.

6.4. Unprotected AS Request Creation Hints

Initially, no secure channel exists to protect the communication between C and RS. Thus, C cannot determine if the AS Request Creation Hints contained in an unprotected response from RS to an unauthorized request (see Section 5.3) are authentic. C therefore MUST determine if an AS is authorized to provide access tokens for a certain RS.

A compromised RS may use the hints for attempting to trick a client into contacting an AS that is not supposed to be in charge of that RS. Therefore, C must not communicate with an AS if it cannot determine that this AS has the authority to issue access tokens for this RS. Otherwise, a compromised RS may use this to perform a

denial of service attack against a specific AS, by redirecting a large number of client requests to that AS.

6.5. Minimal security requirements for communication

This section summarizes the minimal requirements for the communication security of the different protocol interactions.

C-AS All communication between the client and the Authorization Server MUST be encrypted, integrity and replay protected. Furthermore responses from the AS to the client MUST be bound to the client's request to avoid attacks where the attacker swaps the intended response for an older one valid for a previous request. This requires that the client and the Authorization Server have previously exchanged either a shared secret or their public keys in order to negotiate a secure communication. Furthermore the client MUST be able to determine whether an AS has the authority to issue access tokens for a certain RS. This can for example be done through pre-configured lists, or through an online lookup mechanism that in turn also must be secured.

RS-AS The communication between the Resource Server and the Authorization Server via the introspection endpoint MUST be encrypted, integrity and replay protected. Furthermore responses from the AS to the RS MUST be bound to the RS's request. This requires that the RS and the Authorization Server have previously exchanged either a shared secret, or their public keys in order to negotiate a secure communication. Furthermore the RS MUST be able to determine whether an AS has the authority to issue access tokens itself. This is usually configured out of band, but could also be performed through an online lookup mechanism provided that it is also secured in the same way.

C-RS The initial communication between the client and the Resource Server can not be secured in general, since the RS is not in possession of on access token for that client, which would carry the necessary parameters. If both parties support DTLS without client authentication it is RECOMMEND to use this mechanism for protecting the initial communication. After the client has successfully transmitted the access token to the RS, a secure communication protocol MUST be established between client and RS for the actual resource request. This protocol MUST provide confidentiality, integrity and replay protection as well as a binding between requests and responses. This requires that the client learned either the RS's public key or received a symmetric proof-of-possession key bound to the access token from the AS. The RS must have learned either the client's public key or a shared symmetric key from the claims in the token or an

introspection request. Since ACE does not provide profile negotiation between C and RS, the client MUST have learned what profile the RS supports (e.g. from the AS or pre-configured) and initiate the communication accordingly.

6.6. Token Freshness and Expiration

An RS that is offline faces the problem of clock drift. Since it cannot synchronize its clock with the AS, it may be tricked into accepting old access tokens that are no longer valid or have been compromised. In order to prevent this, an RS may use the nonce-based mechanism defined in Section 5.3 to ensure freshness of an Access Token subsequently presented to this RS.

Another problem with clock drift is that evaluating the standard token expiration claim "exp" can give unpredictable results.

Acceptable ranges of clock drift are highly dependent on the concrete application. Important factors are how long access tokens are valid, and how critical timely expiration of access token is.

The expiration mechanism implemented by the "exi" claim, based on the first time the RS sees the token was defined to provide a more predictable alternative. The "exi" approach has some drawbacks that need to be considered:

A malicious client may hold back tokens with the "exi" claim in order to prolong their lifespan.

If an RS loses state (e.g. due to an unscheduled reboot), it may loose the current values of counters tracking the "exi" claims of tokens it is storing.

The first drawback is inherent to the deployment scenario and the "exi" solution. It can therefore not be mitigated without requiring the the RS be online at times. The second drawback can be mitigated by regularly storing the value of "exi" counters to persistent memory.

6.7. Combining profiles

There may be use cases were different profiles of this framework are combined. For example, an MQTT-TLS profile is used between the client and the RS in combination with a CoAP-DTLS profile for interactions between the client and the AS. The security of a profile MUST NOT depend on the assumption that the profile is used for all the different types of interactions in this framework.

6.8. Unprotected Information

Communication with the authz-info endpoint, as well as the various error responses defined in this framework, all potentially include sending information over an unprotected channel. These messages may leak information to an adversary, or may be manipulated by active attackers to induce incorrect behavior. For example error responses for requests to the Authorization Information endpoint can reveal information about an otherwise opaque access token to an adversary who has intercepted this token.

As far as error messages are concerned, this framework is written under the assumption that, in general, the benefits of detailed error messages outweigh the risk due to information leakage. For particular use cases, where this assessment does not apply, detailed error messages can be replaced by more generic ones.

In some scenarios it may be possible to protect the communication with the authz-info endpoint (e.g. through DTLS with only server-side authentication). In cases where this is not possible this framework RECOMMENDS to use encrypted CWTs or tokens that are opaque references and need to be subjected to introspection by the RS.

If the initial unauthorized resource request message (see Section 5.2) is used, the client MUST make sure that it is not sending sensitive content in this request. While GET and DELETE requests only reveal the target URI of the resource, POST and PUT requests would reveal the whole payload of the intended operation.

Since the client is not authenticated at the point when it is submitting an access token to the authz-info endpoint, attackers may be pretending to be a client and trying to trick an RS to use an obsolete profile that in turn specifies a vulnerable security mechanism via the authz-info endpoint. Such an attack would require a valid access token containing an "ace_profile" claim requesting the use of said obsolete profile. Resource Owners should update the configuration of their RS's to prevent them from using such obsolete profiles.

6.9. Identifying audiences

The audience claim as defined in [RFC7519] and the equivalent "audience" parameter from [RFC8693] are intentionally vague on how to match the audience value to a specific RS. This is intended to allow application specific semantics to be used. This section attempts to give some general guidance for the use of audiences in constrained environments.

URLs are not a good way of identifying mobile devices that can switch networks and thus be associated with new URLs. If the audience represents a single RS, and asymmetric keys are used, the RS can be uniquely identified by a hash of its public key. If this approach is used this framework RECOMMENDS to apply the procedure from section 3 of [RFC6920].

If the audience addresses a group of resource servers, the mapping of group identifier to individual RS has to be provisioned to each RS before the group-audience is usable. Managing dynamic groups could be an issue, if any RS is not always reachable when the groups' memberships change. Furthermore, issuing access tokens bound to symmetric proof-of-possession keys that apply to a group-audience is problematic, as an RS that is in possession of the access token can impersonate the client towards the other RSs that are part of the group. It is therefore NOT RECOMMENDED to issue access tokens bound to a group audience and symmetric proof-of possession keys.

Even the client must be able to determine the correct values to put into the "audience" parameter, in order to obtain a token for the intended RS. Errors in this process can lead to the client inadvertently obtaining a token for the wrong RS. The correct values for "audience" can either be provisioned to the client as part of its configuration, or dynamically looked up by the client in some directory. In the latter case the integrity and correctness of the directory data must be assured. Note that the "audience" hint provided by the RS as part of the "AS Request Creation Hints" Section 5.3 is not typically source authenticated and integrity protected, and should therefore not be treated a trusted value.

6.10. Denial of service against or with Introspection

The optional introspection mechanism provided by OAuth and supported in the ACE framework allows for two types of attacks that need to be considered by implementers.

First, an attacker could perform a denial of service attack against the introspection endpoint at the AS in order to prevent validation of access tokens. To maintain the security of the system, an RS that is configured to use introspection MUST NOT allow access based on a token for which it couldn't reach the introspection endpoint.

Second, an attacker could use the fact that an RS performs introspection to perform a denial of service attack against that RS by repeatedly sending tokens to its authz-info endpoint that require an introspection call. RS can mitigate such attacks by implementing rate limits on how many introspection requests they perform in a given time interval for a certain client IP address submitting tokens

to /authz-info. When that limit has been reached, incoming requests from that address are rejected for a certain amount of time. A general rate limit on the introspection requests should also be considered, to mitigate distributed attacks.

7. Privacy Considerations

Implementers and users should be aware of the privacy implications of the different possible deployments of this framework.

The AS is in a very central position and can potentially learn sensitive information about the clients requesting access tokens. If the client credentials grant is used, the AS can track what kind of access the client intends to perform. With other grants this can be prevented by the Resource Owner. To do so, the resource owner needs to bind the grants it issues to anonymous, ephemeral credentials that do not allow the AS to link different grants and thus different access token requests by the same client.

The claims contained in a token can reveal privacy sensitive information about the client and the RS to any party having access to them (whether by processing the content of a self-contained token or by introspection). The AS SHOULD be configured to minimize the information about clients and RSs disclosed in the tokens it issues.

If tokens are only integrity protected and not encrypted, they may reveal information to attackers listening on the wire, or able to acquire the access tokens in some other way. In the case of CWTs the token may, e.g., reveal the audience, the scope and the confirmation method used by the client. The latter may reveal the identity of the device or application running the client. This may be linkable to the identity of the person using the client (if there is a person and not a machine-to-machine interaction).

Clients using asymmetric keys for proof-of-possession should be aware of the consequences of using the same key pair for proof-of-possession towards different RSs. A set of colluding RSs or an attacker able to obtain the access tokens will be able to link the requests, or even to determine the client's identity.

An unprotected response to an unauthorized request (see Section 5.3) may disclose information about RS and/or its existing relationship with C. It is advisable to include as little information as possible in an unencrypted response. Even the absolute URI of the AS may reveal sensitive information about the service that RS provides. Developers must ensure that the RS does not disclose information that has an impact on the privacy of the stakeholders in the AS Request Creation Hints. They may choose to use a different mechanism for the

discovery of the AS if necessary. If means of encrypting communication between C and RS already exist, more detailed information may be included with an error response to provide C with sufficient information to react on that particular error.

8. IANA Considerations

This document creates several registries with a registration policy of "Expert Review"; guidelines to the experts are given in Section 8.17.

8.1. ACE Authorization Server Request Creation Hints

This specification establishes the IANA "ACE Authorization Server Request Creation Hints" registry. The registry has been created to use the "Expert Review" registration procedure [RFC8126]. It should be noted that, in addition to the expert review, some portions of the registry require a specification, potentially a Standards Track RFC, be supplied as well.

The columns of the registry are:

Name The name of the parameter

CBOR Key CBOR map key for the parameter. Different ranges of values use different registration policies [RFC8126]. Integer values from -256 to 255 are designated as Standards Action. Integer values from -65536 to -257 and from 256 to 65535 are designated as Specification Required. Integer values greater than 65535 are designated as Expert Review. Integer values less than -65536 are marked as Private Use.

Value Type The CBOR data types allowable for the values of this parameter.

Reference This contains a pointer to the public specification of the request creation hint abbreviation, if one exists.

This registry will be initially populated by the values in Figure 2. The Reference column for all of these entries will be this document.

8.2. CoRE Resource Type registry

IANA is requested to register a new Resource Type (rt=) Link Target Attribute in the "Resource Type (rt=) Link Target Attribute Values" subregistry under the "Constrained RESTful Environments (CoRE) Parameters" [IANA.CoreParameters] registry:

rt="ace.ai". This resource type describes an ACE-OAuth authz-info endpoint resource.

Specific ACE-OAuth profiles can use this common resource type for defining their profile-specific discovery processes.

8.3. OAuth Extensions Error Registration

This specification registers the following error values in the OAuth Extensions Error registry [IANA.OAuthExtensionsErrorRegistry].

- Error name: "unsupported_pop_key"
- Error usage location: token error response
- Related protocol extension: [this document]
- Change Controller: IESG
- Specification document(s): Section 5.8.3 of [this document]

- Error name: "incompatible_ace_profiles"
- Error usage location: token error response
- Related protocol extension: [this document]
- Change Controller: IESG
- Specification document(s): Section 5.8.3 of [this document]

8.4. OAuth Error Code CBOR Mappings Registry

This specification establishes the IANA "OAuth Error Code CBOR Mappings" registry. The registry has been created to use the "Expert Review" registration procedure [RFC8126], except for the value range designated for private use.

The columns of the registry are:

Name The OAuth Error Code name, refers to the name in Section 5.2. of [RFC6749], e.g., "invalid_request".
CBOR Value CBOR abbreviation for this error code. Integer values less than -65536 are marked as "Private Use", all other values use the registration policy "Expert Review" [RFC8126].
Reference This contains a pointer to the public specification of the error code abbreviation, if one exists.

This registry will be initially populated by the values in Figure 10. The Reference column for all of these entries will be this document.

8.5. OAuth Grant Type CBOR Mappings

This specification establishes the IANA "OAuth Grant Type CBOR Mappings" registry. The registry has been created to use the "Expert

Review" registration procedure [RFC8126], except for the value range designated for private use.

The columns of this registry are:

Name The name of the grant type as specified in Section 1.3 of [RFC6749].
CBOR Value CBOR abbreviation for this grant type. Integer values less than -65536 are marked as "Private Use", all other values use the registration policy "Expert Review" [RFC8126].
Reference This contains a pointer to the public specification of the grant type abbreviation, if one exists.
Original Specification This contains a pointer to the public specification of the grant type, if one exists.

This registry will be initially populated by the values in Figure 11. The Reference column for all of these entries will be this document.

8.6. OAuth Access Token Types

This section registers the following new token type in the "OAuth Access Token Types" registry [IANA.OAuthAccessTokenTypes].

- Type name: "PoP"
- Additional Token Endpoint Response Parameters: "cnf", "rs_cnf" see section 3.3 of [I-D.ietf-ace-oauth-params].
- HTTP Authentication Scheme(s): N/A
- Change Controller: IETF
- Specification document(s): [this document]

8.7. OAuth Access Token Type CBOR Mappings

This specification established the IANA "OAuth Access Token Type CBOR Mappings" registry. The registry has been created to use the "Expert Review" registration procedure [RFC8126], except for the value range designated for private use.

The columns of this registry are:

Name The name of token type as registered in the OAuth Access Token Types registry, e.g., "Bearer".
CBOR Value CBOR abbreviation for this token type. Integer values less than -65536 are marked as "Private Use", all other values use the registration policy "Expert Review" [RFC8126].
Reference This contains a pointer to the public specification of the OAuth token type abbreviation, if one exists.
Original Specification This contains a pointer to the public specification of the OAuth token type, if one exists.

8.7.1. Initial Registry Contents

- Name: "Bearer"
- Value: 1
- Reference: [this document]
- Original Specification: [RFC6749]

- Name: "PoP"
- Value: 2
- Reference: [this document]
- Original Specification: [this document]

8.8. ACE Profile Registry

This specification establishes the IANA "ACE Profile" registry. The registry has been created to use the "Expert Review" registration procedure [RFC8126]. It should be noted that, in addition to the expert review, some portions of the registry require a specification, potentially a Standards Track RFC, be supplied as well.

The columns of this registry are:

Name The name of the profile, to be used as value of the profile attribute.

Description Text giving an overview of the profile and the context it is developed for.

CBOR Value CBOR abbreviation for this profile name. Different ranges of values use different registration policies [RFC8126]. Integer values from -256 to 255 are designated as Standards Action. Integer values from -65536 to -257 and from 256 to 65535 are designated as Specification Required. Integer values greater than 65535 are designated as "Expert Review". Integer values less than -65536 are marked as Private Use.

Reference This contains a pointer to the public specification of the profile abbreviation, if one exists.

This registry will be initially empty and will be populated by the registrations from the ACE framework profiles.

8.9. OAuth Parameter Registration

This specification registers the following parameter in the "OAuth Parameters" registry [IANA.OAuthParameters]:

- Name: "ace_profile"
- Parameter Usage Location: token response
- Change Controller: IESG
- Reference: Section 5.8.2 and Section 5.8.4.3 of [this document]

8.10. OAuth Parameters CBOR Mappings Registry

This specification establishes the IANA "OAuth Parameters CBOR Mappings" registry. The registry has been created to use the "Expert Review" registration procedure [RFC8126], except for the value range designated for private use.

The columns of this registry are:

Name The OAuth Parameter name, refers to the name in the OAuth parameter registry, e.g., "client_id".
CBOR Key CBOR map key for this parameter. Integer values less than -65536 are marked as "Private Use", all other values use the registration policy "Expert Review" [RFC8126].
Value Type The allowable CBOR data types for values of this parameter.
Reference This contains a pointer to the public specification of the OAuth parameter abbreviation, if one exists.

This registry will be initially populated by the values in Figure 12. The Reference column for all of these entries will be this document.

8.11. OAuth Introspection Response Parameter Registration

This specification registers the following parameters in the OAuth Token Introspection Response registry [IANA.TokenIntrospectionResponse].

- Name: "ace_profile"
- Description: The ACE profile used between client and RS.
- Change Controller: IESG
- Reference: Section 5.9.2 of [this document]

- Name: "cnonce"
- Description: "client-nonce". A nonce previously provided to the AS by the RS via the client. Used to verify token freshness when the RS cannot synchronize its clock with the AS.
- Change Controller: IESG
- Reference: Section 5.9.2 of [this document]

- Name: "exi"
- Description: "Expires in". Lifetime of the token in seconds from the time the RS first sees it. Used to implement a weaker from of token expiration for devices that cannot synchronize their internal clocks.
- Change Controller: IESG
- Reference: Section 5.9.2 of [this document]

8.12. OAuth Token Introspection Response CBOR Mappings Registry

This specification establishes the IANA "OAuth Token Introspection Response CBOR Mappings" registry. The registry has been created to use the "Expert Review" registration procedure [RFC8126], except for the value range designated for private use.

The columns of this registry are:

Name The OAuth Parameter name, refers to the name in the OAuth parameter registry, e.g., "client_id".
CBOR Key CBOR map key for this parameter. Integer values less than -65536 are marked as "Private Use", all other values use the registration policy "Expert Review" [RFC8126].
Value Type The allowable CBOR data types for values of this parameter.
Reference This contains a pointer to the public specification of the introspection response parameter abbreviation, if one exists.

This registry will be initially populated by the values in Figure 16. The Reference column for all of these entries will be this document.

Note that the mappings of parameters corresponding to claim names intentionally coincide with the CWT claim name mappings from [RFC8392].

8.13. JSON Web Token Claims

This specification registers the following new claims in the JSON Web Token (JWT) registry of JSON Web Token Claims [IANA.JsonWebTokenClaims]:

- Claim Name: "ace_profile"
- Claim Description: The ACE profile a token is supposed to be used with.
- Change Controller: IESG
- Reference: Section 5.10 of [this document]

- Claim Name: "cnonce"
- Claim Description: "client-nonce". A nonce previously provided to the AS by the RS via the client. Used to verify token freshness when the RS cannot synchronize its clock with the AS.
- Change Controller: IESG
- Reference: Section 5.10 of [this document]

- Claim Name: "exi"
- Claim Description: "Expires in". Lifetime of the token in seconds from the time the RS first sees it. Used to implement a weaker

from of token expiration for devices that cannot synchronize their internal clocks.
- Change Controller: IESG
- Reference: Section 5.10.3 of [this document]

8.14. CBOR Web Token Claims

This specification registers the following new claims in the "CBOR Web Token (CWT) Claims" registry [IANA.CborWebTokenClaims].

- Claim Name: "ace_profile"
- Claim Description: The ACE profile a token is supposed to be used with.
- JWT Claim Name: ace_profile
- Claim Key: TBD (suggested: 38)
- Claim Value Type(s): integer
- Change Controller: IESG
- Specification Document(s): Section 5.10 of [this document]

- Claim Name: "cnonce"
- Claim Description: The client-nonce sent to the AS by the RS via the client.
- JWT Claim Name: cnonce
- Claim Key: TBD (suggested: 39)
- Claim Value Type(s): byte string
- Change Controller: IESG
- Specification Document(s): Section 5.10 of [this document]

- Claim Name: "exi"
- Claim Description: The expiration time of a token measured from when it was received at the RS in seconds.
- JWT Claim Name: exi
- Claim Key: TBD (suggested: 40)
- Claim Value Type(s): integer
- Change Controller: IESG
- Specification Document(s): Section 5.10.3 of [this document]

- Claim Name: "scope"
- Claim Description: The scope of an access token as defined in [RFC6749].
- JWT Claim Name: scope
- Claim Key: TBD (suggested: 9)
- Claim Value Type(s): byte string or text string
- Change Controller: IESG
- Specification Document(s): Section 4.2 of [RFC8693]

8.15. Media Type Registrations

This specification registers the 'application/ace+cbor' media type for messages of the protocols defined in this document carrying parameters encoded in CBOR. This registration follows the procedures specified in [RFC6838].

Type name: application

Subtype name: ace+cbor

Required parameters: N/A

Optional parameters: N/A

Encoding considerations: Must be encoded as CBOR map containing the protocol parameters defined in [this document].

Security considerations: See Section 6 of [this document]

Interoperability considerations: N/A

Published specification: [this document]

Applications that use this media type: The type is used by authorization servers, clients and resource servers that support the ACE framework as specified in [this document].

Fragment identifier considerations: N/A

Additional information: N/A

Person & email address to contact for further information: <iesg@ietf.org>

Intended usage: COMMON

Restrictions on usage: none

Author: Ludwig Seitz <ludwig.seitz@combitech.se>

Change controller: IESG

8.16. CoAP Content-Format Registry

This specification registers the following entry to the "CoAP Content-Formats" registry:

Media Type: application/ace+cbor

Encoding: -

ID: TBD (suggested: 19)

Reference: [this document]

8.17. Expert Review Instructions

All of the IANA registries established in this document are defined to use a registration policy of Expert Review. This section gives some general guidelines for what the experts should be looking for, but they are being designated as experts for a reason, so they should be given substantial latitude.

Expert reviewers should take into consideration the following points:

- Point squatting should be discouraged. Reviewers are encouraged to get sufficient information for registration requests to ensure that the usage is not going to duplicate one that is already registered, and that the point is likely to be used in deployments. The zones tagged as private use are intended for testing purposes and closed environments; code points in other ranges should not be assigned for testing.
- Specifications are needed for the first-come, first-serve range if they are expected to be used outside of closed environments in an interoperable way. When specifications are not provided, the description provided needs to have sufficient information to identify what the point is being used for.
- Experts should take into account the expected usage of fields when approving point assignment. The fact that there is a range for standards track documents does not mean that a standards track document cannot have points assigned outside of that range. The length of the encoded value should be weighed against how many code points of that length are left, the size of device it will be used on.
- Since a high degree of overlap is expected between these registries and the contents of the OAuth parameters [IANA.OAuthParameters] registries, experts should require new registrations to maintain alignment with parameters from OAuth that have comparable functionality. Deviation from this alignment should only be allowed if there are functional differences, that are motivated by the use case and that cannot be easily or efficiently addressed by comparable OAuth parameters.

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Appendix A. Design Justification

This section provides further insight into the design decisions of the solution documented in this document. Section 3 lists several building blocks and briefly summarizes their importance. The justification for offering some of those building blocks, as opposed to using OAuth 2.0 as is, is given below.

Common IoT constraints are:

Low Power Radio:

Many IoT devices are equipped with a small battery which needs to last for a long time. For many constrained wireless devices, the highest energy cost is associated to transmitting or receiving messages (roughly by a factor of 10 compared to AES) [Margi10impact]. It is therefore important to keep the total communication overhead low, including minimizing the number and size of messages sent and received, which has an impact of choice on the message format and protocol. By using CoAP over UDP and CBOR encoded messages, some of these aspects are addressed. Security protocols contribute to the communication overhead and can, in some cases, be optimized. For example, authentication and key establishment may, in certain cases where security requirements allow, be replaced by provisioning of security context by a trusted third party, using transport or application layer security.

Low CPU Speed:

Some IoT devices are equipped with processors that are significantly slower than those found in most current devices on the Internet. This typically has implications on what timely cryptographic operations a device is capable of performing, which in turn impacts, e.g., protocol latency. Symmetric key cryptography may be used instead of the computationally more expensive public key cryptography where the security requirements so allow, but this may also require support for trusted-third-party-assisted secret key establishment using transport- or application-layer security.

Small Amount of Memory:

Microcontrollers embedded in IoT devices are often equipped with only a small amount of RAM and flash memory, which places limitations on what kind of processing can be performed and how much code can be put on those devices. To reduce code size, fewer and smaller protocol implementations can be put on the firmware of such a device. In this case, CoAP may be used instead of HTTP, symmetric-key cryptography instead of public-key cryptography, and CBOR instead of JSON. An authentication and key establishment protocol, e.g., the DTLS handshake, in comparison with assisted key establishment, also has an impact on memory and code footprints.

User Interface Limitations:

Protecting access to resources is both an important security as well as privacy feature. End users and enterprise customers may

not want to give access to the data collected by their IoT device or to functions it may offer to third parties. Since the classical approach of requesting permissions from end users via a rich user interface does not work in many IoT deployment scenarios, these functions need to be delegated to user-controlled devices that are better suitable for such tasks, such as smart phones and tablets.

Communication Constraints:

In certain constrained settings an IoT device may not be able to communicate with a given device at all times. Devices may be sleeping, or just disconnected from the Internet because of general lack of connectivity in the area, for cost reasons, or for security reasons, e.g., to avoid an entry point for Denial-of-Service attacks.

The communication interactions this framework builds upon (as shown graphically in Figure 1) may be accomplished using a variety of different protocols, and not all parts of the message flow are used in all applications due to the communication constraints. Deployments making use of CoAP are expected, but this framework is not limited to them. Other protocols such as HTTP, or even protocols such as Bluetooth Smart communication that do not necessarily use IP, could also be used. The latter raises the need for application layer security over the various interfaces.

In the light of these constraints we have made the following design decisions:

CBOR, COSE, CWT:

This framework RECOMMENDS the use of CBOR [RFC7049] as data format. Where CBOR data needs to be protected, the use of COSE [RFC8152] is RECOMMENDED. Furthermore, where self-contained tokens are needed, this framework RECOMMENDS the use of CWT [RFC8392]. These measures aim at reducing the size of messages sent over the wire, the RAM size of data objects that need to be kept in memory and the size of libraries that devices need to support.

CoAP:

This framework RECOMMENDS the use of CoAP [RFC7252] instead of HTTP. This does not preclude the use of other protocols specifically aimed at constrained devices, like, e.g., Bluetooth Low Energy (see Section 3.2). This aims again at reducing the size of messages sent over the wire, the RAM size of data objects

that need to be kept in memory and the size of libraries that devices need to support.

Access Information:

This framework defines the name "Access Information" for data concerning the RS that the AS returns to the client in an access token response (see Section 5.8.2). This aims at enabling scenarios where a powerful client, supporting multiple profiles, needs to interact with an RS for which it does not know the supported profiles and the raw public key.

Proof-of-Possession:

This framework makes use of proof-of-possession tokens, using the "cnf" claim [RFC8747]. A request parameter "cnf" and a Response parameter "cnf", both having a value space semantically and syntactically identical to the "cnf" claim, are defined for the token endpoint, to allow requesting and stating confirmation keys. This aims at making token theft harder. Token theft is specifically relevant in constrained use cases, as communication often passes through middle-boxes, which could be able to steal bearer tokens and use them to gain unauthorized access.

Authz-Info endpoint:

This framework introduces a new way of providing access tokens to an RS by exposing a authz-info endpoint, to which access tokens can be POSTed. This aims at reducing the size of the request message and the code complexity at the RS. The size of the request message is problematic, since many constrained protocols have severe message size limitations at the physical layer (e.g., in the order of 100 bytes). This means that larger packets get fragmented, which in turn combines badly with the high rate of packet loss, and the need to retransmit the whole message if one packet gets lost. Thus separating sending of the request and sending of the access tokens helps to reduce fragmentation.

Client Credentials Grant:

This framework RECOMMENDS the use of the client credentials grant for machine-to-machine communication use cases, where manual intervention of the resource owner to produce a grant token is not feasible. The intention is that the resource owner would instead pre-arrange authorization with the AS, based on the client's own credentials. The client can then (without manual intervention) obtain access tokens from the AS.

Introspection:

This framework RECOMMENDS the use of access token introspection in cases where the client is constrained in a way that it can not easily obtain new access tokens (i.e. it has connectivity issues that prevent it from communicating with the AS). In that case this framework RECOMMENDS the use of a long-term token, that could be a simple reference. The RS is assumed to be able to communicate with the AS, and can therefore perform introspection, in order to learn the claims associated with the token reference. The advantage of such an approach is that the resource owner can change the claims associated to the token reference without having to be in contact with the client, thus granting or revoking access rights.

Appendix B. Roles and Responsibilities

Resource Owner

* Make sure that the RS is registered at the AS. This includes making known to the AS which profiles, token_type, scopes, and key types (symmetric/asymmetric) the RS supports. Also making it known to the AS which audience(s) the RS identifies itself with.
* Make sure that clients can discover the AS that is in charge of the RS.
* If the client-credentials grant is used, make sure that the AS has the necessary, up-to-date, access control policies for the RS.

Requesting Party

* Make sure that the client is provisioned the necessary credentials to authenticate to the AS.
* Make sure that the client is configured to follow the security requirements of the Requesting Party when issuing requests (e.g., minimum communication security requirements, trust anchors).
* Register the client at the AS. This includes making known to the AS which profiles, token_types, and key types (symmetric/ asymmetric) the client.

Authorization Server

* Register the RS and manage corresponding security contexts.
* Register clients and authentication credentials.

* Allow Resource Owners to configure and update access control policies related to their registered RSs.
* Expose the token endpoint to allow clients to request tokens.
* Authenticate clients that wish to request a token.
* Process a token request using the authorization policies configured for the RS.
* Optionally: Expose the introspection endpoint that allows RS's to submit token introspection requests.
* If providing an introspection endpoint: Authenticate RSs that wish to get an introspection response.
* If providing an introspection endpoint: Process token introspection requests.
* Optionally: Handle token revocation.
* Optionally: Provide discovery metadata. See [RFC8414]
* Optionally: Handle refresh tokens.

Client

* Discover the AS in charge of the RS that is to be targeted with a request.
* Submit the token request (see step (A) of Figure 1).
  + Authenticate to the AS.
  + Optionally (if not pre-configured): Specify which RS, which resource(s), and which action(s) the request(s) will target.
  + If raw public keys (rpk) or certificates are used, make sure the AS has the right rpk or certificate for this client.
* Process the access token and Access Information (see step (B) of Figure 1).
  + Check that the Access Information provides the necessary security parameters (e.g., PoP key, information on communication security protocols supported by the RS).
  + Safely store the proof-of-possession key.
  + If provided by the AS: Safely store the refresh token.
* Send the token and request to the RS (see step (C) of Figure 1).
  + Authenticate towards the RS (this could coincide with the proof of possession process).
  + Transmit the token as specified by the AS (default is to the authz-info endpoint, alternative options are specified by profiles).
  + Perform the proof-of-possession procedure as specified by the profile in use (this may already have been taken care of through the authentication procedure).
* Process the RS response (see step (F) of Figure 1) of the RS.

Resource Server

* Expose a way to submit access tokens. By default this is the authz-info endpoint.
* Process an access token.
  + Verify the token is from a recognized AS.
  + Check the token's integrity.
  + Verify that the token applies to this RS.
  + Check that the token has not expired (if the token provides expiration information).
  + Store the token so that it can be retrieved in the context of a matching request.

  Note: The order proposed here is not normative, any process that arrives at an equivalent result can be used. A noteworthy consideration is whether one can use cheap operations early on to quickly discard non-applicable or invalid tokens, before performing expensive cryptographic operations (e.g. doing an expiration check before verifying a signature).

* Process a request.
  + Set up communication security with the client.
  + Authenticate the client.
  + Match the client against existing tokens.
  + Check that tokens belonging to the client actually authorize the requested action.
  + Optionally: Check that the matching tokens are still valid, using introspection (if this is possible.)
* Send a response following the agreed upon communication security mechanism(s).
* Safely store credentials such as raw public keys for authentication or proof-of-possession keys linked to access tokens.

Appendix C. Requirements on Profiles

This section lists the requirements on profiles of this framework, for the convenience of profile designers.

- Optionally define new methods for the client to discover the necessary permissions and AS for accessing a resource, different from the one proposed in Section 5.1. Section 4
- Optionally specify new grant types. Section 5.4
- Optionally define the use of client certificates as client credential type. Section 5.5

- Specify the communication protocol the client and RS the must use (e.g., CoAP). Section 5 and Section 5.8.4.3
- Specify the security protocol the client and RS must use to protect their communication (e.g., OSCORE or DTLS). This must provide encryption, integrity and replay protection. Section 5.8.4.3
- Specify how the client and the RS mutually authenticate. Section 4
- Specify the proof-of-possession protocol(s) and how to select one, if several are available. Also specify which key types (e.g., symmetric/asymmetric) are supported by a specific proof-of-possession protocol. Section 5.8.4.2
- Specify a unique ace_profile identifier. Section 5.8.4.3
- If introspection is supported: Specify the communication and security protocol for introspection. Section 5.9
- Specify the communication and security protocol for interactions between client and AS. This must provide encryption, integrity protection, replay protection and a binding between requests and responses. Section 5 and Section 5.8
- Specify how/if the authz-info endpoint is protected, including how error responses are protected. Section 5.10.1
- Optionally define other methods of token transport than the authz-info endpoint. Section 5.10.1

Appendix D. Assumptions on AS knowledge about C and RS

This section lists the assumptions on what an AS should know about a client and an RS in order to be able to respond to requests to the token and introspection endpoints. How this information is established is out of scope for this document.

- The identifier of the client or RS.
- The profiles that the client or RS supports.
- The scopes that the RS supports.
- The audiences that the RS identifies with.
- The key types (e.g., pre-shared symmetric key, raw public key, key length, other key parameters) that the client or RS supports.
- The types of access tokens the RS supports (e.g., CWT).
- If the RS supports CWTs, the COSE parameters for the crypto wrapper (e.g., algorithm, key-wrap algorithm, key-length) that the RS supports.
- The expiration time for access tokens issued to this RS (unless the RS accepts a default time chosen by the AS).
- The symmetric key shared between client and AS (if any).
- The symmetric key shared between RS and AS (if any).
- The raw public key of the client or RS (if any).
- Whether the RS has synchronized time (and thus is able to use the 'exp' claim) or not.

Appendix E. Deployment Examples

There is a large variety of IoT deployments, as is indicated in Appendix A, and this section highlights a few common variants. This section is not normative but illustrates how the framework can be applied.

For each of the deployment variants, there are a number of possible security setups between clients, resource servers and authorization servers. The main focus in the following subsections is on how authorization of a client request for a resource hosted by an RS is performed. This requires the security of the requests and responses between the clients and the RS to be considered.

Note: CBOR diagnostic notation is used for examples of requests and responses.

E.1. Local Token Validation

In this scenario, the case where the resource server is offline is considered, i.e., it is not connected to the AS at the time of the access request. This access procedure involves steps A, B, C, and F of Figure 1.

Since the resource server must be able to verify the access token locally, self-contained access tokens must be used.

This example shows the interactions between a client, the authorization server and a temperature sensor acting as a resource server. Message exchanges A and B are shown in Figure 17.

A: The client first generates a public-private key pair used for communication security with the RS.
The client sends a CoAP POST request to the token endpoint at the AS. The security of this request can be transport or application layer. It is up the the communication security profile to define. In the example it is assumed that both client and AS have performed mutual authentication e.g. via DTLS. The request contains the public key of the client and the Audience parameter set to "tempSensorInLivingRoom", a value that the temperature sensor identifies itself with. The AS evaluates the request and authorizes the client to access the resource.
B: The AS responds with a 2.05 Content response containing the Access Information, including the access token. The PoP access token contains the public key of the client, and the Access Information contains the public key of the RS. For communication security this example uses DTLS RawPublicKey between the client and the RS. The issued token will have a short validity time,

i.e., "exp" close to "iat", in order to mitigate attacks using stolen client credentials. The token includes the claim such as "scope" with the authorized access that an owner of the temperature device can enjoy. In this example, the "scope" claim, issued by the AS, informs the RS that the owner of the token, that can prove the possession of a key is authorized to make a GET request against the /temperature resource and a POST request on the /firmware resource. Note that the syntax and semantics of the scope claim are application specific.
Note: In this example it is assumed that the client knows what resource it wants to access, and is therefore able to request specific audience and scope claims for the access token.

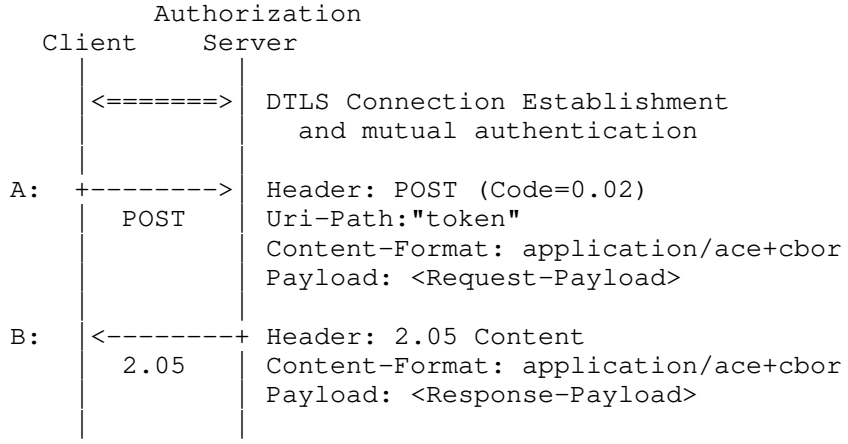

Figure 17: Token Request and Response Using Client Credentials.

The information contained in the Request-Payload and the Response-Payload is shown in Figure 18 Note that the parameter "rs_cnf" from [I-D.ietf-ace-oauth-params] is used to inform the client about the resource server's public key.

```
Request-Payload :
{
  "audience" : "tempSensorInLivingRoom",
  "client_id" : "myclient",
  "req_cnf" : {
    "COSE_Key" : {
      "kid" : b64'1Bg8vub9tLe1gHMzV76e8',
      "kty" : "EC",
      "crv" : "P-256",
      "x" : b64'f83OJ3D2xF1Bg8vub9tLe1gHMzV76e8Tus9uPHvRVEU',
      "y" : b64'x_FEzRu9m36HLN_tue659LNpXW6pCyStikYjKIWI5a0'
    }
  }
}

Response-Payload :
{
  "access_token" : b64'0INDoQEKoQVNKkXfb7xaWqMTf6 ...',
  "rs_cnf" : {
    "COSE_Key" : {
      "kid" : b64'c29tZSBwdWJsaWMga2V5IGlk',
      "kty" : "EC",
      "crv" : "P-256",
      "x"   : b64'MKBCTNIcKUSDii11ySs3526iDZ8AiTo7Tu6KPAqv7D4',
      "y"   : b64'4Etl6SRW2YiLUrN5vfvVHuhp7x8PxltmWWlbbM4IFyM'
    }
  }
}
```

Figure 18: Request and Response Payload Details.

The content of the access token is shown in Figure 19.

```
{
  "aud" : "tempSensorInLivingRoom",
  "iat" : "1563451500",
  "exp" : "1563453000",
  "scope" :  "temperature_g firmware_p",
  "cnf" : {
    "COSE_Key" : {
      "kid" : b64'1Bg8vub9tLe1gHMzV76e8',
      "kty" : "EC",
      "crv" : "P-256",
      "x" : b64'f83OJ3D2xF1Bg8vub9tLe1gHMzV76e8Tus9uPHvRVEU',
      "y" : b64'x_FEzRu9m36HLN_tue659LNpXW6pCyStikYjKIWI5a0'
    }
  }
}
```

Figure 19: Access Token including Public Key of the Client.

Messages C and F are shown in Figure 20 - Figure 21.

C: The client then sends the PoP access token to the authz-info endpoint at the RS. This is a plain CoAP POST request, i.e., no transport or application layer security is used between client and RS since the token is integrity protected between the AS and RS. The RS verifies that the PoP access token was created by a known and trusted AS, that it applies to this RS, and that it is valid. The RS caches the security context together with authorization information about this client contained in the PoP access token.

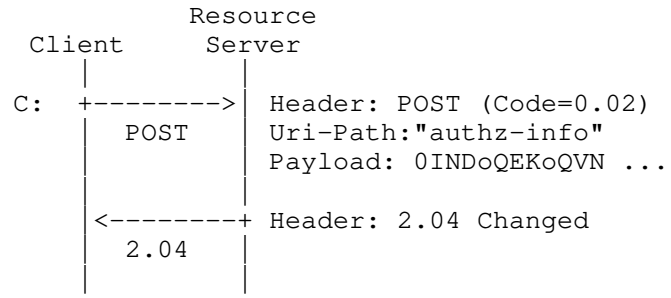

Figure 20: Access Token provisioning to RS

The client and the RS runs the DTLS handshake using the raw public keys established in step B and C.
The client sends a CoAP GET request to /temperature on RS over DTLS. The RS verifies that the request is authorized, based on previously established security context.

F: The RS responds over the same DTLS channel with a CoAP 2.05 Content response, containing a resource representation as payload.

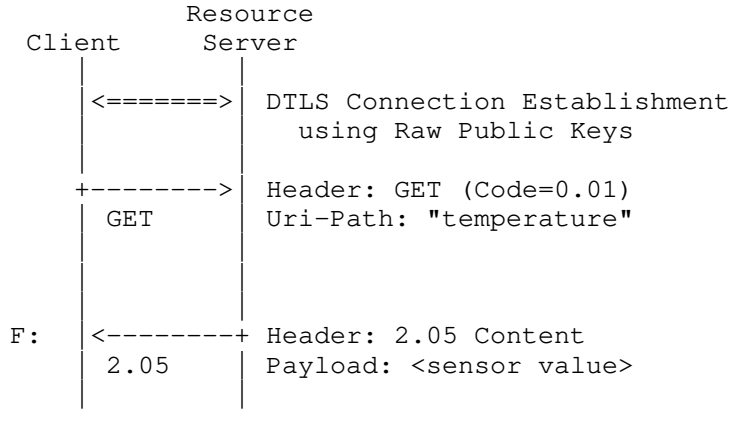

Figure 21: Resource Request and Response protected by DTLS.

E.2. Introspection Aided Token Validation

In this deployment scenario it is assumed that a client is not able to access the AS at the time of the access request, whereas the RS is assumed to be connected to the back-end infrastructure. Thus the RS can make use of token introspection. This access procedure involves steps A-F of Figure 1, but assumes steps A and B have been carried out during a phase when the client had connectivity to AS.

Since the client is assumed to be offline, at least for a certain period of time, a pre-provisioned access token has to be long-lived. Since the client is constrained, the token will not be self contained (i.e. not a CWT) but instead just a reference. The resource server uses its connectivity to learn about the claims associated to the access token by using introspection, which is shown in the example below.

In the example interactions between an offline client (key fob), an RS (online lock), and an AS is shown. It is assumed that there is a provisioning step where the client has access to the AS. This corresponds to message exchanges A and B which are shown in Figure 22.

Authorization consent from the resource owner can be pre-configured, but it can also be provided via an interactive flow with the resource owner. An example of this for the key fob case could be that the resource owner has a connected car, he buys a generic key that he wants to use with the car. To authorize the key fob he connects it

to his computer that then provides the UI for the device. After that OAuth 2.0 implicit flow can used to authorize the key for his car at the the car manufacturers AS.

Note: In this example the client does not know the exact door it will be used to access since the token request is not send at the time of access. So the scope and audience parameters are set quite wide to start with, while tailored values narrowing down the claims to the specific RS being accessed can be provided to that RS during an introspection step.

A: The client sends a CoAP POST request to the token endpoint at AS. The request contains the Audience parameter set to "PACS1337" (PACS, Physical Access System), a value the that identifies the physical access control system to which the individual doors are connected. The AS generates an access token as an opaque string, which it can match to the specific client and the targeted audience. It furthermore generates a symmetric proof-of-possession key. The communication security and authentication between client and AS is assumed to have been provided at transport layer (e.g. via DTLS) using a pre-shared security context (psk, rpk or certificate).
B: The AS responds with a CoAP 2.05 Content response, containing as playload the Access Information, including the access token and the symmetric proof-of-possession key. Communication security between C and RS will be DTLS and PreSharedKey. The PoP key is used as the PreSharedKey.

Note: In this example we are using a symmetric key for a multi-RS audience, which is not recommended normally (see Section 6.9). However in this case the risk is deemed to be acceptable, since all the doors are part of the same physical access control system, and therefore the risk of a malicious RS impersonating the client towards another RS is low.

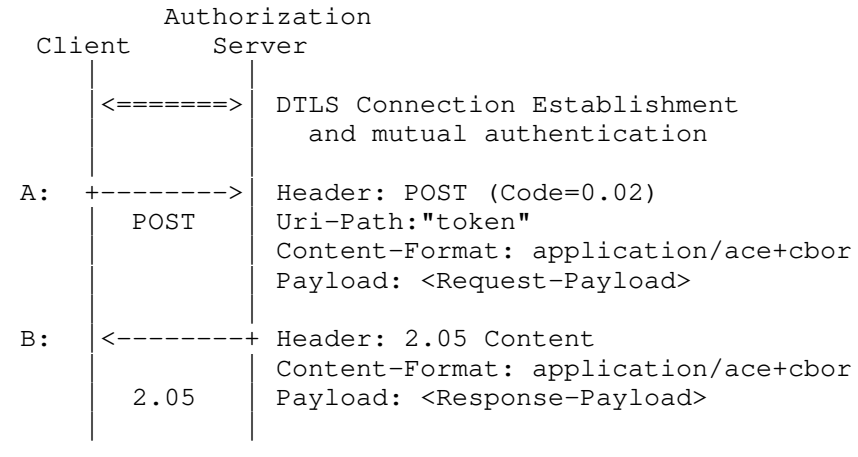

Figure 22: Token Request and Response using Client Credentials.

The information contained in the Request-Payload and the Response-Payload is shown in Figure 23.

```
Request-Payload:
{
  "client_id" : "keyfob",
  "audience" : "PACS1337"
}

Response-Payload:
{
  "access_token" : b64'VGVzdCB0b2tlbg==',
  "cnf" : {
    "COSE_Key" : {
      "kid" : b64'c29tZSBwdWJsaWMga2V5IGlk',
      "kty" : "oct",
      "alg" : "HS256",
      "k": b64'ZoRSOrFzN_FzUA5XKMYoVHyzff5oRJxl-IXRtztJ6uE'
    }
  }
}
```

Figure 23: Request and Response Payload for C offline

The access token in this case is just an opaque byte string referencing the authorization information at the AS.

C: Next, the client POSTs the access token to the authz-info endpoint in the RS. This is a plain CoAP request, i.e., no DTLS between client and RS. Since the token is an opaque string, the

RS cannot verify it on its own, and thus defers to respond the client with a status code until after step E.
D: The RS sends the token to the introspection endpoint on the AS using a CoAP POST request. In this example RS and AS are assumed to have performed mutual authentication using a pre shared security context (psk, rpk or certificate) with the RS acting as DTLS client.
E: The AS provides the introspection response (2.05 Content) containing parameters about the token. This includes the confirmation key (cnf) parameter that allows the RS to verify the client's proof of possession in step F. Note that our example in Figure 25 assumes a pre-established key (e.g. one used by the client and the RS for a previous token) that is now only referenced by its key-identifier 'kid'.
After receiving message E, the RS responds to the client's POST in step C with the CoAP response code 2.01 (Created).

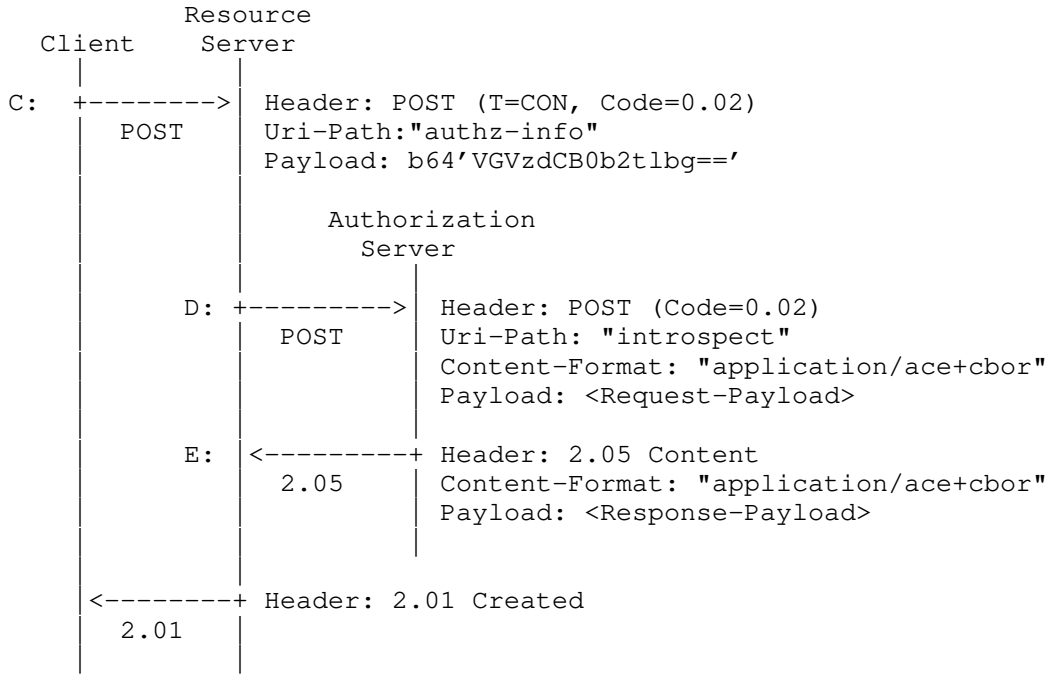

Figure 24: Token Introspection for C offline

The information contained in the Request-Payload and the Response-Payload is shown in Figure 25.

```
Request-Payload:
{
  "token" : b64'VGVzdCB0b2tlbg==',
  "client_id" : "FrontDoor",
}

Response-Payload:
{
  "active" : true,
  "aud" : "lockOfDoor4711",
  "scope" : "open, close",
  "iat" : 1563454000,
  "cnf" : {
    "kid" : b64'c29tZSBwdWJsaWMga2V5IGlk'
  }
}
```

Figure 25: Request and Response Payload for Introspection

The client uses the symmetric PoP key to establish a DTLS PreSharedKey secure connection to the RS. The CoAP request PUT is sent to the uri-path /state on the RS, changing the state of the door to locked.
F: The RS responds with a appropriate over the secure DTLS channel.

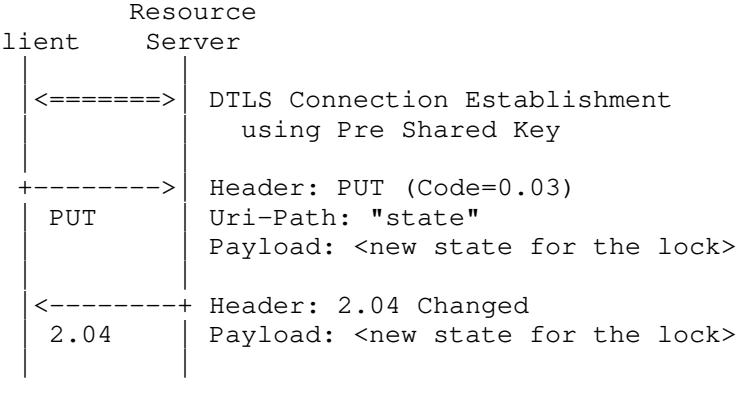

Figure 26: Resource request and response protected by OSCORE

Appendix F. Document Updates

RFC EDITOR: PLEASE REMOVE THIS SECTION.

F.1. Version -21 to 22

- Provided section numbers in references to OAuth RFC.
- Updated IANA mapping registries to only use "Private Use" and "Expert Review".
- Made error messages optional for RS at token submission since it may not be able to send them depending on the profile.
- Corrected errors in examples.

F.2. Version -20 to 21

- Added text about expiration of RS keys.

F.3. Version -19 to 20

- Replaced "req_aud" with "audience" from the OAuth token exchange draft.
- Updated examples to remove unnecessary elements.

F.4. Version -18 to -19

- Added definition of "Authorization Information".
- Explicitly state that ACE allows encoding refresh tokens in binary format in addition to strings.
- Renamed "AS Information" to "AS Request Creation Hints" and added the possibility to specify req_aud and scope as hints.
- Added the "kid" parameter to AS Request Creation Hints.
- Added security considerations about the integrity protection of tokens with multi-RS audiences.
- Renamed IANA registries mapping OAuth parameters to reflect the mapped registry.
- Added JWT claim names to CWT claim registrations.
- Added expert review instructions.
- Updated references to TLS from 1.2 to 1.3.

F.5. Version -17 to -18

- Added OSCORE options in examples involving OSCORE.
- Removed requirement for the client to send application/cwt, since the client has no way to know.
- Clarified verification of tokens by the RS.
- Added exi claim CWT registration.

F.6. Version -16 to -17

- Added references to (D)TLS 1.3.
- Added requirement that responses are bound to requests.

- Specify that grant_type is OPTIONAL in C2AS requests (as opposed to REQUIRED in OAuth).
- Replaced examples with hypothetical COSE profile with OSCORE.
- Added requirement for content type application/ace+cbor in error responses for token and introspection requests and responses.
- Reworked abbreviation space for claims, request and response parameters.
- Added text that the RS may indicate that it is busy at the authz-info resource.
- Added section that specifies how the RS verifies an access token.
- Added section on the protection of the authz-info endpoint.
- Removed the expiration mechanism based on sequence numbers.
- Added reference to RFC7662 security considerations.
- Added considerations on minimal security requirements for communication.
- Added security considerations on unprotected information sent to authz-info and in the error responses.

F.7. Version -15 to -16

- Added text the RS using RFC6750 error codes.
- Defined an error code for incompatible token request parameters.
- Removed references to the actors draft.
- Fixed errors in examples.

F.8. Version -14 to -15

- Added text about refresh tokens.
- Added text about protection of credentials.
- Rephrased introspection so that other entities than RS can do it.
- Editorial improvements.

F.9. Version -13 to -14

- Split out the 'aud', 'cnf' and 'rs_cnf' parameters to [I-D.ietf-ace-oauth-params]
- Introduced the "application/ace+cbor" Content-Type.
- Added claim registrations from 'profile' and 'rs_cnf'.
- Added note on schema part of AS Information Section 5.3
- Realigned the parameter abbreviations to push rarely used ones to the 2-byte encoding size of CBOR integers.

F.10. Version -12 to -13

- Changed "Resource Information" to "Access Information" to avoid confusion.
- Clarified section about AS discovery.
- Editorial changes

F.11. Version -11 to -12

- Moved the Request error handling to a section of its own.
- Require the use of the abbreviation for profile identifiers.
- Added rs_cnf parameter in the introspection response, to inform RS' with several RPKs on which key to use.
- Allowed use of rs_cnf as claim in the access token in order to inform an RS with several RPKs on which key to use.
- Clarified that profiles must specify if/how error responses are protected.
- Fixed label number range to align with COSE/CWT.
- Clarified the requirements language in order to allow profiles to specify other payload formats than CBOR if they do not use CoAP.

F.12. Version -10 to -11

- Fixed some CBOR data type errors.
- Updated boilerplate text

F.13. Version -09 to -10

- Removed CBOR major type numbers.
- Removed the client token design.
- Rephrased to clarify that other protocols than CoAP can be used.
- Clarifications regarding the use of HTTP

F.14. Version -08 to -09

- Allowed scope to be byte strings.
- Defined default names for endpoints.
- Refactored the IANA section for briefness and consistency.
- Refactored tables that define IANA registry contents for consistency.
- Created IANA registry for CBOR mappings of error codes, grant types and Authorization Server Information.
- Added references to other document sections defining IANA entries in the IANA section.

F.15. Version -07 to -08

- Moved AS discovery from the DTLS profile to the framework, see Section 5.1.
- Made the use of CBOR mandatory. If you use JSON you can use vanilla OAuth.
- Made it mandatory for profiles to specify C-AS security and RS-AS security (the latter only if introspection is supported).
- Made the use of CBOR abbreviations mandatory.

- Added text to clarify the use of token references as an alternative to CWTs.
- Added text to clarify that introspection must not be delayed, in case the RS has to return a client token.
- Added security considerations about leakage through unprotected AS discovery information, combining profiles and leakage through error responses.
- Added privacy considerations about leakage through unprotected AS discovery.
- Added text that clarifies that introspection is optional.
- Made profile parameter optional since it can be implicit.
- Clarified that CoAP is not mandatory and other protocols can be used.
- Clarified the design justification for specific features of the framework in appendix A.
- Clarified appendix E.2.
- Removed specification of the "cnf" claim for CBOR/COSE, and replaced with references to [RFC8747]

F.16. Version -06 to -07

- Various clarifications added.
- Fixed erroneous author email.

F.17. Version -05 to -06

- Moved sections that define the ACE framework into a subsection of the framework Section 5.
- Split section on client credentials and grant into two separate sections, Section 5.4, and Section 5.5.
- Added Section 5.6 on AS authentication.
- Added Section 5.7 on the Authorization endpoint.

F.18. Version -04 to -05

- Added RFC 2119 language to the specification of the required behavior of profile specifications.
- Added Section 5.5 on the relation to the OAuth2 grant types.
- Added CBOR abbreviations for error and the error codes defined in OAuth2.
- Added clarification about token expiration and long-running requests in Section 5.10.3
- Added security considerations about tokens with symmetric PoP keys valid for more than one RS.
- Added privacy considerations section.
- Added IANA registry mapping the confirmation types from RFC 7800 to equivalent COSE types.

- Added appendix D, describing assumptions about what the AS knows about the client and the RS.

F.19. Version -03 to -04

- Added a description of the terms "framework" and "profiles" as used in this document.
- Clarified protection of access tokens in section 3.1.
- Clarified uses of the "cnf" parameter in section 6.4.5.
- Clarified intended use of Client Token in section 7.4.

F.20. Version -02 to -03

- Removed references to draft-ietf-oauth-pop-key-distribution since the status of this draft is unclear.
- Copied and adapted security considerations from draft-ietf-oauth-pop-key-distribution.
- Renamed "client information" to "RS information" since it is information about the RS.
- Clarified the requirements on profiles of this framework.
- Clarified the token endpoint protocol and removed negotiation of "profile" and "alg" (section 6).
- Renumbered the abbreviations for claims and parameters to get a consistent numbering across different endpoints.
- Clarified the introspection endpoint.
- Renamed token, introspection and authz-info to "endpoint" instead of "resource" to mirror the OAuth 2.0 terminology.
- Updated the examples in the appendices.

F.21. Version -01 to -02

- Restructured to remove communication security parts. These shall now be defined in profiles.
- Restructured section 5 to create new sections on the OAuth endpoints token, introspection and authz-info.
- Pulled in material from draft-ietf-oauth-pop-key-distribution in order to define proof-of-possession key distribution.
- Introduced the "cnf" parameter as defined in RFC7800 to reference or transport keys used for proof of possession.
- Introduced the "client-token" to transport client information from the AS to the client via the RS in conjunction with introspection.
- Expanded the IANA section to define parameters for token request, introspection and CWT claims.
- Moved deployment scenarios to the appendix as examples.

F.22. Version -00 to -01

- Changed 5.1. from "Communication Security Protocol" to "Client Information".
- Major rewrite of 5.1 to clarify the information exchanged between C and AS in the PoP access token request profile for IoT.
  - Allow the client to indicate preferences for the communication security protocol.
  - Defined the term "Client Information" for the additional information returned to the client in addition to the access token.
  - Require that the messages between AS and client are secured, either with (D)TLS or with COSE_Encrypted wrappers.
  - Removed dependency on OSCOAP and added generic text about object security instead.
  - Defined the "rpk" parameter in the client information to transmit the raw public key of the RS from AS to client.
  - (D)TLS MUST use the PoP key in the handshake (either as PSK or as client RPK with client authentication).
  - Defined the use of x5c, x5t and x5tS256 parameters when a client certificate is used for proof of possession.
  - Defined "tktn" parameter for signaling for how to transfer the access token.
- Added 5.2. the CoAP Access-Token option for transferring access tokens in messages that do not have payload.
- 5.3.2. Defined success and error responses from the RS when receiving an access token.
- 5.6.:Added section giving guidance on how to handle token expiration in the absence of reliable time.
- Appendix B Added list of roles and responsibilities for C, AS and RS.

Authors' Addresses

Ludwig Seitz
Combitech
Djaeknegatan 31
Malmoe 211 35
Sweden

Email: ludwig.seitz@combitech.se

Goeran Selander
Ericsson
Faroegatan 6
Kista 164 80
Sweden

Email: goran.selander@ericsson.com

Erik Wahlstroem
Sweden

Email: erik@wahlstromstekniska.se

Samuel Erdtman
Spotify AB
Birger Jarlsgatan 61, 4tr
Stockholm 113 56
Sweden

Email: erdtman@spotify.com

Hannes Tschofenig
Arm Ltd.
Absam 6067
Austria

Email: Hannes.Tschofenig@arm.com

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L. Seitz
Combitech

April 29, 2020

Additional OAuth Parameters for Authorization in Constrained Environments (ACE) draft-ietf-ace-oauth-params-13

Abstract

This specification defines new parameters and encodings for the OAuth 2.0 token and introspection endpoints when used with the framework for authentication and authorization for constrained environments (ACE). These are used to express the proof-of-possession key the client wishes to use, the proof-of-possession key that the Authorization Server has selected, and the key the Resource Server uses to authenticate to the client.

Status of This Memo

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

Internet-Drafts are working documents of the Internet Engineering Task Force (IETF). Note that other groups may also distribute working documents as Internet-Drafts. The list of current Internet-Drafts is at https://datatracker.ietf.org/drafts/current/.

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This Internet-Draft will expire on October 31, 2020.

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Table of Contents

1. Introduction

The Authentication and Authorization for Constrained Environments (ACE) specification [I-D.ietf-ace-oauth-authz] requires some new parameters for interactions with the OAuth 2.0 [RFC6749] token and introspection endpoints, as well as some new claims to be used in access tokens. These parameters and claims can also be used in other contexts and have therefore been put into a dedicated document, to facilitate their use in a manner independent of [I-D.ietf-ace-oauth-authz].

Note that although all examples are shown in Concise Binary Object Respresentation (CBOR) [RFC7049], JSON [RFC8259] MAY be used as an alternative for HTTP-based communications, as specified in [I-D.ietf-ace-oauth-authz].

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.

Readers are assumed to be familiar with the terminology from [I-D.ietf-ace-oauth-authz], especially the terminology for entities in the architecture such as client (C), resource server (RS) and authorization server (AS).

Terminology from [RFC8152] is used in the examples, especially COSE_Key defined in section 7 of [RFC8152].

Note that the term "endpoint" is used here following its OAuth 2.0 [RFC6749] definition, which is to denote resources such as token and introspection at the AS and authz-info at the RS. The Constrained Application Protocol (CoAP) [RFC7252] definition, which is "An entity participating in the CoAP protocol" is not used in this specification.

3. Parameters for the Token Endpoint

This section defines additional parameters for the interactions with the token endpoint in the ACE framework [I-D.ietf-ace-oauth-authz].

3.1. Client-to-AS Request

This section defines the "req_cnf" parameter allowing clients to request a specific proof-of-possession key in an access token from a token endpoint in the ACE framework [I-D.ietf-ace-oauth-authz]:

req_cnf
: OPTIONAL. This field contains information about the key the client would like to bind to the access token for proof-of-possession. It is RECOMMENDED that an AS reject a request containing a symmetric key value in the 'req_cnf' field (kty=Symmetric), since the AS is expected to be able to generate better symmetric keys than a constrained client. The AS MUST verify that the client really is in possession of the corresponding key. Values of this parameter follow the syntax and semantics of the "cnf" claim either from section 3.1 of [I-D.ietf-ace-cwt-proof-of-possession] for CBOR-based interactions or from section 3.1 of [RFC7800] for JSON-based interactions.

Figure 1 shows a request for an access token using the "req_cnf" parameter to request a specific public key as proof-of-possession key. The content is displayed in CBOR diagnostic notation, without abbreviations and with line-breaks for better readability.

```
Header: POST (Code=0.02)
Uri-Host: "as.example.com"
Uri-Path: "token"
Content-Format: "application/ace+cbor"
Payload:
{
   "req_cnf" : {
      "COSE_Key" : {
         "kty" : "EC2",
         "kid" : h'11',
         "crv" : "P-256",
         "x" : h'BAC5B11CAD8F99F9C72B05CF4B9E26D24
                 4DC189F745228255A219A86D6A09EFF',
         "y" : h'20138BF82DC1B6D562BE0FA54AB7804A3
                 A64B6D72CCFED6B6FB6ED28BBFC117E'
      }
   }
 }
```

Figure 1: Example request for an access token bound to an asymmetric key.

3.2. AS-to-Client Response

This section defines the following additional parameters for an AS response to a request to the token endpoint:

cnf
: REQUIRED if the token type is "pop" and a symmetric key is used. MAY be present for asymmetric proof-of-possession keys. This field contains the proof-of-possession key that the AS selected for the token. Values of this parameter follow the syntax and semantics of the "cnf" claim either from section 3.1 of [I-D.ietf-ace-cwt-proof-of-possession] for CBOR-based interactions of from section 3.1 of [RFC7800] for JSON-based interactions. See Section 5 for additional discussion of the usage of this parameter.

rs_cnf
: OPTIONAL if the token type is "pop" and asymmetric keys are used. MUST NOT be present otherwise. This field contains information about the public key used by the RS to authenticate. If this

parameter is absent, either the RS does not use a public key or the AS knows that the RS can authenticate itself to the client without additional information. Values of this parameter follow the syntax and semantics of the "cnf" claim either from section 3.1 of [I-D.ietf-ace-cwt-proof-of-possession] for CBOR-based interactions or from section 3.1 of [RFC7800] for JSON-based interactions. See Section 5 for additional discussion of the usage of this parameter.

Figure 2 shows an AS response containing a token and a "cnf" parameter with a symmetric proof-of-possession key.

```
Header: Created (Code=2.01)
Content-Format: "application/ace+cbor"
Payload:
{
  "access_token" : h'4A5015DF686428 ...
   (remainder of CWT omitted for brevity;
   CWT contains COSE_Key in the "cnf" claim)',
  "cnf" : {
    "COSE_Key" : {
      "kty" : "Symmetric",
      "kid" : h'DFD1AA97',
      "k" : h'849B5786457C1491BE3A76DCEA6C427108'
    }
  }
}
```

Figure 2: Example AS response with an access token bound to a symmetric key.

Figure 3 shows an AS response containing a token bound to a previously requested asymmetric proof-of-possession key (not shown) and a "rs_cnf" parameter containing the public key of the RS.

```
Header: Created (Code=2.01)
Content-Format: "application/ace+cbor"
Payload:
{
  "access_token" : h'D08343A1010AA1054D2A45DF6FBC5A5A ...
   (remainder of CWT omitted for brevity)',
  "rs_cnf" : {
    "COSE_Key" : {
      "kty" : "EC2",
      "kid" : h'12',
      "crv" : "P-256",
      "x" : h'BCEE7EAAC162F91E6F330F5771211E220
              B8B546C96589B0AC4AD0FD24C77E1F1',
      "y" : h'C647B38C55EFBBC4E62E651720F002D5D
              75B2E0C02CD1326E662BCA222B90416'
    }
  }
}
```

Figure 3: Example AS response, including the RS's public key.

4. Parameters for the Introspection Endpoint

This section defines the use of CBOR instead of JSON for the "cnf" introspection response parameter specified in section 9.4 of [I-D.ietf-oauth-mtls].

If CBOR is used instead of JSON in an interaction with the introspection endpoint, the AS MUST use the parameter mapping specified in Figure 5 and the value must follow the syntax of "cnf" claim values from section 3.1 of [I-D.ietf-ace-cwt-proof-of-possession].

Figure 4 shows an AS response to an introspection request including the "cnf" parameter to indicate the proof-of-possession key bound to the token.

```
Header: Created Code=2.01)
Content-Format: "application/ace+cbor"
Payload:
{
  "active" : true,
  "scope" : "read",
  "aud" : "tempSensor4711",
  "cnf" : {
    "COSE_Key" : {
      "kty" : "EC2",
      "kid" : h'11',
      "crv" : "P-256",
      "x" : h'BAC5B11CAD8F99F9C72B05CF4B9E26D24
              4DC189F745228255A219A86D6A09EFF',
      "y" : h'20138BF82DC1B6D562BE0FA54AB7804A3
              A64B6D72CCFED6B6FB6ED28BBFC117E'
    }
  }
}
```

Figure 4: Example introspection response.

5. Confirmation Method Parameters

The confirmation method parameters are used as follows:

- "req_cnf" in the access token request C -> AS, OPTIONAL to indicate the client's raw public key, or the key-identifier of a previously established key between C and RS that the client wishes to use for proof-of-possession of the access token.

- "cnf" in the token response AS -> C, OPTIONAL if using an asymmetric key or a key that the client requested via a key identifier in the request. REQUIRED if the client didn't specify a "req_cnf" and symmetric keys are used. Used to indicate the symmetric key generated by the AS for proof-of-possession of the access token.

- "cnf" in the introspection response AS -> RS, REQUIRED if the access token that was subject to introspection is a proof-of-possession token, absent otherwise. Indicates the proof-of-possession key bound to the access token.

- "rs_cnf" in the token response AS -> C, OPTIONAL to indicate the public key of the RS, if it uses one to authenticate itself to the client and the binding between key and RS identity is not established through other means.

Note that the COSE_Key structure in a confirmation claim or parameter may contain an "alg" or "key_ops" parameter. If such parameters are present, a client MUST NOT use a key that is incompatible with the profile or proof-of-possession algorithm according to those parameters. An RS MUST reject a proof-of-possession using such a key.

If an access token is issued for an audience that includes several RS, the "rs_cnf" parameter MUST NOT be used, since the client cannot determine for which RS the key applies. This document recommends to specify a different endpoint that the client can use to acquire RS authentication keys in such cases. The specification of such an endpoint is out of scope for this document.

6. CBOR Mappings

If CBOR is used, the new parameters and claims defined in this document MUST be mapped to CBOR types as specified in Figure 5, using the given integer abbreviation for the map key.

Name	CBOR Key	Value Type	Usage
req_cnf	TBD (4)	map	token request
cnf	TBD (8)	map	token response
cnf	TBD (8)	map	introspection response
rs_cnf	TBD (41)	map	token response

Figure 5: CBOR mappings for new parameters and claims.

7. Requirements when using asymmetric keys

An RS using asymmetric keys to authenticate to the client MUST NOT hold several different asymmetric key pairs, applicable to the same authentication algorithm. For example when using DTLS, the RS MUST NOT hold several asymmetric key pairs applicable to the same cipher suite. The reason for this restriction is that the RS has no way of determining which key to use before the client's identity is established. Therefore authentication attempts by the RS could randomly fail based on which key the RS selects, unless the algorithm negotiation produces a unique choice of key pair for the RS.

8. Security Considerations

This document is an extension to [I-D.ietf-ace-oauth-authz]. All security considerations from that document apply here as well.

9. Privacy Considerations

This document is an extension to [I-D.ietf-ace-oauth-authz]. All privacy considerations from that document apply here as well.

10. IANA Considerations

10.1. OAuth Parameter Registration

This section registers the following parameters in the "OAuth Parameters" registry [IANA.OAuthParameters]:

- Name: "req_cnf"
- Parameter Usage Location: token request
- Change Controller: IESG
- Reference: Section 5 of [this document]

- Name: "rs_cnf"
- Parameter Usage Location: token response
- Change Controller: IESG
- Reference: Section 5 of [this document]

- Name: "cnf"
- Parameter Usage Location: token response
- Change Controller: IESG
- Reference: Section 5 of [this document]

10.2. OAuth Parameters CBOR Mappings Registration

This section registers the following parameter mappings in the "OAuth Parameters CBOR Mappings" registry established in section 8.9. of [I-D.ietf-ace-oauth-authz].

- Name: "req_cnf"
- CBOR key: TBD (suggested: 4)
- Change Controller: IESG
- Reference: Section 3.1 of [this document]

- Name: "cnf"
- CBOR key: TBD (suggested: 8)
- Change Controller: IESG
- Reference: Section 3.2 of [this document]

- Name: "rs_cnf"
- CBOR key: TBD (suggested: 41)
- Change Controller: IESG
- Reference: Section 3.2 of [this document]

10.3. OAuth Token Introspection Response CBOR Mappings Registration

This section registers the following parameter mapping in the "OAuth Token Introspection Response CBOR Mappings" registry established in section 8.11. of [I-D.ietf-ace-oauth-authz].

- Name: "cnf"
- CBOR key: TBD (suggested: 8)
- Change Controller: IESG
- Reference: Section 4 of [this document]

11. Acknowledgments

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12. References

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Author's Address

Ludwig Seitz
Combitech
Djaeknegatan 31
Malmoe 211 35
Sweden

Email: ludwig.seitz@combitech.se

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F. Palombini
Ericsson AB
L. Seitz
Combitech
G. Selander
Ericsson AB
M. Gunnarsson
RISE

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OSCORE Profile of the Authentication and Authorization for Constrained Environments Framework
draft-ietf-ace-oscore-profile-13

Abstract

This memo specifies a profile for the Authentication and Authorization for Constrained Environments (ACE) framework. It utilizes Object Security for Constrained RESTful Environments (OSCORE) to provide communication security and proof-of-possession for a key owned by the client and bound to an OAuth 2.0 access token.

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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This Internet-Draft will expire on April 30, 2021.

Table of Contents

1. Introduction

This memo specifies a profile of the ACE framework [I-D.ietf-ace-oauth-authz]. In this profile, a client and a resource server use the Constrained Application Protocol (CoAP) [RFC7252] to communicate. The client uses an access token, bound to a symmetric key (the proof-of-possession key) to authorize its access to the resource server. Note that this profile uses a symmetric-crypto-based scheme, where the symmetric secret is used as input material for keying material derivation. In order to provide communication security and proof of possession, the client and resource server use Object Security for Constrained RESTful Environments (OSCORE) [RFC8613]. Note that the proof of possession is not done by a dedicated protocol element, but rather occurs after the first OSCORE exchange.

OSCORE specifies how to use CBOR Object Signing and Encryption (COSE) [RFC8152] to secure CoAP messages. Note that OSCORE can be used to secure CoAP messages, as well as HTTP and combinations of HTTP and CoAP; a profile of ACE similar to the one described in this document, with the difference of using HTTP instead of CoAP as communication protocol, could be specified analogously to this one.

1.1. 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.

Certain security-related terms such as "authentication", "authorization", "confidentiality", "(data) integrity", "message authentication code", and "verify" are taken from [RFC4949].

RESTful terminology follows HTTP [RFC7231].

Terminology for entities in the architecture is defined in OAuth 2.0 [RFC6749], such as client (C), resource server (RS), and authorization server (AS). It is assumed in this document that a given resource on a specific RS is associated to a unique AS.

Concise Binary Object Representation (CBOR) [I-D.ietf-cbor-7049bis] and Concise Data Definition Language (CDDL) [RFC8610] are used in this specification. CDDL predefined type names, especially bstr for CBOR byte strings and tstr for CBOR text strings, are used extensively in the document.

Note that the term "endpoint" is used here, as in [I-D.ietf-ace-oauth-authz], following its OAuth definition, which is to denote resources such as token and introspect at the AS and authz-info at the RS. The CoAP [RFC7252] definition, which is "An entity participating in the CoAP protocol" is not used in this memo.

2. Protocol Overview

This section gives an overview of how to use the ACE Framework [I-D.ietf-ace-oauth-authz] to secure the communication between a client and a resource server using OSCORE [RFC8613]. The parameters needed by the client to negotiate the use of this profile with the authorization server, as well as the OSCORE setup process, are described in detail in the following sections.

The RS maintains a collection of OSCORE Security Contexts with associated authorization information for all the clients that it is communicating with. The authorization information is maintained as policy that is used as input to processing requests from those clients.

This profile requires a client to retrieve an access token from the AS for the resource it wants to access on an RS, by sending an access token request to the token endpoint, as specified in section 5.6 of [I-D.ietf-ace-oauth-authz]. The access token request and response MUST be confidentiality-protected and ensure authenticity. This profile RECOMMENDS the use of OSCORE between client and AS, but other protocols (such as TLS or DTLS) can be used as well.

Once the client has retrieved the access token, it generates a nonce N1. The client also generates its OSCORE Recipient ID (see Section 3.1 of [RFC8613]), ID1, for use with the keying material associated to the RS. The client posts the token, N1 and its Recipient ID to the RS using the authz-info endpoint and mechanisms specified in section 5.8 of [I-D.ietf-ace-oauth-authz] and Content-Format = application/ace+cbor. When using this profile, the communication with the authz-info endpoint is not protected, except for update of access rights.

If the access token is valid, the RS replies to this request with a 2.01 (Created) response with Content-Format = application/ace+cbor, which contains a nonce N2 and its newly generated OSCORE Recipient ID, ID2, for use with the keying material associated to the client. Moreover, the server concatenates the input salt received in the token, N1, and N2 to obtain the Master Salt of the OSCORE Security Context (see section 3 of [RFC8613]). The RS then derives the complete Security Context associated with the received token from the Master Salt, the OSCORE Recipient ID generated by the client (set as

its OSCORE Sender ID), its own OSCORE Recipient ID, plus the parameters received in the access token from the AS, following section 3.2 of [RFC8613].

In a similar way, after receiving the nonce N2, the client concatenates the input salt, N1 and N2 to obtain the Master Salt of the OSCORE Security Context. The client then derives the complete Security Context from the Master Salt, the OSCORE Recipient ID generated by the RS (set as its OSCORE Sender ID), its own OSCORE Recipient ID, plus the parameters received from the AS.

Finally, the client sends a request protected with OSCORE to the RS. If the request verifies, the server stores the complete Security Context state that is ready for use in protecting messages, and uses it in the response, and in further communications with the client, until token expiration. This Security Context is discarded when a token (whether the same or different) is used to successfully derive a new Security Context for that client.

The use of random nonces during the exchange prevents the reuse of an Authenticated Encryption with Associated Data (AEAD) nonces/key pair for two different messages. Two-time pad might otherwise occur when client and RS derive a new Security Context from an existing (non-expired) access token, as might occur when either party has just rebooted. Instead, by using random nonces as part of the Master Salt, the request to the authz-info endpoint posting the same token results in a different Security Context, by OSCORE construction, since even though the Master Secret, Sender ID and Recipient ID are the same, the Master Salt is different (see Section 3.2.1 of [RFC8613]). Therefore, the main requirement for the nonces is that they have a good amount of randomness. If random nonces were not used, a node re-using a non-expired old token would be susceptible to on-path attackers provoking the creation of OSCORE messages using old AEAD keys and nonces.

After the whole message exchange has taken place, the client can contact the AS to request an update of its access rights, sending a similar request to the token endpoint that also includes an identifier so that the AS can find the correct OSCORE security material it has previously shared with the client. This specific identifier, encoded as a byte string, is assigned by the AS to be unique in the sets of its OSCORE Security Contexts, and is not used as input material to derive the full OSCORE Security Context.

An overview of the profile flow for the OSCORE profile is given in Figure 1. The names of messages coincide with those of [I-D.ietf-ace-oauth-authz] when applicable.

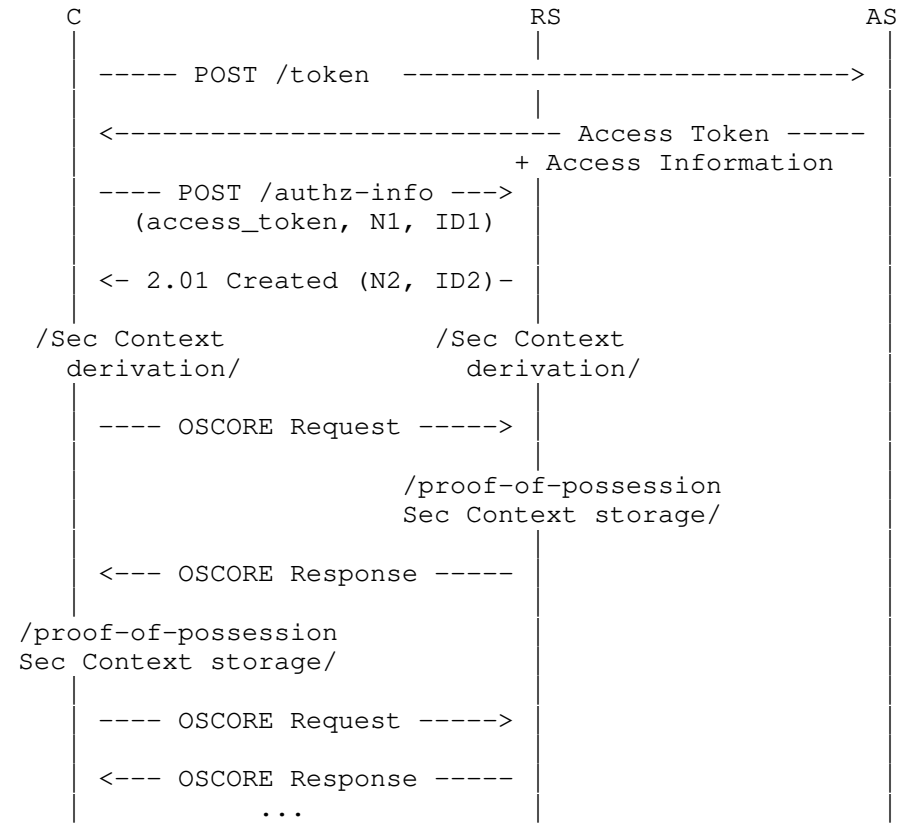

Figure 1: Protocol Overview

3. Client-AS Communication

The following subsections describe the details of the POST request and response to the token endpoint between client and AS. Section 3.2 of [RFC8613] defines how to derive a Security Context based on a shared master secret and a set of other parameters, established between client and server, which the client receives from the AS in this exchange. The proof-of-possession key (pop-key) included in the response from the AS MUST be used as master secret in OSCORE.

3.1. C-to-AS: POST to token endpoint

The client-to-AS request is specified in Section 5.6.1 of [I-D.ietf-ace-oauth-authz].

The client must send this POST request to the token endpoint over a secure channel that guarantees authentication, message integrity and confidentiality (see Section 5).

An example of such a request, with payload in CBOR diagnostic notation without the tag and value abbreviations is reported in Figure 2

```
Header: POST (Code=0.02)
Uri-Host: "as.example.com"
Uri-Path: "token"
Content-Format: "application/ace+cbor"
Payload:
{
  "req_aud" : "tempSensor4711",
  "scope" : "read"
 }
```

Figure 2: Example C-to-AS POST /token request for an access token bound to a symmetric key.

If the client wants to update its access rights without changing an existing OSCORE Security Context, it MUST include in its POST request to the token endpoint a req_cnf object. kid field carrying a CBOR byte string containing the OSCORE_Input_Material Identifier (assigned as discussed in Section 3.2). This identifier, together with other information such as audience (see Section 5.6.1 of [I-D.ietf-ace-oauth-authz]), can be used by the AS to determine the shared secret bound to the proof-of-possession token and therefore MUST identify a symmetric key that was previously generated by the AS as a shared secret for the communication between the client and the RS. The AS MUST verify that the received value identifies a proof-of-possession key that has previously been issued to the requesting client. If that is not the case, the Client-to-AS request MUST be declined with the error code 'invalid_request' as defined in Section 5.6.3 of [I-D.ietf-ace-oauth-authz].

An example of such a request, with payload in CBOR diagnostic notation without the tag and value abbreviations is reported in Figure 3

```
Header: POST (Code=0.02)
Uri-Host: "as.example.com"
Uri-Path: "token"
Content-Format: "application/ace+cbor"
Payload:
{
  "req_aud" : "tempSensor4711",
  "scope" : "write",
  "req_cnf" : {
    "kid" : h'01'
 }
```

Figure 3: Example C-to-AS POST /token request for updating rights to an access token bound to a symmetric key.

3.2. AS-to-C: Access Token

After verifying the POST request to the token endpoint and that the client is authorized to obtain an access token corresponding to its access token request, the AS responds as defined in section 5.6.2 of [I-D.ietf-ace-oauth-authz]. If the client request was invalid, or not authorized, the AS returns an error response as described in section 5.6.3 of [I-D.ietf-ace-oauth-authz].

The AS can signal that the use of OSCORE is REQUIRED for a specific access token by including the "profile" parameter with the value "coap_oscore" in the access token response. This means that the client MUST use OSCORE towards all resource servers for which this access token is valid, and follow Section 4.3 to derive the security context to run OSCORE. Usually it is assumed that constrained devices will be pre-configured with the necessary profile, so that this kind of profile negotiation can be omitted.

Moreover, the AS MUST send the following data:

- a master secret
- an identifier of the OSCORE Input Material

Additionally, the AS MAY send the following data, in the same response.

- a context identifier
- an AEAD algorithm
- an HMAC-based key derivation function (HKDF) algorithm

- a salt
- the OSCORE version number

This data is transported in the the OSCORE_Input_Material. The OSCORE_Input_Material is a CBOR map object, defined in Section 3.2.1. This object is transported in the 'cnf' parameter of the access token response as defined in Section 3.2 of [I-D.ietf-ace-oauth-params], as the value of a field named 'osc', registered in Section 9.5 and Section 9.6.

The AS MAY assign an identifier to the context (context identifier). This identifier is used as ID Context in the OSCORE context as described in section 3.1 of [RFC8613]. If assigned, this parameters MUST be communicated as the 'contextId' field in the OSCORE_Input_Material. The applications needs to consider that this identifier is sent in the clear and may reveal information about the endpoints, as mentioned in section 12.8 of [RFC8613].

The master secret and the identifier of the OSCORE_Input_Material MUST be communicated as the 'ms' and 'id' field in the 'osc' field in the 'cnf' parameter of the access token response. If included, the AEAD algorithm is sent in the 'alg' parameter in the OSCORE_Input_Material; the HKDF algorithm in the 'hkdf' parameter of the OSCORE_Input_Material; a salt in the 'salt' parameter of the OSCORE_Input_Material; and the OSCORE version in the 'version' parameter of the OSCORE_Input_Material.

The same parameters MUST be included in the claims associated with the access token. This profile RECOMMENDS the use of CBOR web token (CWT) as specified in [RFC8392]. If the token is a CWT, the same OSCORE_Input_Material structure defined above MUST be placed in the 'osc' field of the 'cnf' claim of this token.

The AS MUST send different OSCORE_Input_Material (and therefore different access tokens) to different authorized clients, in order for the RS to differentiate between clients.

Figure 4 shows an example of an AS response, with payload in CBOR diagnostic notation without the tag and value abbreviations. The access token has been truncated for readability.

```
Header: Created (Code=2.01)
Content-Type: "application/ace+cbor"
Payload:
{
  "access_token" : h'8343a1010aa2044c53 ...
   (remainder of access token (CWT) omitted for brevity)',
  "profile" : "coap_oscore",
  "expires_in" : "3600",
  "cnf" : {
    "osc" : {
      "id" : h'01',
      "ms" : h'f9af838368e353e78888e1426bd94e6f'
    }
  }
}
```

Figure 4: Example AS-to-C Access Token response with OSCORE profile.

Figure 5 shows an example CWT Claims Set, including the relevant OSCORE parameters in the 'cnf' claim, in CBOR diagnostic notation without tag and value abbreviations.

```
{
  "aud" : "tempSensorInLivingRoom",
  "iat" : "1360189224",
  "exp" : "1360289224",
  "scope" :  "temperature_g firmware_p",
  "cnf" : {
    "osc" : {
      "ms" : h'f9af838368e353e78888e1426bd94e6f',
      "id" : h'01'
    }
  }
}
```

Figure 5: Example CWT Claims Set with OSCORE parameters.

The same CWT Claims Set as in Figure 5, using the value abbreviations defined in [I-D.ietf-ace-oauth-authz] and [RFC8747] and encoded in CBOR is shown in Figure 6. The bytes in hexadecimal are reported in the first column, while their corresponding CBOR meaning is reported after the '#' sign on the second column, for easiness of readability.

NOTE TO THE RFC EDITOR: before publishing, it should be checked (and in case fixed) that the values used below (which are not yet registered) are the final values registered in IANA.

```
A5                                      # map(5)
   63                                   # text(3)
      617564                            # "aud"
   76                                   # text(22)
      74656D7053656E736F72496E4C6976696E67526F6F6D
                                        # "tempSensorInLivingRoom"
   63                                   # text(3)
      696174                            # "iat"
   6A                                   # text(10)
      31333630313839323234              # "1360189224"
   63                                   # text(3)
      657870                            # "exp"
   6A                                   # text(10)
      31333630323839323234              # "1360289224"
   65                                   # text(5)
      73636F7065                        # "scope"
   78 18                                # text(24)
      74656D7065726174757265F67206669726D776172655F70
                                        # "temperature_g firmware_p"
   63                                   # text(3)
      636E66                            # "cnf"
   A1                                   # map(1)
      63                                # text(3)
         6F7363                         # "osc"
      A2                                # map(2)
         62                             # text(2)
            6D73                        # "ms"
         50                             # bytes(16)
            F9AF838368E353E78888E1426BD94E6F
                                        # "\xF9\xAF\x83\x83h\xE3S\xE7
                                        \x88\x88\xE1Bk\xD9No"
         62                             # text(2)
            6964                        # "id"
         41                             # bytes(1)
            01                          # "\x01"
```

Figure 6: Example CWT Claims Set with OSCORE parameters, CBOR encoded.

If the client has requested an update to its access rights using the same OSCORE Security Context, which is valid and authorized, the AS MUST omit the 'cnf' parameter in the response, and MUST carry the OSCORE Input Material identifier in the 'kid' field in the 'cnf' parameter of the token. This identifier needs to be included in the token in order for the RS to identify the correct OSCORE Input Material.

Figure 7 shows an example of such an AS response, with payload in CBOR diagnostic notation without the tag and value abbreviations. The access token has been truncated for readability.

```
Header: Created (Code=2.01)
Content-Type: "application/ace+cbor"
Payload:
{
  "access_token" : h'8343a1010aa2044c53 ...
   (remainder of access token (CWT) omitted for brevity)',
  "profile" : "coap_oscore",
  "expires_in" : "3600"
}
```

Figure 7: Example AS-to-C Access Token response with OSCORE profile, for update of access rights.

Figure 8 shows an example CWT Claims Set, containing the necessary OSCORE parameters in the 'cnf' claim for update of access rights, in CBOR diagnostic notation without tag and value abbreviations.

```
{
  "aud" : "tempSensorInLivingRoom",
  "iat" : "1360189224",
  "exp" : "1360289224",
  "scope" :  "temperature_h",
  "cnf" : {
    "kid" : h'01'
  }
}
```

Figure 8: Example CWT Claims Set with OSCORE parameters for update of access rights.

3.2.1. The OSCORE_Input_Material

An OSCORE_Input_Material is an object that represents the input material to derive an OSCORE Security Context, i.e., the local set of information elements necessary to carry out the cryptographic operations in OSCORE (Section 3.1 of [RFC8613]). In particular, the OSCORE_Input_Material is defined to be serialized and transported between nodes, as specified by this document, but can also be used by other specifications if needed. The OSCORE_Input_Material can either be encoded as a JSON object or as a CBOR map. The set of common parameters that can appear in an OSCORE_Input_Material can be found in the IANA "OSCORE Security Context Parameters" registry

(Section 9.4), defined for extensibility, and is specified below. All parameters are optional. Table 1 provides a summary of the OSCORE_Input_Material parameters defined in this section.

name	CBOR label	CBOR type	registry	description
version	0	unsigned integer		OSCORE Version
ms	1	byte string		OSCORE Master Secret value
id	2	byte string		OSCORE Input Material Identifier
hkdf	3	text string / integer	[COSE.Algorithms] Values (HMAC-based)	OSCORE HKDF value
alg	4	text string / integer	[COSE.Algorithms] Values (AEAD)	OSCORE AEAD Algorithm value
salt	5	byte string		an input to OSCORE Master Salt value
contextId	6	byte string		OSCORE ID Context value

Table 1: OSCORE_Input_Material Parameters

version: This parameter identifies the OSCORE Version number, which is an unsigned integer. For more information about this field, see section 5.4 of [RFC8613]. In JSON, the "version" value is an integer. In CBOR, the "version" type is int, and has label 0.

ms: This parameter identifies the OSCORE Master Secret value, which is a byte string. For more information about this field, see

section 3.1 of [RFC8613]. In JSON, the "ms" value is a Base64 encoded byte string. In CBOR, the "ms" type is bstr, and has label 1.

id: This parameter identifies the OSCORE_Input_Material and is encoded as a byte string. In JSON, the "id" value is a Base64 encoded byte string. In CBOR, the "id" type is byte string, and has label 8.

hkdf: This parameter identifies the OSCORE HKDF Algorithm. For more information about this field, see section 3.1 of [RFC8613]. The values used MUST be registered in the IANA "COSE Algorithms" registry (see [COSE.Algorithms]) and MUST be HMAC-based HKDF algorithms. The value can either be the integer or the text string value of the HMAC-based HKDF algorithm in the "COSE Algorithms" registry. In JSON, the "hkdf" value is a case-sensitive ASCII string or an integer. In CBOR, the "hkdf" type is tstr or int, and has label 4.

alg: This parameter identifies the OSCORE AEAD Algorithm. For more information about this field, see section 3.1 of [RFC8613] The values used MUST be registered in the IANA "COSE Algorithms" registry (see [COSE.Algorithms]) and MUST be AEAD algorithms. The value can either be the integer or the text string value of the HMAC-based HKDF algorithm in the "COSE Algorithms" registry. In JSON, the "alg" value is a case-sensitive ASCII string or an integer. In CBOR, the "alg" type is tstr or int, and has label 5.

salt: This parameter identifies an input to the OSCORE Master Salt value, which is a byte string. For more information about this field, see section 3.1 of [RFC8613]. In JSON, the "salt" value is a Base64 encoded byte string. In CBOR, the "salt" type is bstr, and has label 6.

contextId: This parameter identifies the security context as a byte string. This identifier is used as OSCORE ID Context. For more information about this field, see section 3.1 of [RFC8613]. In JSON, the "contextID" value is a Base64 encoded byte string. In CBOR, the "contextID" type is bstr, and has label 7.

An example of JSON OSCORE_Input_Material is given in Figure 9.

```
          "osc" : {
            "alg" : "AES-CCM-16-64-128",
            "id" : b64'AQ=='
            "ms" : b64'+a+Dg2jjU+eIiOFCa9lObw'
          }
```

Figure 9: Example JSON OSCORE_Input_Material

The CDDL grammar describing the CBOR OSCORE_Input_Material is:

```
OSCORE_Input_Material = {
    ? 0 => int,               ; version
    ? 1 => bstr,              ; ms
    ? 2 => bstr,              ; id
    ? 3 => tstr / int,        ; hkdf
    ? 4 => tstr / int,        ; alg
    ? 5 => bstr,              ; salt
    ? 6 => bstr,              ; contextId
    * int / tstr => any
}
```

4. Client-RS Communication

The following subsections describe the details of the POST request and response to the authz-info endpoint between client and RS. The client generates a nonce N1 and an identifier ID1 unique in the sets of its own Recipient IDs, and posts them together with the token that includes the materials (e.g., OSCORE parameters) received from the AS to the RS. The RS then generates a nonce N2 and an identifier ID2 unique in the sets of its own Recipient IDs, and uses Section 3.2 of [RFC8613] to derive a security context based on a shared master secret, the two nonces and the two identifiers, established between client and server. The nonces and identifiers are encoded as CBOR byte string if CBOR is used, and as Base64 string if JSON is used. This security context is used to protect all future communication between client and RS using OSCORE, as long as the access token is valid.

Note that the RS and client authenticates themselves by generating the shared OSCORE Security Context using the pop-key as master secret. An attacker posting a valid token to the RS will not be able to generate a valid OSCORE context and thus not be able to prove possession of the pop-key. Additionally, the mutual authentication is only achieved after the client has successfully verified the response from the RS.

4.1. C-to-RS: POST to authz-info endpoint

The client MUST generate a nonce value very unlikely to have been previously used with the same input keying material. This profile RECOMMENDS to use a 64-bit long random number as nonce's value. The client MUST store the nonce N1 as long as the response from the RS is not received and the access token related to it is still valid.

The client generates its own Recipient ID, ID1, for the OSCORE Security Context that it is establishing with the RS. By generating its own Recipient ID, the client makes sure that it does not collide with any of its Recipient IDs.

The client MUST use CoAP and the Authorization Information resource as described in section 5.8.1 of [I-D.ietf-ace-oauth-authz] to transport the token, N1 and ID1 to the RS.

Note that the use of the payload and the Content-Format is different from what is described in section 5.8.1 of [I-D.ietf-ace-oauth-authz], which only transports the token without any CBOR wrapping. In this profile, the client MUST wrap the token and N1 in a CBOR map. The client MUST use the Content-Format "application/ace+cbor" defined in section 8.14 of [I-D.ietf-ace-oauth-authz]. The client MUST include the access token using the "access_token" parameter, N1 using the 'nonce1' parameter defined in Section 4.1.1, and ID1 using the 'ace_client_recipientid' parameter defined in Section 4.1.2.

The communication with the authz-info endpoint does not have to be protected, except for the update of access rights case described below.

Note that a client may be required to re-POST the access token in order to complete a request, since an RS may delete a stored access token (and associated Security Context) at any time, for example due to all storage space being consumed. This situation is detected by the client when it receives an AS Request Creation Hints response. Reposting the same access token will result in deriving a new OSCORE Security Context to be used with the RS, as different nonces will be used.

Figure 10 shows an example of the request sent from the client to the RS, with payload in CBOR diagnostic notation without the tag and value abbreviations. The access token has been truncated for readability.

```
Header: POST (Code=0.02)
Uri-Host: "rs.example.com"
Uri-Path: "authz-info"
Content-Format: "application/ace+cbor"
Payload:
  {
    "access_token": h'8343a1010aa2044c53 ...
  (remainder of access token (CWT) omitted for brevity)',
    "nonce1": h'018a278f7faab55a',
    "ace_client_recipientid" : h'1645'
  }
```

Figure 10: Example C-to-RS POST /authz-info request using CWT

If the client has already posted a valid token, has already established a security association with the RS, and wants to update its access rights, the client can do so by posting the new token (retrieved from the AS and containing the update of access rights) to the /authz-info endpoint. The client MUST protect the request using the OSCORE Security Context established during the first token exchange. The client MUST only send the access token in the payload, no nonce or identifier are sent. After proper verification (see Section 4.2), the RS will replace the old token with the new one, maintaining the same Security Context.

4.1.1. The Nonce 1 Parameter

This parameter MUST be sent from the client to the RS, together with the access token, if the ace profile used is coap_oscore. The parameter is encoded as a byte string for CBOR-based interactions, and as a string (Base64 encoded binary) for JSON-based interactions. This parameter is registered in Section 9.2.

4.1.2. The ace_client_recipientid Parameter

This parameter MUST be sent from the client to the RS, together with the access token, if the ace profile used is coap_oscore. The parameter is encoded as a byte string for CBOR-based interactions, and as a string (Base64 encoded binary) for JSON-based interactions. This parameter is registered in Section 9.2.

4.2. RS-to-C: 2.01 (Created)

The RS MUST follow the procedures defined in section 5.8.1 of [I-D.ietf-ace-oauth-authz]: the RS must verify the validity of the token. If the token is valid, the RS must respond to the POST request with 2.01 (Created). If the token is valid but is associated

to claims that the RS cannot process (e.g., an unknown scope), or if any of the expected parameters is missing (e.g., any of the mandatory parameters from the AS or the identifier), or if any parameters received in the 'osc' is unrecognized, the RS must respond with an error response code equivalent to the CoAP code 4.00 (Bad Request). In the latter two cases, the RS may provide additional information in the error response, in order to clarify what went wrong. The RS may make an introspection request (see Section 5.7.1 of [I-D.ietf-ace-oauth-authz]) to validate the token before responding to the POST request to the authz-info endpoint.

Additionally, the RS MUST generate a nonce N2 very unlikely to have been previously used with the same input keying material, and its own Recipient ID, ID2. The RS makes sure that ID2 does not collide with any of its Recipient IDs. The RS MUST ensure that ID2 is different from the ace_client_recipientid. The RS sends N2 and ID2 within the 2.01 (Created) response. The payload of the 2.01 (Created) response MUST be a CBOR map containing the 'nonce2' parameter defined in Section 4.2.1, set to N2, and the 'ace_server_recipientid' parameter defined in Section 4.2.2, set to ID2. This profile RECOMMENDS to use a 64-bit long random number as nonce's value. The RS MUST use the Content-Format "application/ace+cbor" defined in section 8.14 of [I-D.ietf-ace-oauth-authz].

Figure 11 shows an example of the response sent from the RS to the client, with payload in CBOR diagnostic notation without the tag and value abbreviations.

```
Header: Created (Code=2.01)
Content-Format: "application/ace+cbor"
Payload:
  {
    "nonce2": h'25a8991cd700ac01',
    "ace_server_recipientid" : h'0000'
  }
```

Figure 11: Example RS-to-C 2.01 (Created) response

As specified in section 5.8.3 of [I-D.ietf-ace-oauth-authz], the RS must notify the client with an error response with code 4.01 (Unauthorized) for any long running request before terminating the session, when the access token expires.

If the RS receives the token in a OSCORE protected message, it means that the client is requesting an update of access rights. The RS MUST discard any nonce and identifiers in the request, if any was sent. The RS MUST check that the "kid" of the "cnf" parameter of the

new access token matches the OSCORE Input Material of the context used to protect the message. If that is the case, the RS MUST discard the old token and associate the new token to the Security Context identified by the "kid" value in the "cnf" parameter. The RS MUST respond with a 2.01 (Created) response protected with the same Security Context, with no payload. If any verification fails, the RS MUST respond with a 4.01 (Unauthorized) error response.

As specified in section 5.8.1 of [I-D.ietf-ace-oauth-authz], when receiving an updated access token with updated authorization information from the client (see Section 3.1), it is recommended that the RS overwrites the previous token, that is only the latest authorization information in the token received by the RS is valid. This simplifies the process needed by the RS to keep track of authorization information for a given client.

4.2.1. The Nonce 2 Parameter

This parameter MUST be sent from the RS to the client if the ace profile used is coap_oscore. The parameter is encoded as a byte string for CBOR-based interactions, and as a string (Base64 encoded binary) for JSON-based interactions. This parameter is registered in Section 9.2

4.2.2. The ace_server_recipientid Parameter

This parameter MUST be sent from the RS to the client if the ace profile used is coap_oscore. The parameter is encoded as a byte string for CBOR-based interactions, and as a string (Base64 encoded binary) for JSON-based interactions. This parameter is registered in Section 9.2

4.3. OSCORE Setup

Once receiving the 2.01 (Created) response from the RS, following the POST request to authz-info endpoint, the client MUST extract the bstr nonce N2 from the 'nonce2' parameter in the CBOR map in the payload of the response. Then, the client MUST set the Master Salt of the Security Context created to communicate with the RS to the concatenation of salt, N1, and N2, in this order: Master Salt = salt | N1 | N2, where | denotes byte string concatenation, where salt is the CBOR byte string received from the AS in Section 3.2, and where N1 and N2 are the two nonces encoded as CBOR byte strings. An example of Master Salt construction using CBOR encoding is given in Figure 12.

```
N1, N2 and input salt expressed in CBOR diagnostic notation:
      nonce1 = h'018a278f7faab55a'
      nonce2 = h'25a8991cd700ac01'
      input salt = h'f9af838368e353e78888e1426bd94e6f'

N1, N2 and input salt as CBOR encoded byte strings:
      nonce1 = 0x48018a278f7faab55a
      nonce2 = 0x4825a8991cd700ac01
      input salt = 0x50f9af838368e353e78888e1426bd94e6f

Master Salt = 0x50 f9af838368e353e78888e1426bd94e6f 48 018a278f7faab55a 48 25a899
1cd700ac01
```

Figure 12: Example of Master Salt construction using CBOR encoding

If JSON is used instead of CBOR, the Master Salt of the Security Context is the Base64 encoding of the concatenation of the same parameters, each of them prefixed by their size, encoded in 1 byte. When using JSON, the nonces and input salt have a maximum size of 255 bytes. An example of Master Salt construction using Base64 encoding is given in Figure 13.

```
N1, N2 and input salt values:
      nonce1 = 0x018a278f7faab55a (8 bytes)
      nonce2 = 0x25a8991cd700ac01 (8 bytes)
      input salt = 0xf9af838368e353e78888e1426bd94e6f (16 bytes)

Input to Base64 encoding: 0x10 f9af838368e353e78888e1426bd94e6f 08 018a278f7faab5
5a 08 25a8991cd700ac01

Master Salt = b64'EPmvg4No41PniIjhQmvZTm8IAYonj3+qtVoIJaiZHNcArAE='
```

Figure 13: Example of Master Salt construction using Base64 encoding

The client MUST set the Sender ID to the ace_server_recipientid received in Section 4.2, and the Recipient ID to the ace_client_recipientid sent in Section 4.1. The client MUST set the Master Secret from the parameter received from the AS in Section 3.2. The client MUST set the AEAD Algorithm, ID Context, HKDF, and OSCORE Version from the parameters received from the AS in Section 3.2, if present. In case an optional parameter is omitted, the default value SHALL be used as described in sections 3.2 and 5.4 of [RFC8613]. After that, the client MUST derive the complete Security Context following section 3.2.1 of [RFC8613]. From this point on, the client MUST use this Security Context to communicate with the RS when accessing the resources as specified by the authorization information.

If any of the expected parameters is missing (e.g., any of the mandatory parameters from the AS or the RS), or if ace_client_recipientid equals ace_server_recipientid, then the client MUST stop the exchange, and MUST NOT derive the Security Context. The client MAY restart the exchange, to get the correct security material.

The client then uses this Security Context to send requests to RS using OSCORE.

After sending the 2.01 (Created) response, the RS MUST set the Master Salt of the Security Context created to communicate with the client to the concatenation of salt, N1, and N2, in the same way described above. An example of Master Salt construction using CBOR encoding is given in Figure 12 and using Base64 encoding is given in Figure 13. The RS MUST set the Sender ID from the ace_client_recipientid received in Section 4.1, and the Recipient ID from the ace_server_recipientid sent in Section 4.2. The RS MUST set the Master Secret from the parameter, received from the AS and forwarded by the client in the access token in Section 4.1 after validation of the token as specified in Section 4.2. The RS MUST set the AEAD Algorithm, ID Context, HKDF, and OSCORE Version from the parameters received from the AS and forwarded by the client in the access token in Section 4.1 after validation of the token as specified in Section 4.2, if present. In case an optional parameter is omitted, the default value SHALL be used as described in sections 3.2 and 5.4 of [RFC8613]. After that, the RS MUST derive the complete Security Context following section 3.2.1 of [RFC8613], and MUST associate this Security Context with the authorization information from the access token.

The RS then uses this Security Context to verify requests and send responses to C using OSCORE. If OSCORE verification fails, error responses are used, as specified in section 8 of [RFC8613]. Additionally, if OSCORE verification succeeds, the verification of access rights is performed as described in section Section 4.4. The RS MUST NOT use the Security Context after the related token has expired, and MUST respond with a unprotected 4.01 (Unauthorized) error message to requests received that correspond to a Security Context with an expired token.

Note that the ID Context can be assigned by the AS, communicated and set in both the RS and client after the exchange specified in this profile is executed. Subsequently, client and RS can update their ID Context by running a mechanism such as the one defined in Appendix B.2 of [RFC8613] if they both support it and are configured to do so. In that case, the ID Context in the OSCORE Security Context will not match the "contextId" parameter of the corresponding

OSCORE_Input_Material. Running Appendix B.2 results in the keying material in the Security Contexts of client and RS being updated; this same result can also be achieved by the client reposting the access token as described in Section 4.1, but without updating the ID Context.

4.4. Access rights verification

The RS MUST follow the procedures defined in section 5.8.2 of [I-D.ietf-ace-oauth-authz]: if an RS receives an OSCORE-protected request from a client, then the RS processes it according to [RFC8613]. If OSCORE verification succeeds, and the target resource requires authorization, the RS retrieves the authorization information using the access token associated to the Security Context. The RS then must verify that the authorization information covers the resource and the action requested.

5. Secure Communication with AS

As specified in the ACE framework (section 5.7 of [I-D.ietf-ace-oauth-authz]), the requesting entity (RS and/or client) and the AS communicates via the introspection or token endpoint. The use of CoAP and OSCORE ([RFC8613]) for this communication is RECOMMENDED in this profile, other protocols (such as HTTP and DTLS or TLS) MAY be used instead.

If OSCORE is used, the requesting entity and the AS are expected to have pre-established security contexts in place. How these security contexts are established is out of scope for this profile. Furthermore the requesting entity and the AS communicate through the introspection endpoint as specified in section 5.7 of [I-D.ietf-ace-oauth-authz] and through the token endpoint as specified in section 5.6 of [I-D.ietf-ace-oauth-authz].

6. Discarding the Security Context

There are a number of scenarios where a client or RS needs to discard the OSCORE security context, and acquire a new one.

The client MUST discard the current Security Context associated with an RS when:

- the Sequence Number space ends.
- the access token associated with the context expires.

- the client receives a number of 4.01 Unauthorized responses to OSCORE requests using the same Security Context. The exact number needs to be specified by the application.

- the client receives a new nonce in the 2.01 (Created) response (see Section 4.2) to a POST request to the authz-info endpoint, when re-posting a (non-expired) token associated to the existing context.

The RS MUST discard the current Security Context associated with a client when:

- the Sequence Number space ends.

- the access token associated with the context expires.

- the client has successfully replaced the current security context with a newer one by posting an access token to the unprotected /authz-info endpoint at the RS, e.g., by re-posting the same token, as specified in Section 4.1.

Whenever one more access token is successfully posted to the RS, and a new Security Context is derived between the client and RS, messages in transit that were protected with the previous Security Context might not pass verification, as the old context is discarded. That means that messages sent shortly before the client posts one more access token to the RS might not successfully reach the destination. Analogously, implementations may want to cancel CoAP observations at the RS registered before the Security Context is replaced, or conversely they will need to implement a mechanism to ensure that those observation are to be protected with the newly derived Security Context.

7. Security Considerations

This document specifies a profile for the Authentication and Authorization for Constrained Environments (ACE) framework [I-D.ietf-ace-oauth-authz]. Thus the general security considerations from the framework also apply to this profile.

Furthermore the general security considerations of OSCORE [RFC8613] also apply to this specific use of the OSCORE protocol.

As previously stated, the proof-of-possession in this profile is performed by both parties verifying that they have established the same Security Context, as specified in Section 4.3, which means that both the OSCORE request and OSCORE response pass verification. RS

authentication requires both that the client trusts the AS and that the OSCORE response from the RS pass verification.

OSCORE is designed to secure point-to-point communication, providing a secure binding between the request and the response(s). Thus the basic OSCORE protocol is not intended for use in point-to-multipoint communication (e.g., multicast, publish-subscribe). Implementers of this profile should make sure that their usecase corresponds to the expected use of OSCORE, to prevent weakening the security assurances provided by OSCORE.

Since the use of nonces in the exchange guarantees uniqueness of AEAD keys and nonces, it is REQUIRED that nonces are not reused with the same input keying material even in case of re-boots. This document RECOMMENDS the use of 64 bit random nonces. Considering the birthday paradox, the average collision for each nonce will happen after 2^32 messages, which is considerably more token provisionings than expected for intended applications. If applications use something else, such as a counter, they need to guarantee that reboot and loss of state on either node does not provoke re-use. If that is not guaranteed, nodes are susceptible to re-use of AEAD (nonces, keys) pairs, especially since an on-path attacker can cause the client to use an arbitrary nonce for Security Context establishment by replaying client-to-server messages.

This profile recommends that the RS maintains a single access token for a client. The use of multiple access tokens for a single client increases the strain on the resource server as it must consider every access token and calculate the actual permissions of the client. Also, tokens indicating different or disjoint permissions from each other may lead the server to enforce wrong permissions. If one of the access tokens expires earlier than others, the resulting permissions may offer insufficient protection. Developers should avoid using multiple access tokens for a client.

If a single OSCORE_Input_Material is used with multiple RSs, the RSs can impersonate C to one of the other RS, and impersonate another RS to the client. If a master secret is used with several clients, the Cs can impersonate RS to one of the other C. Similarly if symmetric keys are used to integrity protect the token between AS and RS and the token can be used with multiple RSs, the RSs can impersonate AS to one of the other RS. If the token key is used for any other communication between the RSs and AS, the RSs can impersonate each other to the AS.

8. Privacy Considerations

This document specifies a profile for the Authentication and Authorization for Constrained Environments (ACE) framework [I-D.ietf-ace-oauth-authz]. Thus the general privacy considerations from the framework also apply to this profile.

As this document uses OSCORE, thus the privacy considerations from [RFC8613] apply here as well.

An unprotected response to an unauthorized request may disclose information about the resource server and/or its existing relationship with the client. It is advisable to include as little information as possible in an unencrypted response. When an OSCORE Security Context already exists between the client and the resource server, more detailed information may be included.

The token is sent in the clear to the authz-info endpoint, so if a client uses the same single token from multiple locations with multiple Resource Servers, it can risk being tracked by the token's value even when the access token is encrypted.

The nonces exchanged in the request and response to the authz-info endpoint are also sent in the clear, so using random nonces is best for privacy (as opposed to, e.g., a counter, that might leak some information about the client).

The identifiers used in OSCORE, negotiated between client and RS are privacy sensitive (see Section 12.8 of [RFC8613]), and could reveal information about the client, or may be used for correlating requests from one client.

Note that some information might still leak after OSCORE is established, due to observable message sizes, the source, and the destination addresses.

9. IANA Considerations

Note to RFC Editor: Please replace all occurrences of "[[this specification]]" with the RFC number of this specification and delete this paragraph.

9.1. ACE Profile Registry

The following registration is done for the ACE Profile Registry following the procedure specified in section 8.8 of [I-D.ietf-ace-oauth-authz]:

- Name: coap_oscore
- Description: Profile for using OSCORE to secure communication between constrained nodes using the Authentication and Authorization for Constrained Environments framework.
- CBOR Value: TBD (value between 1 and 255)
- Reference: [[this specification]]

9.2. OAuth Parameters Registry

The following registrations are done for the OAuth Parameters Registry following the procedure specified in section 11.2 of [RFC6749]:

- Parameter name: nonce1
- Parameter usage location: client-rs request
- Change Controller: IESG
- Specification Document(s): [[this specification]]

- Parameter name: nonce2
- Parameter usage location: rs-client response
- Change Controller: IESG
- Specification Document(s): [[this specification]]

- Parameter name: ace_client_recipientid
- Parameter usage location: client-rs request
- Change Controller: IESG
- Specification Document(s): [[this specification]]

- Parameter name: ace_server_recipientid
- Parameter usage location: rs-client response
- Change Controller: IESG
- Specification Document(s): [[this specification]]

9.3. OAuth Parameters CBOR Mappings Registry

The following registrations are done for the OAuth Parameters CBOR Mappings Registry following the procedure specified in section 8.10 of [I-D.ietf-ace-oauth-authz]:

- Name: nonce1
- CBOR Key: TBD1
- Value Type: bstr
- Reference: [[this specification]]

- Name: nonce2
- CBOR Key: TBD2
- Value Type: bstr
- Reference: [[this specification]]

- Name: ace_client_recipientid
- CBOR Key: TBD3
- Value Type: bstr
- Reference: [[this specification]]

- Name: ace_server_recipientid
- CBOR Key: TBD4
- Value Type: bstr
- Reference: [[this specification]]

9.4. OSCORE Security Context Parameters Registry

It is requested that IANA create a new registry entitled "OSCORE Security Context Parameters" registry. The registry is to be created as Expert Review Required. Guidelines for the experts is provided Section 9.7. It should be noted that in addition to the expert review, some portions of the registry require a specification, potentially on standards track, be supplied as well.

The columns of the registry are:

name The JSON name requested (e.g., "ms"). Because a core goal of this specification is for the resulting representations to be compact, it is RECOMMENDED that the name be short. This name is case sensitive. Names may not match other registered names in a case-insensitive manner unless the Designated Experts determine that there is a compelling reason to allow an exception. The name is not used in the CBOR encoding.

CBOR label The value to be used to identify this algorithm. Map key labels MUST be unique. The label can be a positive integer, a negative integer or a string. Integer values between -256 and 255 and strings of length 1 are designated as Standards Track Document required. Integer values from -65536 to -257 and from 256 to 65535 and strings of length 2 are designated as Specification Required. Integer values greater than 65535 and strings of length greater than 2 are designated as expert review. Integer values less than -65536 are marked as private use.

CBOR Type This field contains the CBOR type for the field.

registry This field denotes the registry that values may come from, if one exists.

description This field contains a brief description for the field.

specification This contains a pointer to the public specification for the field if one exists

This registry will be initially populated by the values in Table 1. The specification column for all of these entries will be this document and [RFC8613].

9.5. CWT Confirmation Methods Registry

The following registration is done for the CWT Confirmation Methods Registry following the procedure specified in section 7.2.1 of [RFC8747]:

- Confirmation Method Name: "osc"
- Confirmation Method Description: OSCORE_Input_Material carrying the parameters for using OSCORE per-message security with implicit key confirmation
- Confirmation Key: TBD (value between 4 and 255)
- Confirmation Value Type(s): map
- Change Controller: IESG
- Specification Document(s): Section 3.2.1 of [[this specification]]

9.6. JWT Confirmation Methods Registry

The following registration is done for the JWT Confirmation Methods Registry following the procedure specified in section 6.2.1 of [RFC7800]:

- Confirmation Method Value: "osc"
- Confirmation Method Description: OSCORE_Input_Material carrying the parameters for using OSCORE per-message security with implicit key confirmation
- Change Controller: IESG
- Specification Document(s): Section 3.2.1 of [[this specification]]

9.7. Expert Review Instructions

The IANA registry established in this document is defined to use the Expert Review registration policy. This section gives some general guidelines for what the experts should be looking for, but they are being designated as experts for a reason so they should be given substantial latitude.

Expert reviewers should take into consideration the following points:

- Point squatting should be discouraged. Reviewers are encouraged to get sufficient information for registration requests to ensure that the usage is not going to duplicate one that is already registered and that the point is likely to be used in deployments. The zones tagged as private use are intended for testing purposes and closed environments. Code points in other ranges should not be assigned for testing.
- Specifications are required for the standards track range of point assignment. Specifications should exist for specification required ranges, but early assignment before a specification is

available is considered to be permissible. Specifications are needed for the first-come, first-serve range if they are expected to be used outside of closed environments in an interoperable way. When specifications are not provided, the description provided needs to have sufficient information to identify what the point is being used for.

- Experts should take into account the expected usage of fields when approving point assignment. The fact that there is a range for standards track documents does not mean that a standards track document cannot have points assigned outside of that range. The length of the encoded value should be weighed against how many code points of that length are left, the size of device it will be used on, and the number of code points left that encode to that size.

10. References

10.1. Normative References

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[I-D.ietf-ace-oauth-authz]
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Bormann, C. and P. Hoffman, "Concise Binary Object Representation (CBOR)", draft-ietf-cbor-7049bis-16 (work in progress), September 2020.

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10.2. Informative References

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[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>.

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[RFC8747] Jones, M., Seitz, L., Selander, G., Erdtman, S., and H. Tschofenig, "Proof-of-Possession Key Semantics for CBOR Web Tokens (CWTs)", RFC 8747, DOI 10.17487/RFC8747, March 2020, <https://www.rfc-editor.org/info/rfc8747>.

Appendix A. Profile Requirements

This section lists the specifications on this profile based on the requirements on the framework, as requested in Appendix C of [I-D.ietf-ace-oauth-authz].

- Optionally define new methods for the client to discover the necessary permissions and AS for accessing a resource, different from the one proposed in: Not specified
- Optionally specify new grant types: Not specified
- Optionally define the use of client certificates as client credential type: Not specified
- Specify the communication protocol the client and RS the must use: CoAP
- Specify the security protocol the client and RS must use to protect their communication: OSCORE
- Specify how the client and the RS mutually authenticate: Implicitly by possession of a common OSCORE security context. Note that the mutual authentication is not completed before the client has verified an OSCORE response using this security context.
- Specify the proof-of-possession protocol(s) and how to select one, if several are available. Also specify which key types (e.g., symmetric/asymmetric) are supported by a specific proof-of-possession protocol: OSCORE algorithms; pre-established symmetric keys
- Specify a unique ace_profile identifier: coap_oscore
- If introspection is supported: Specify the communication and security protocol for introspection: HTTP/CoAP (+ TLS/DTLS/OSCORE)
- Specify the communication and security protocol for interactions between client and AS: HTTP/CoAP (+ TLS/DTLS/OSCORE)
- Specify how/if the authz-info endpoint is protected, including how error responses are protected: Not protected.
- Optionally define other methods of token transport than the authz-info endpoint: Not defined

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The authors wish to thank Jim Schaad and Marco Tiloca for the input on this memo. Special thanks to the responsible area director Benjamin Kaduk for his extensive review and contributed text. Ludwig Seitz worked on this document as part of the CelticNext projects CyberWI, and CRITISEC with funding from Vinnova.

Authors' Addresses

Francesca Palombini
Ericsson AB

Email: francesca.palombini@ericsson.com

Ludwig Seitz
Combitech
Djaeknegatan 31
Malmoe 211 35
Sweden

Email: ludwig.seitz@combitech.se

Goeran Selander
Ericsson AB

Email: goran.selander@ericsson.com

Martin Gunnarsson
RISE
Scheelevagen 17
Lund 22370
Sweden

Email: martin.gunnarsson@ri.se

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F. Palombini
Ericsson

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CoAP Pub-Sub Profile for Authentication and Authorization for Constrained Environments (ACE) draft-palombini-ace-coap-pubsub-profile-06

Abstract

This specification defines an application profile for authentication and authorization for publishers and subscribers in a pub-sub setting scenario in a constrained environment, using the ACE framework. This profile relies on transport layer or application layer security to authorize the publisher to the broker. Moreover, it relies on application layer security for publisher-broker and subscriber-broker communication.

Status of This Memo

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Table of Contents

1. Introduction

The publisher-subscriber setting allows for devices with limited reachability to communicate via a broker that enables store-and-forward messaging between the devices. The pub-sub scenario using the Constrained Application Protocol (CoAP) is specified in [I-D.ietf-core-coap-pubsub]. This document defines a way to authorize nodes in a CoAP pub-sub type of setting, using the ACE framework [I-D.ietf-ace-oauth-authz], and to provide the keys for protecting the communication between these nodes.

1.1. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

Readers are expected to be familiar with the terms and concepts described in [I-D.ietf-ace-oauth-authz], [I-D.ietf-ace-key-groupcomm] and [I-D.ietf-core-coap-pubsub]. In particular, analogously to [I-D.ietf-ace-oauth-authz], terminology for entities in the architecture such as Client (C), Resource Server (RS), and

Authorization Server (AS) is defined in OAuth 2.0 [RFC6749] and [I-D.ietf-ace-actors], and terminology for entities such as the Key Distribution Center (KDC) and Dispatcher in [I-D.ietf-ace-key-groupcomm].

2. Application Profile Overview

The objective of this document is to specify how to authorize nodes, provide keys, and protect a CoAP pub-sub communication, as described in [I-D.ietf-core-coap-pubsub], using [I-D.ietf-ace-key-groupcomm], which itself expands the Ace framework ([I-D.ietf-ace-oauth-authz]), and transport profiles ([I-D.ietf-ace-dtls-authorize], [I-D.ietf-ace-oscore-profile]).

The architecture of the scenario is shown in Figure 1.

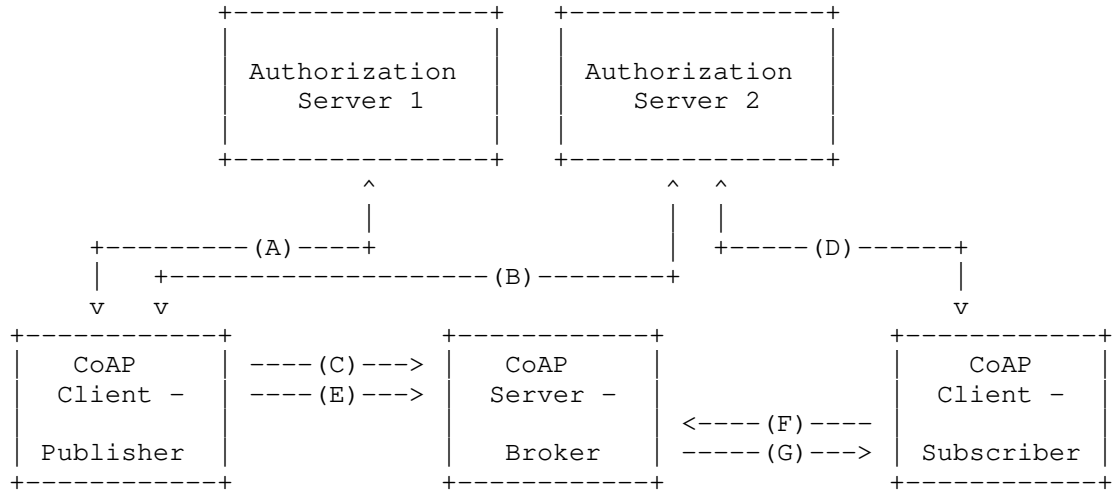


Figure 1: Architecture CoAP pubsub with Authorization Servers

The RS is the broker, which contains the topic. This node corresponds to the Dispatcher, in [I-D.ietf-ace-key-groupcomm]. The AS1 hosts the policies about the Broker: what endpoints are allowed to Publish on the Broker. The Clients access this node to get write access to the Broker. The AS2 hosts the policies about the topic: what endpoints are allowed to access what topic. This node represents both the AS and Key Distribution Center roles from [I-D.ietf-ace-key-groupcomm].

There are four phases, the first three can be done in parallel.

1. The Publisher requests publishing access to the Broker at the AS1, and communicates with the Broker to set up security.

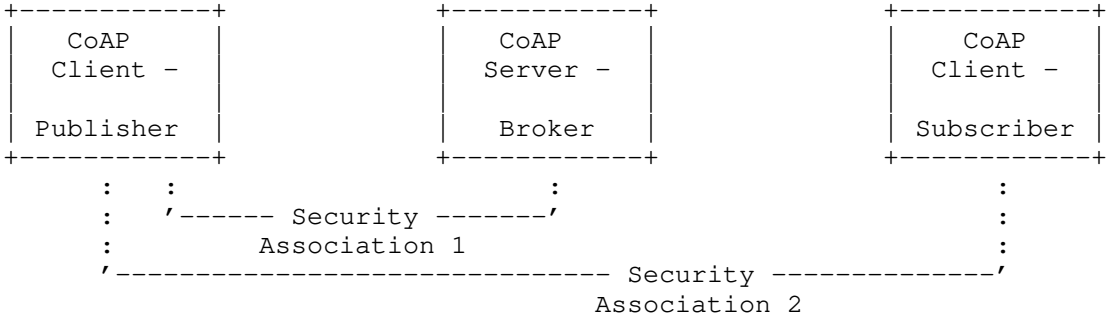
2. The Publisher requests access to a specific topic at the AS2

3. The Subscriber requests access to a specific topic at the AS2.

4. The Publisher and the Subscriber securely post to and get publications from the Broker.

This exchange aims at setting up 2 different security associations: on the one hand, the Publisher has a security association with the Broker, to protect the communication and securely authorize the Publisher to publish on a topic (Security Association 1). On the other hand, the Publisher has a security association with the Subscriber, to protect the publication content itself (Security Association 2). The Security Association 1 is set up using AS1 and a transport profile of [I-D.ietf-ace-oauth-authz], the Security Association 2 is set up using AS2 and [I-D.ietf-ace-key-groupcomm].

Note that, analogously to the Publisher, the Subscriber can also set up an additional security association with the Broker, using an AS, in the same way the Publisher does with AS1. In this case, only authorized Subscribers would be able to get notifications from the Broker. The overhead would be that each Subscriber should access the AS and get all the information to start a secure exchange with the Broker.



Note that AS1 and AS2 might either be co-resident or be 2 separate physical entities, in which case access control policies must be exchanged between AS1 and AS2, so that they agree on rights for joining nodes about specific topics. How the policies are exchanged is out of scope for this specification.

3. coap_pubsub_app Application Profile

This profile uses [I-D.ietf-ace-key-groupcomm], which expands the ACE framework. This document specifies which exact parameters from [I-D.ietf-ace-key-groupcomm] have to be used, and the values for each parameter.

The Publisher and the Subscriber map to the Client in [I-D.ietf-ace-key-groupcomm], the AS2 maps to the AS and to the KDC, the Broker maps to the Dispatcher.

Note that both publishers and subscribers use the same profile, called "coap_pubsub_app".

3.1. Retrieval of COSE Key for protection of content

This phase is common to both Publisher and Subscriber. To maintain the generality, the Publisher or Subscriber is referred as Client in this section.

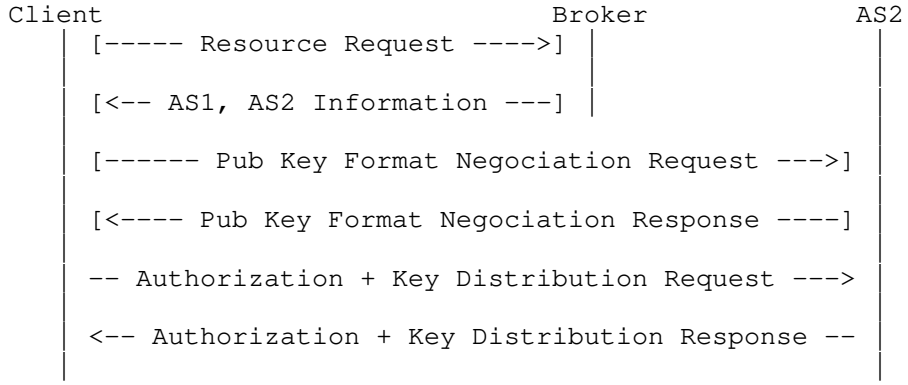


Figure 2: B: Access request - response

Complementary to what is defined in [I-D.ietf-ace-oauth-authz] (Section 5.1.1), to determine the AS2 in charge of a topic hosted at the Broker, the Broker MAY send the address of both the AS in charge of the topic back to the Client in the 'AS' parameter in the AS Information, as a response to an Unauthorized Resource Request (Section 5.1.2). The uri of AS2 is concatenated to the uri of AS1, and separated by a comma. An example using CBOR diagnostic notation is given below:

```
4.01 Unauthorized
Content-Format: application/ace+cbor
{"AS": "coaps://as1.example.com/token,
coaps://as2.example.com/pubsubkey"}
```

Figure 3: AS1, AS2 Information example

After retrieving the AS2 address, the Client MAY send a request to the AS, in order to retrieve necessary information concerning the public keys in the group, as well as concerning the algorithm and related parameters for computing signatures in the group. This request is a subset of the Token POST request defined in Section 3.3 of [I-D.ietf-ace-key-groupcomm], specifically a CoAP POST request to a specific resource at the AS, including only the parameters 'sign_info' and 'pub_key_enc' in the CBOR map in the payload. The default url-path for this resource is /ace-group/gid/cs-info, where "gid" is the topic identifier, but implementations are not required to use this name, and can use their own instead. The AS MUST respond with the response defined in Section 3.3 of [I-D.ietf-ace-key-groupcomm], specifically including the parameters 'sign_info', 'pub_key_enc', and 'rsnonce' (8 bytes pseudo-random nonce generated by the AS).

After that, the Client sends an Authorization + Joining Request, which is an Authorization Request merged with a Joining Request, as described in [I-D.ietf-ace-key-groupcomm], Sections 3.1 and 4.2. The reason for merging these two messages is that the AS2 is both the AS and the KDC, in this setting, so the Authorization Response and the Post Token message are not necessary.

More specifically, the Client sends a POST request to the /ace-group/gid endpoint on AS2, with Content-Format = "application/ace+cbor" that MUST contain in the payload (formatted as a CBOR map):

- the following fields from the Joining Request (Section 4.2 of [I-D.ietf-ace-key-groupcomm]):
  - 'scope' parameter set to a CBOR array containing:
    - the broker's topic as first element, and
    - the text string "publisher" if the client request to be a publisher, "subscriber" if the client request to be a subscriber, or a CBOR array containing both, if the client request to be both.
  - 'get_pub_keys' parameter set to the empty array if the Client needs to retrieve the public keys of the other pubsub members,

* 'client_cred' parameter containing the Client's public key formatted as a COSE_Key, if the Client needs to directly send that to the AS2,

* 'cnonce', set to a 8 bytes long pseudo-random nonce, if 'client_cred' is present,

* 'client_cred_verify', set to a singature computed over the rsnonce concatenated with cnonce, if 'client_cred' is present,

* OPTIONALLY, if needed, the 'pub_keys_repos' parameter

o the following fields from the Authorization Request (Section 3.1 of [I-D.ietf-ace-key-groupcomm]):

* OPTIONALLY, if needed, additional parameters such as 'client_id'

Note that the alg parameter in the 'client_cred' COSE_Key MUST be a signing algorithm, as defined in section 8 of [RFC8152], and that it is the same algorithm used to compute the signature sent in 'client_cred_verify'.

Examples of the payload of a Authorization + Joining Request are specified in Figure 5 and Figure 8.

The AS2 verifies that the Client is authorized to access the topic and, if the 'client_cred' parameter is present, stores the public key of the Client.

The AS2 response is an Authorization + Joining Response, with Content-Format = "application/ace+cbor". The payload (formatted as a CBOR map) MUST contain:

o the following fields from the Joining Response (Section 4.1 of [I-D.ietf-ace-key-groupcomm]):

* 'kty' identifies a key type "COSE_Key", as defined in Section 8.2.

* 'key', which contains a "COSE_Key" object (defined in [RFC8152], containing:

+ 'kty' with value 4 (symmetric)

+ 'alg' with value defined by the AS2 (Content Encryption Algorithm)

+ 'Base IV' with value defined by the AS2

+ 'k' with value the symmetric key value

+ OPTIONALLY, 'kid' with an identifier for the key value

* OPTIONALLY, 'exp' with the expiration time of the key

* 'pub_keys', containing the public keys of all authorized signing members formatted as COSE_Keys, if the 'get_pub_keys' parameter was present and set to the empty array in the Authorization + Key Distribution Request

o the following fields from the Authorization Response (Section 3.2 of [I-D.ietf-ace-key-groupcomm]):

* 'profile' set to "coap_pubsub_app", as specified in Section 8.1

* OPTIONALLY 'scope', set to a CBOR array containing:

+ the broker's topic as first element, and

+ the string "publisher" if the client is an authorized publisher, "subscriber" if the client is an authorized subscriber, or a CBOR array containing both, if the client is authorized to be both.

Examples for the response payload are detailed in Figure 6 and Figure 9.

4. Publisher

In this section, it is specified how the Publisher requests, obtains and communicates to the Broker the access token, as well as the retrieval of the keying material to protect the publication.

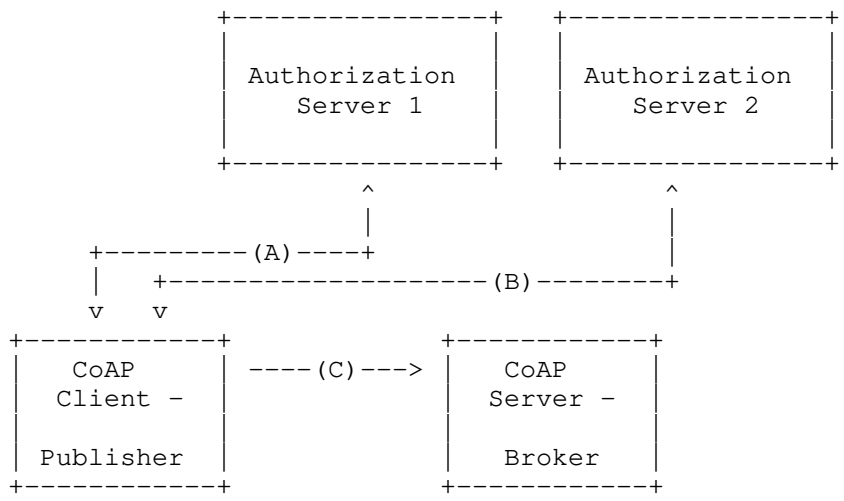


Figure 4: Phase 1: Publisher side

This is a combination of two independent phases:

- one is the establishment of a secure connection between Publisher and Broker, using an ACE transport profile such as DTLS [I-D.ietf-ace-dtls-authorize] or OSCORE [I-D.ietf-ace-oscore-profile]. (A)(C)

- the other is the Publisher's retrieval of keying material to protect the publication. (B)

In detail:

(A) corresponds to the Access Token Request and Response between Publisher and Authorization Server to retrieve the Access Token and RS (Broker) Information. As specified, the Publisher has the role of a CoAP client, the Broker has the role of the CoAP server.

(C) corresponds to the exchange between Publisher and Broker, where the Publisher sends its access token to the Broker and establishes a secure connection with the Broker. Depending on the Information received in (A), this can be for example DTLS handshake, or other protocols. Depending on the application, there may not be the need for this set up phase: for example, if OSCORE is used directly.

(A) and (C) details are specified in the profile used.

(B) corresponds to the retrieval of the keying material to protect the publication end-to-end with the subscribers (see Section 6.1),

and uses [I-D.ietf-ace-key-groupcomm]. The details are defined in Section 3.1.

An example of the payload of an Authorization + Joining Request and corresponding Response for a Publisher is specified in Figure 5 and Figure 6, where SIG is a signature computed using the private key associated to the public key and the algorithm in "client_cred".

```
{
  "scope" : ["Broker1/Temp", "publisher"],
  "client_id" : "publisher1",
  "client_cred" :
    { / COSE_Key /
      / type / 1 : 2, / EC2 /
      / kid / 2 : h'11',
      / alg / 3 : -7, / ECDSA with SHA-256 /
      / crv / -1 : 1 , / P-256 /
      / x / -2 : h'65eda5a12577c2bae829437fe338701a10aaa375e1bb5b5de1
      08de439c08551d',
      / y /-3 : h'1e52ed75701163f7f9e40ddf9f341b3dc9ba860af7e0ca7ca7e
      9eecd0084d19c',
  "cnonce" : h'd36b581d1eef9c7c,
  "client_cred_verify" : SIG
    }
}
```

Figure 5: Authorization + Joining Request payload for a Publisher

```
      {
        "profile" : "coap_pubsub_app",
        "kty" : "COSE_Key",
        "key" : {1: 4, 2: h'1234', 3: 12, 5: h'1f389d14d17dc7',
                -1: h'02e2cc3a9b92855220f255fff1c615bc'}
      }
```

Figure 6: Authorization + Joining Response payload for a Publisher

5. Subscriber

In this section, it is specified how the Subscriber retrieves the keying material to protect the publication.

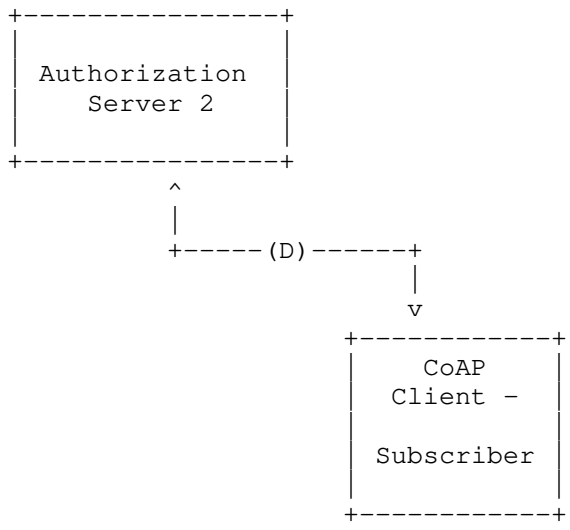


Figure 7: Phase 2: Subscriber side

Step (D) between Subscriber and AS2 corresponds to the retrieval of the keying material to verify the publication end-to-end with the publishers (see Section 6.1). The details are defined in Section 3.1

This step is the same as (B) between Publisher and AS2 (Section 3.1), with the following differences:

- The Authorization + Joining Request MUST NOT contain the 'client_cred parameter', the role element in the 'scope' parameter MUST be set to "subscriber". The Subscriber MUST have access to the public keys of all the Publishers; this MAY be achieved in the Authorization + Joining Request by using the parameter 'get_pub_keys' set to empty array.

- The Authorization + Key Distribution Response MUST contain the 'pub_keys' parameter.

An example of the payload of an Authorization + Joining Request and corresponding Response for a Subscriber is specified in Figure 8 and Figure 9.

```
{
  "scope" : ["Broker1/Temp", "subscriber"],
  "get_pub_keys" : [ ]
}
```

Figure 8: Authorization + Joining Request payload for a Subscriber

```
{
  "profile" : "coap_pubsub_app",
  "scope" : ["Broker1/Temp", "subscriber"],
  "kty" : "COSE_Key"
  "key" : {1: 4, 2: h'1234', 3: 12, 5: h'1f389d14d17dc7',
          -1: h'02e2cc3a9b92855220f255fff1c615bc'},
  "pub_keys" : [
   {
      1 : 2, / type EC2 /
      2 : h'11', / kid /
      3 : -7, / alg ECDSA with SHA-256 /
      -1 : 1 , / crv P-256 /
      -2 : h'65eda5a12577c2bae829437fe338701a10aaa375e1bb5b5de108de43
      9c08551d', / x /
      -3 : h'1e52ed75701163f7f9e40ddf9f341b3dc9ba860af7e0ca7ca7e9eecd
      0084d19c' / y /
    }
  ]
}
```

Figure 9: Authorization + Joining Response payload for a Subscriber

6. Pub-Sub Protected Communication

This section specifies the communication Publisher-Broker and Subscriber-Broker, after the previous phases have taken place. The operations of publishing and subscribing are defined in [I-D.ietf-core-coap-pubsub].

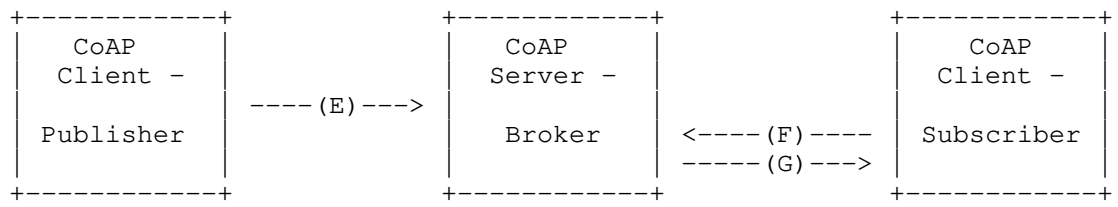


Figure 10: Phase 3: Secure communication between Publisher and Subscriber

The (E) message corresponds to the publication of a topic on the Broker. The publication (the resource representation) is protected with COSE ([RFC8152]). The (F) message is the subscription of the Subscriber, which is unprotected, unless a profile of ACE [I-D.ietf-ace-oauth-authz] is used between Subscriber and Broker. The (G) message is the response from the Broker, where the publication is protected with COSE.

The flow graph is presented below.

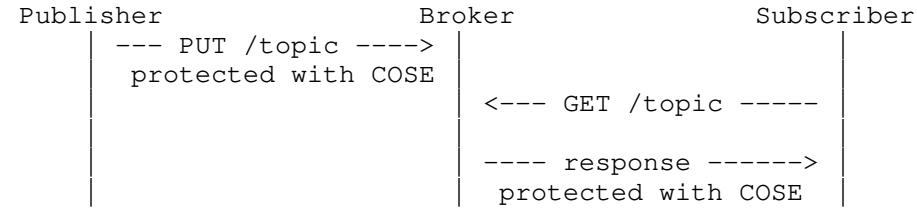


Figure 11: (E), (F), (G): Example of protected communication

6.1. Using COSE Objects To Protect The Resource Representation

The Publisher uses the symmetric COSE Key received from AS2 in exchange B (Section 3.1) to protect the payload of the PUBLISH operation (Section 4.3 of [I-D.ietf-core-coap-pubsub]). Specifically, the COSE Key is used to create a COSE_Encrypt0 with algorithm specified by AS2. The Publisher uses the private key corresponding to the public key sent to the AS2 in exchange B (Section 3.1) to countersign the COSE Object as specified in Section 4.5 of [RFC8152]. The CoAP payload is replaced by the COSE object before the publication is sent to the Broker.

The Subscriber uses the kid in the countersignature field in the COSE object to retrieve the right public key to verify the countersignature. It then uses the symmetric key received from AS2 to verify and decrypt the publication received in the payload of the CoAP Notification from the Broker.

The COSE object is constructed in the following way:

- The protected Headers (as described in Section 3 of [RFC8152]) MAY contain the kid parameter, with value the kid of the symmetric COSE Key received in Section 3.1 and MUST contain the content encryption algorithm.

- The unprotected Headers MUST contain the Partial IV, with value a sequence number that is incremented for every message sent, and the counter signature that includes:

  * the algorithm (same value as in the asymmetric COSE Key received in (B)) in the protected header;

  * the kid (same value as the kid of the asymmetric COSE Key received in (B)) in the unprotected header;

* the signature computed as specified in Section 4.5 of [RFC8152].

- The ciphertext, computed over the plaintext that MUST contain the CoAP payload.

The external_aad is an empty string.

An example is given in Figure 12

```
16(
  [
    / protected / h'a2010c04421234' / {
        \ alg \ 1:12, \ AES-CCM-64-64-128 \
        \ kid \ 4: h'1234'
      } / ,
    / unprotected / {
      / iv / 5:h'89f52f65a1c580',
      / countersign / 7:[
        / protected / h'a10126' / {
          \ alg \ 1:-7
        } / ,
        / unprotected / {
          / kid / 4:h'11'
        },
        / signature / SIG / 64 bytes signature /
      ]
    },
    / ciphertext / h'8df0a3b62fccff37aa313c8020e971f8aC8d'
  ]
)
```

Figure 12: Example of COSE Object sent in the payload of a PUBLISH operation

The encryption and decryption operations are described in sections 5.3 and 5.4 of [RFC8152].

7. Security Considerations

In the profile described above, the Publisher and Subscriber use asymmetric crypto, which would make the message exchange quite heavy for small constrained devices. Moreover, all Subscribers must be able to access the public keys of all the Publishers to a specific topic to be able to verify the publications. Such a database could be set up and managed by the same entity having control of the topic, i.e. AS2.

An application where it is not critical that only authorized Publishers can publish on a topic may decide not to make use of the asymmetric crypto and only use symmetric encryption/MAC to confidentiality and integrity protect the publication, but this is not recommended since, as a result, any authorized Subscribers with access to the Broker may forge unauthorized publications without being detected. In this symmetric case the Subscribers would only need one symmetric key per topic, and would not need to know any information about the Publishers, that can be anonymous to it and the Broker.

Subscribers can be excluded from future publications through re-keying for a certain topic. This could be set up to happen on a regular basis, for certain applications. How this could be done is out of scope for this work.

The Broker is only trusted with verifying that the Publisher is authorized to publish, but is not trusted with the publications itself, which it cannot read nor modify. In this setting, caching of publications on the Broker is still allowed.

TODO: expand on security and privacy considerations

8. IANA Considerations

8.1. ACE Groupcomm Profile Registry

The following registrations are done for the "ACE Groupcomm Profile" Registry following the procedure specified in [I-D.ietf-ace-key-groupcomm].

Note to RFC Editor: Please replace all occurrences of "[[This document]]" with the RFC number of this specification and delete this paragraph.

Name: coap_pubsub_app

Description: Profile for delegating client authentication and authorization for publishers and subscribers in a pub-sub setting scenario in a constrained environment.

CBOR Key: TBD

Reference: [[This document]]

8.2. ACE Groupcomm Key Registry

The following registrations are done for the ACE Groupcomm Key Registry following the procedure specified in [I-D.ietf-ace-key-groupcomm].

Note to RFC Editor: Please replace all occurrences of "[[This document]]" with the RFC number of this specification and delete this paragraph.

Name: COSE_Key

Key Type Value: TBD

Profile: coap_pubsub_app

Description: COSE_Key object

References: [RFC8152], [[This document]]

9. References

9.1. Normative References

[I-D.ietf-ace-key-groupcomm]
Palombini, F. and M. Tiloca, "Key Provisioning for Group Communication using ACE", draft-ietf-ace-key-groupcomm-03 (work in progress), November 2019.

[I-D.ietf-ace-oauth-authz]
Seitz, L., Selander, G., Wahlstroem, E., Erdtman, S., and H. Tschofenig, "Authentication and Authorization for Constrained Environments (ACE) using the OAuth 2.0 Framework (ACE-OAuth)", draft-ietf-ace-oauth-authz-25 (work in progress), October 2019.

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Koster, M., Keranen, A., and J. Jimenez, "Publish-Subscribe Broker for the Constrained Application Protocol (CoAP)", draft-ietf-core-coap-pubsub-09 (work in progress), September 2019.

[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>.

[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>.

[RFC8152] Schaad, J., "CBOR Object Signing and Encryption (COSE)", RFC 8152, DOI 10.17487/RFC8152, July 2017, <https://www.rfc-editor.org/info/rfc8152>.

9.2. Informative References

[I-D.ietf-ace-actors]
Gerdes, S., Seitz, L., Selander, G., and C. Bormann, "An architecture for authorization in constrained environments", draft-ietf-ace-actors-07 (work in progress), October 2018.

[I-D.ietf-ace-dtls-authorize]
Gerdes, S., Bergmann, O., Bormann, C., Selander, G., and L. Seitz, "Datagram Transport Layer Security (DTLS) Profile for Authentication and Authorization for Constrained Environments (ACE)", draft-ietf-ace-dtls-authorize-08 (work in progress), April 2019.

[I-D.ietf-ace-oscore-profile]
Palombini, F., Seitz, L., Selander, G., and M. Gunnarsson, "OSCORE profile of the Authentication and Authorization for Constrained Environments Framework", draft-ietf-ace-oscore-profile-08 (work in progress), July 2019.

Appendix A. Requirements on Application Profiles

This section lists the specifications on this profile based on the requirements defined in Appendix A of [I-D.ietf-ace-key-groupcomm]

- REQ1: Specify the encoding and value of the identifier of group or topic of 'scope': see Section 3.1).
- REQ2: Specify the encoding and value of roles of 'scope': see Section 3.1).
- REQ3: Optionally, specify the acceptable values for 'sign_alg': TODO
- REQ4: Optionally, specify the acceptable values for 'sign_parameters': TODO
- REQ5: Optionally, specify the acceptable values for 'sign_key_parameters': TODO

- REQ6: Optionally, specify the acceptable values for 'pub_key_enc': TODO
- REQ7: Specify the exact format of the 'key' value: COSE_Key, see Section 3.1.
- REQ8: Specify the acceptable values of 'kty' : "COSE_Key", see Section 3.1.
- REQ9: Specity the format of the identifiers of group members: TODO
- REQ10: Optionally, specify the format and content of 'group_policies' entries: not defined
- REQ11: Specify the communication protocol the members of the group must use: CoAP pub/sub.
- REQ12: Specify the security protocol the group members must use to protect their communication. This must provide encryption, integrity and replay protection: Object Security of Content using COSE, see Section 6.1.
- REQ13: Specify and register the application profile identifier : "coap_pubsub_app", see Section 8.1.
- REQ14: Optionally, specify the encoding of public keys, of 'client_cred', and of 'pub_keys' if COSE_Keys are not used: NA.
- REQ15: Specify policies at the KDC to handle id that are not included in get_pub_keys: TODO
- REQ16: Specify the format and content of 'group_policies': TODO
- REQ17: Specify the format of newly-generated individual keying material for group members, or of the information to derive it, and corresponding CBOR label : not defined
- REQ18: Specify how the communication is secured between Client and KDC. Optionally, specify tranport profile of ACE [I-D.ietf-ace-oauth-authz] to use between Client and KDC: pre-set, as KDC is AS.
- OPT1: Optionally, specify the encoding of public keys, of 'client_cred', and of 'pub_keys' if COSE_Keys are not used: NA
- OPT2: Optionally, specify the negotiation of parameter values for signature algorithm and signature keys, if 'sign_info' and 'pub_key_enc' are not used: NA

- OPT3: Optionally, specify the format and content of 'mgt_key_material': not defined

- OPT4: Optionally, specify policies that instruct clients to retain unsuccessfully decrypted messages and for how long, so that they can be decrypted after getting updated keying material: not defined

Acknowledgments

The author wishes to thank Ari Keraenen, John Mattsson, Ludwig Seitz, Goeran Selander, Jim Schaad and Marco Tiloca for the useful discussion and reviews that helped shape this document.

Author's Address

Francesca Palombini
Ericsson

Email: francesca.palombini@ericsson.com

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F. Palombini
Ericsson AB
M. Tiloca
RISE AB

October 22, 2018

Key Provisioning for Group Communication using ACE
draft-palombini-ace-key-groupcomm-02

Abstract

This document defines message formats and procedures for requesting and distributing group keying material using the ACE framework, to protect communications between group members.

Status of This Memo

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

Internet-Drafts are working documents of the Internet Engineering Task Force (IETF). Note that other groups may also distribute working documents as Internet-Drafts. The list of current Internet-Drafts is at https://datatracker.ietf.org/drafts/current/.

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This Internet-Draft will expire on April 25, 2019.

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Table of Contents

1. Introduction

This document expands the ACE framework [I-D.ietf-ace-oauth-authz] to define the format of messages used to request, distribute and renew the keying material in a group communication scenario, e.g. based on multicast [RFC7390] or on publishing-subscribing [I-D.ietf-core-coap-pubsub].

Profiles that use group communication can build on this document to specify the selection of the message parameters defined in this document to use and their values. Known applications that can benefit from this document would be, for example, profiles addressing group communication based on multicast [RFC7390] or publishing/ subscribing [I-D.ietf-core-coap-pubsub] in ACE.

If the application requires backward and forward security, updated keying material is generated and distributed to the group members (rekeying), when membership changes. A key management scheme performs the actual distribution of the updated keying material to

the group. In particular, the key management scheme rekeys the current group members when a new node joins the group, and the remaining group members when a node leaves the group. This document provides a message format for group rekeying that allows to fulfill these requirements. Rekeying mechanisms can be based on [RFC2093], [RFC2094] and [RFC2627].

1.1. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119]. These words may also appear in this document in lowercase, absent their normative meanings.

Readers are expected to be familiar with the terms and concepts described in [I-D.ietf-ace-oauth-authz] and [RFC8152], such as Authorization Server (AS) and Resource Server (RS).

2. Overview

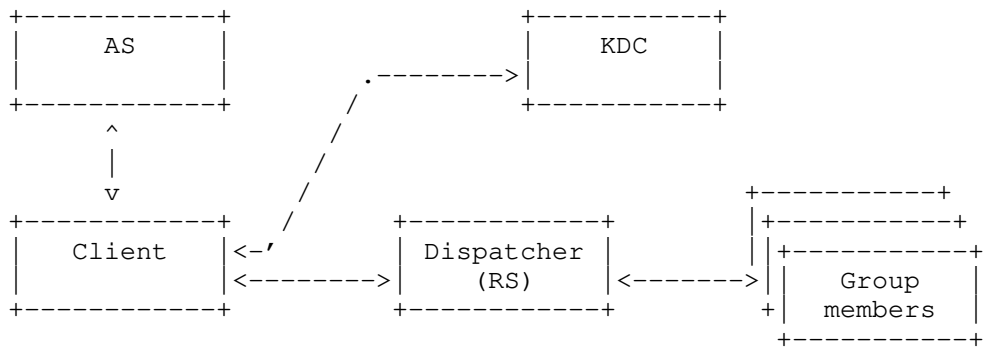

Figure 1: Key Distribution Participants

The following participants (see Figure 1) take part in the authorization and key distribution.

- Client (C): node that wants to join the group communication. It can request write and/or read rights.

- Authorization Server (AS): same as AS in the ACE Framework; it enforces access policies, and knows if a node is allowed to join the group with write and/or read rights.

- Key Distribution Center (KDC): maintains the keying material to protect group communications, and provides it to Clients

authorized to join the group. During the first part of the exchange (Section 3), it takes the role of the RS in the ACE Framework. During the second part (Section 4), which is not based on the ACE Framework, it distributes the keying material. In addition, it provides the latest keying material to group members when requested. If required by the application, the KDC renews and re-distributes the keying material in the group when membership changes.

- Dispatcher: entity through which the Clients communicate with the group and which distributes messages to the group members. Examples of dispatchers are: the Broker node in a pub-sub setting; a relayer node for group communication that delivers group messages as multiple unicast messages to all group members; an implicit entity as in a multicast communication setting, where messages are transmitted to a multicast IP address and delivered on the transport channel.

This document specifies the message flows and formats for:

- Authorizing a new node to join the group (Section 3), and providing it with the group keying material to communicate with the other group members (Section 4).

- Removing of a current member from the group (Section 5).

- Retrieving keying material as a current group member (Section 6 and Section 7).

- Renewing and re-distributing the group keying material (rekeying) upon a membership change in the group (Section 4.2 and Section 5).

Figure 2 provides a high level overview of the message flow for a node joining a group communication setting.

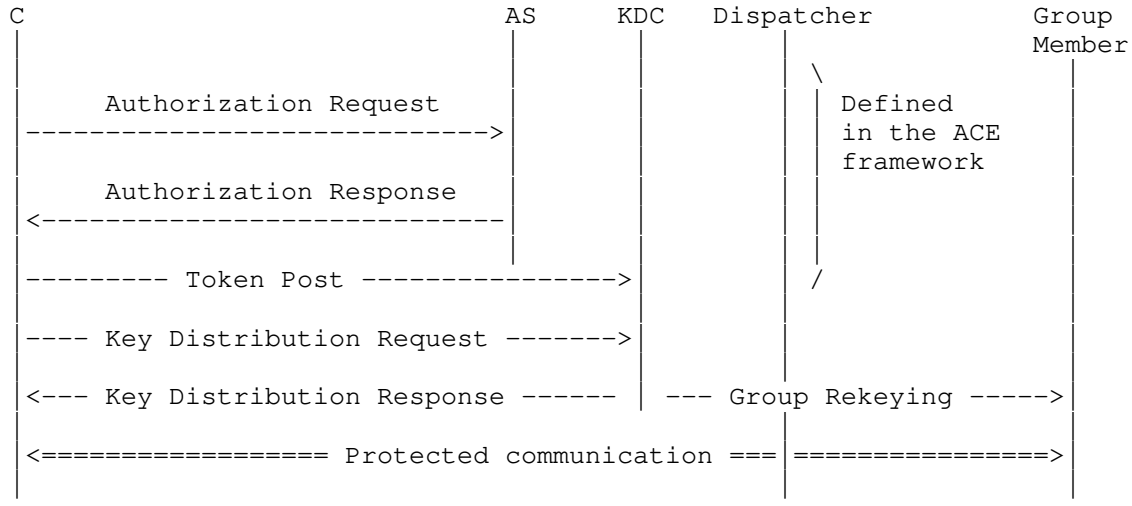

Figure 2: Message Flow Upon New Node's Joining

The exchange of Authorization Request and Authorization Response between Client and AS MUST be secured, as specified by the ACE profile used between Client and KDC.

The exchange of Key Distribution Request and Key Distribution Response between Client and KDC MUST be secured, as a result of the ACE profile used between Client and KDC.

All further communications between the Client and the KDC MUST be secured, for instance with the same security mechanism used for the Key Distribution exchange.

All further communications between a Client and the other group members MUST be secured using the keying material provided in Section 4.

3. Authorization to Join a Group

This section describes in detail the format of messages exchanged by the participants when a node requests access to a group. The first part of the exchange is based on ACE [I-D.ietf-ace-oauth-authz].

As defined in [I-D.ietf-ace-oauth-authz], the Client requests from the AS an authorization to join the group through the KDC (see Section 3.1). If the request is approved and authorization is granted, the AS provides the Client with a proof-of-possession access token and parameters to securely communicate with the KDC (see

Section 3.2). Communications between the Client and the AS MUST be secured, and depends on the profile of ACE used.

Figure 3 gives an overview of the exchange described above.

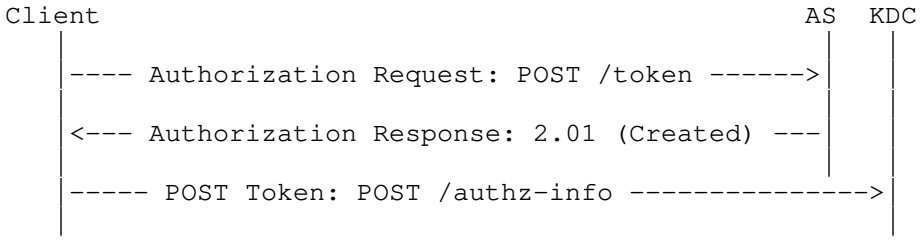

Figure 3: Message Flow of Join Authorization

3.1. Authorization Request

The Authorization Request sent from the Client to the AS is as defined in Section 5.6.1 of [I-D.ietf-ace-oauth-authz] and MUST contain the following parameters:

- 'grant_type', with value "client_credentials".

Additionally, the Authorization Request MAY contain the following parameters, which, if included, MUST have the corresponding values:

- 'scope', with value the identifier of the specific group or topic the Client wishes to access, and optionally the role(s) the Client wishes to take. This value is a CBOR array encoded as a byte string, which contains:

  * As first element, the identifier of the specific group or topic.

  * Optionally, as second element, the role (or CBOR array of roles) the Client wishes to take in the group.

  The encoding of the group or topic identifier and of the role identifiers is application specific.

- 'req_aud', as defined in Section 3.1 of [I-D.ietf-ace-oauth-params], with value an identifier of the KDC.

- 'req_cnf', as defined in Section 3.1 of [I-D.ietf-ace-oauth-params], optionally containing the public key or the certificate of the Client, if it wishes to communicate that to the AS.

- Other additional parameters as defined in [I-D.ietf-ace-oauth-authz], if necessary.

3.2. Authorization Response

The Authorization Response sent from the AS to the Client is as defined in Section 5.6.2 of [I-D.ietf-ace-oauth-authz] and MUST contain the following parameters:

- 'access_token', containing the proof-of-possession access token.

- 'cnf' if symmetric keys are used, not present if asymmetric keys are used. This parameter is defined in Section 3.2 of [I-D.ietf-ace-oauth-params] and contains the symmetric proof-of-possession key that the Client is supposed to use with the KDC.

- 'rs_cnf' if asymmetric keys are used, not present if symmetric keys are used. This parameter is as defined in Section 3.2 of [I-D.ietf-ace-oauth-params] and contains information about the public key of the KDC.

- 'exp', contains the lifetime in seconds of the access token. This parameter MAY be omitted if the application defines how the expiration time is communicated to the Client via other means, or if it establishes a default value.

Additionally, the Authorization Response MAY contain the following parameters, which, if included, MUST have the corresponding values:

- 'scope', which mirrors the 'scope' parameter in the Authorization Request (see Section 3.1). Its value is a CBOR array encoded as a byte string, containing:

  * As first element, the identifier of the specific group or topic the Client is authorized to access.

  * Optionally, as second element, the role (or CBOR array of roles) the Client is authorized to take in the group.

  The encoding of the group or topic identifier and of the role identifiers is application specific.

- Other additional parameters as defined in [I-D.ietf-ace-oauth-authz], if necessary.

The access token MUST contain all the parameters defined above (including the same 'scope' as in this message, if present, or the

'scope' of the Authorization Request otherwise), and additionally other optional parameters the profile requires.

When receiving an Authorization Request from a Client that was previously authorized, and which still owns a valid non expired access token, the AS can simply reply with an Authorization Response including a new access token.

3.3. Token Post

The Client sends a CoAP POST request including the access token to the KDC, as specified in section 5.8.1 of [I-D.ietf-ace-oauth-authz]. If the specific ACE profile defines it, the Client MAY use a different endpoint than /authz-info at the KDC to post the access token to. After successful verification, the Client is authorized to receive the group keying material from the KDC and join the group.

Note that this step could be merged with the following message from the Client to the KDC, namely Key Distribution Request.

4. Key Distribution

This section defines how the keying material used for group communication is distributed from the KDC to the Client, when joining the group as a new member.

If not previously established, the Client and the KDC MUST first establish a pairwise secure communication channel using ACE. The exchange of Key Distribution Request-Response MUST occur over that secure channel. The Client and the KDC MAY use that same secure channel to protect further pairwise communications, that MUST be secured.

During this exchange, the Client sends a request to the AS, specifying the group it wishes to join (see Section 4.1). Then, the KDC verifies the access token and that the Client is authorized to join that group; if so, it provides the Client with the keying material to securely communicate with the member of the group (see Section 4.2).

Figure 4 gives an overview of the exchange described above.

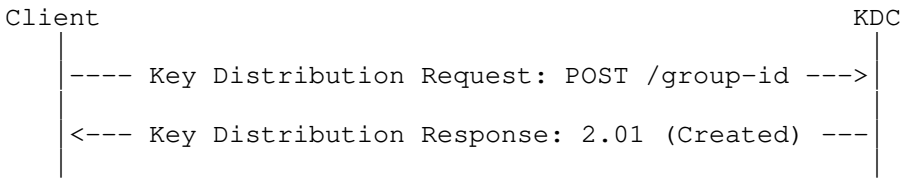

Figure 4: Message Flow of Key Distribution to a New Group Member

The same set of message can also be used for the following cases, when the Client is already a group member:

- The Client wishes to (re-)get the current keying material, for cases such as expiration, loss or suspected mismatch, due to e.g. reboot or missed group rekeying. This is further discussed in Section 6.

- The Client wishes to (re-)get the public keys of other group members, e.g. if it is aware of new nodes joining the group after itself. This is further discussed in Section 7.

Additionally, the format of the payload of the Key Distribution Response (Section 4.2) can be reused for messages sent by the KDC to distribute updated group keying material, in case of a new node joining the group or of a current member leaving the group. The key management scheme used to send such messages could rely on, e.g., multicast in case of a new node joining or unicast in case of a node leaving the group.

Note that proof-of-possession to bind the access token to the Client is performed by using the proof-of-possession key bound to the access token for establishing secure communication between the Client and the KDC.

4.1. Key Distribution Request

The Client sends a Key Distribution request to the KDC. This corresponds to a CoAP POST request to the endpoint in the KDC associated to the group to join. The endpoint in the KDC is associated to the 'scope' value of the Authorization Request/ Response. The payload of this request is a CBOR Map which MAY contain the following fields, which, if included, MUST have the corresponding values:

- 'scope', with value the specific resource that the Client is authorized to access (i.e. group or topic identifier) and role(s), encoded as in Section 3.1.

- 'get_pub_keys', if the Client wishes to receive the public keys of the other nodes in the group from the KDC. The value is an empty CBOR Array. This parameter may be present if the KDC stores the public keys of the nodes in the group and distributes them to the Client; it is useless to have here if the set of public keys of the members of the group is known in another way, e.g. it was provided by the AS.

- 'client_cred', with value the public key or certificate of the Client. If the KDC is managing (collecting from/distributing to the Client) the public keys of the group members, this field contains the public key of the Client.

- 'pub_keys_repos', can be present if a certificate is present in the 'client_cred' field, with value a list of public key repositories storing the certificate of the Client.

4.2. Key Distribution Response

The KDC verifies the access token and, if verification succeeds, sends a Key Distribution success Response to the Client. This corresponds to a 2.01 Created message. The payload of this response is a CBOR Map which MUST contain the following fields:

- 'key', used to send the keying material to the Client, as a COSE_Key ([RFC8152]) containing the following parameters:

  * 'kty', as defined in [RFC8152].

  * 'k', as defined in [RFC8152].

  * 'exp' (optionally), as defined below. This parameter is RECOMMENDED to be included in the COSE_Key. If omitted, the authorization server SHOULD provide the expiration time via other means or document the default value.

  * 'alg' (optionally), as defined in [RFC8152].

  * 'kid' (optionally), as defined in [RFC8152].

  * 'base iv' (optionally), as defined in [RFC8152].

  * 'clientID' (optionally), as defined in [I-D.ietf-ace-oscore-profile].

  * 'serverID' (optionally), as defined in [I-D.ietf-ace-oscore-profile].

* 'kdf' (optionally), as defined in [I-D.ietf-ace-oscore-profile].

* 'slt' (optionally), as defined in [I-D.ietf-ace-oscore-profile].

* 'cs_alg' (optionally), containing the algorithm value to countersign the message, taken from Table 5 and 6 of [RFC8152].

The parameter 'exp' identifies the expiration time in seconds after which the COSE_Key is not valid anymore for secure communication in the group. A summary of 'exp' can be found in Figure 5.

Name	Label	CBOR Type	Value Registry	Description
exp	TBD	Integer or floating-point number	COSE Key Common Parameters	Expiration time in seconds

Figure 5: COSE Key Common Header Parameter 'exp'

Optionally, the Key Distribution Response MAY contain the following parameters, which, if included, MUST have the corresponding values:

o 'pub_keys', may only be present if 'get_pub_keys' was present in the Key Distribution Request; this parameter is a COSE_KeySet (see [RFC8152]), which contains the public keys of all the members of the group.

o 'group_policies', with value a list of parameters indicating how the group handles specific management aspects. This includes, for instance, approaches to achieve synchronization of sequence numbers among group members. The exact format of this parameter is specific to the profile.

o 'mgt_key_material', with value the administrative keying material to participate in the group rekeying performed by the KDC. The exact format and content depend on the specific rekeying scheme used in the group, which may be specified in the profile.

Specific profiles need to specify how exactly the keying material is used to protect the group communication.

If the application requires backward security, the KDC SHALL generate new group keying material and securely distribute it to all the

current group members, using the message format defined in this section. Application profiles may define alternative message formats.

TBD: define for verification failure

5. Removal of a Node from the Group

This section describes at a high level how a node can be removed from the group.

If the application requires forward security, the KDC SHALL generate new group keying material and securely distribute it to all the current group members but the leaving node, using the message format defined in Section 4.2. Application profiles may define alternative message formats.

5.1. Expired Authorization

If the node is not authorized anymore, the AS can directly communicate that to the KDC. Alternatively, the access token might have expired. If Token introspection is provided by the AS, the KDC can use it as per Section 5.7 of [I-D.ietf-ace-oauth-authz], in order to verify that the access token is still valid.

Either case, once aware that a node is not authorized anymore, the KDC has to remove the unauthorized node from the list of group members, if the KDC keeps track of that.

5.2. Request to Leave the Group

A node can actively request to leave the group. In this case, the Client can send a request formatted as follows to the KDC, to abandon the group.

TBD: Format of the message to leave the group

The KDC should then remove the leaving node from the list of group members, if the KDC keeps track of that.

Note that, after having left the group, a node may wish to join it again. Then, as long as the node is still authorized to join the group, i.e. it has a still valid access token, it can re-request to join the group directly to the KDC without needing to retrieve a new access token from the AS. This means that the KDC needs to keep track of nodes with valid access tokens, before deleting all information about the leaving node.

6. Retrieval of Updated Keying Material

A node stops using the group keying material upon its expiration, according to the 'exp' parameter specified in the retained COSE Key. Then, if it wants to continue participating in the group communication, the node has to request new updated keying material to the KDC.

The Client may perform the same request to the KDC also upon receiving messages from other group members without being able to correctly decrypt them. This may be due to a previous update of the group keying material (rekeying) triggered by the KDC, that the Client was not able to receive or decrypt.

Note that policies can be set up so that the Client sends a request to the KDC only after a given number of unsuccessfully decrypted incoming messages.

6.1. Key Re-Distribution Request

To request a re-distribution of keying material, the Client sends a shortened Key Distribution Request to the KDC (Section 4.1), formatted as follows. The payload MUST contain only the following field:

- 'scope', which contains only the identifier of the specific group or topic, encoded as in Section 3.1. That is, the role field is not present.

6.2. Key Re-Distribution Response

The KDC receiving a Key Re-Distribution Request MUST check that it is storing a valid access token from that client for that scope.

TODO: defines error response if it does not have it / is not valid.

The KDC replies to the Client with a Key Distribution Response containing the 'key' parameter, and optionally 'group_policies' and 'mgt_key_material', as specified in Section 4.2. Note that this response might simply re-provide the same keying material currently owned by the Client, if it has not been renewed.

7. Retrieval of Public Keys for Group Members

In case the KDC maintains the public keys of group members, a node in the group can contact the KDC to request public keys of either all group members or a specified subset, using the messages defined below.

Figure 6 gives an overview of the exchange described above.

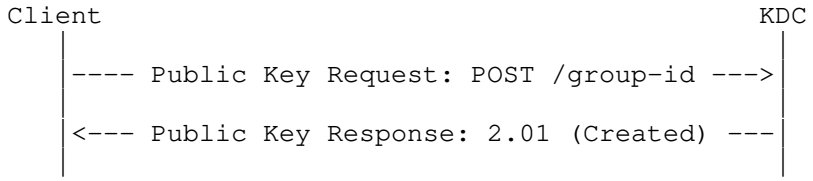

Figure 6: Message Flow of Public Key Request-Response

Note that these messages can be combined with the Key Re-Distribution messages in Section 6, to request at the same time the keying material and the public keys. In this case, either a new endpoint at the KDC may be used, or additional information needs to be sent in the request payload, to distinguish these combined messages from the Public Key messages described below, since they would be identical otherwise.

7.1. Public Key Request

To request public keys, the Client sends a shortened Key Distribution Request to the KDC (Section 4.1), formatted as follows. The payload of this request MUST contain the following fields:

- 'get_pub_keys', which has as value a CBOR array including either:
  - no elements, i.e. an empty array, in order to request the public key of all current group members; or
  - N elements, each of which is the identifier of a group member, in order to request the public key of the specified nodes.
- 'scope', which contains only the identifier of the specific group or topic, encoded as in Section 3.1. That is, the role field is not present.

7.2. Public Key Response

The KDC replies to the Client with a Key Distribution Response containing only the 'pub_keys' parameter, as specified in Section 4.2. The payload of this response contains the following field:

- 'pub_keys', which contains either:

* the public keys of all the members of the group, if the 'get_pub_keys' parameter of the Public Key request was an empty array; or

* the public keys of the group members with the identifiers specified in the 'get_pub_keys' parameter of the Public Key request.

The KDC ignores possible identifiers included in the 'get_pub_keys' parameter of the Public Key request if they are not associated to any current group member.

8. Security Considerations

The KDC must renew the group keying material upon its expiration.

The KDC should renew the keying material upon group membership change, and should provide it to the current group members through the rekeying scheme used in the group.

9. IANA Considerations

The following registration is required for the COSE Key Common Parameter Registry specified in Section 16.5 of [RFC8152]:

- Name: exp
- Label: TBD
- CBOR Type: Integer or floating-point number
- Value Registry: COSE Key Common Parameters
- Description: Identifies the expiration time in seconds of the COSE Key
- Reference: [[this specification]]

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Authors' Addresses

Francesca Palombini
Ericsson AB
Torshamnsgatan 23
Kista SE-16440 Stockholm
Sweden

Email: francesca.palombini@ericsson.com

Marco Tiloca
RISE AB
Isafjordsgatan 22
Kista SE-16440 Stockholm
Sweden

Email: marco.tiloca@ri.se

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G. Selander
J. Mattsson
F. Palombini
Ericsson AB

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Ephemeral Diffie-Hellman Over COSE (EDHOC)
draft-selander-ace-cose-ecdhe-14

Abstract

This document specifies Ephemeral Diffie-Hellman Over COSE (EDHOC), a very compact, and lightweight authenticated Diffie-Hellman key exchange with ephemeral keys. EDHOC provides mutual authentication, perfect forward secrecy, and identity protection. EDHOC is intended for usage in constrained scenarios and a main use case is to establish an OSCORE security context. By reusing COSE for cryptography, CBOR for encoding, and CoAP for transport, the additional code footprint can be kept very low.

Table of Contents

1. Introduction

Security at the application layer provides an attractive option for protecting Internet of Things (IoT) deployments, for example where transport layer security is not sufficient [I-D.hartke-core-e2e-security-reqs] or where the protection needs to work over a variety of underlying protocols. IoT devices may be constrained in various ways, including memory, storage, processing capacity, and energy [RFC7228]. A method for protecting individual messages at the application layer suitable for constrained devices, is provided by CBOR Object Signing and Encryption (COSE) [RFC8152]), which builds on the Concise Binary Object Representation (CBOR) [I-D.ietf-cbor-7049bis]. Object Security for Constrained RESTful Environments (OSCORE) [RFC8613] is a method for application-layer protection of the Constrained Application Protocol (CoAP), using COSE.

In order for a communication session to provide forward secrecy, the communicating parties can run an Elliptic Curve Diffie-Hellman (ECDH) key exchange protocol with ephemeral keys, from which shared key material can be derived. This document specifies Ephemeral Diffie-Hellman Over COSE (EDHOC), a lightweight key exchange protocol providing perfect forward secrecy and identity protection. Authentication is based on credentials established out of band, e.g. from a trusted third party, such as an Authorization Server as specified by [I-D.ietf-ace-oauth-authz]. EDHOC supports authentication using pre-shared keys (PSK), raw public keys (RPK), and public key certificates. After successful completion of the EDHOC protocol, application keys and other application specific data can be derived using the EDHOC-Exporter interface. A main use case for EDHOC is to establish an OSCORE security context. EDHOC uses COSE for cryptography, CBOR for encoding, and CoAP for transport. By reusing existing libraries, the additional code footprint can be kept very low. Note that this document focuses on authentication and key establishment: for integration with authorization of resource access, refer to [I-D.ietf-ace-oscore-profile].

EDHOC is designed to work in highly constrained scenarios making it especially suitable for network technologies such as Cellular IoT, 6TiSCH [I-D.ietf-6tisch-dtsecurity-zerotouch-join], and LoRaWAN [LoRa1][LoRa2]. These network technologies are characterized by their low throughput, low power consumption, and small frame sizes. Compared to the DTLS 1.3 handshake [I-D.ietf-tls-dtls13] with ECDH and connection ID, the number of bytes in EDHOC is less than 1/4 when PSK authentication is used and less than 1/3 when RPK authentication is used, see [I-D.ietf-lwig-security-protocol-comparison]. Typical message sizes for EDHOC with pre-shared keys, raw public keys, and X.509 certificates are shown in Figure 1.

	PSK	RPK	x5t	x5chain
message_1	40	38	38	38
message_2	45	114	126	116 + Certificate chain
message_3	11	80	91	81 + Certificate chain
Total	96	232	255	235 + Certificate chains

Figure 1: Typical message sizes in bytes

The ECDH exchange and the key derivation follow [SIGMA], NIST SP-800-56A [SP-800-56A], and HKDF [RFC5869]. CBOR [I-D.ietf-cbor-7049bis] and COSE [RFC8152] are used to implement these standards. The use of COSE provides crypto agility and enables use of future algorithms and headers designed for constrained IoT.

This document is organized as follows: Section 2 describes how EDHOC builds on SIGMA-I, Section 3 specifies general properties of EDHOC, including message flow, formatting of the ephemeral public keys, and key derivation, Section 4 specifies EDHOC with asymmetric key authentication, Section 5 specifies EDHOC with symmetric key authentication, Section 6 specifies the EDHOC error message, and Section 7 describes how EDHOC can be transferred in CoAP and used to establish an OSCORE security context.

1.1. Rationale for EDHOC

Many constrained IoT systems today do not use any security at all, and when they do, they often do not follow best practices. One reason is that many current security protocols are not designed with constrained IoT in mind. Constrained IoT systems often deal with personal information, valuable business data, and actuators interacting with the physical world. Not only do such systems need security and privacy, they often need end-to-end protection with

source authentication and perfect forward secrecy. EDHOC and OSCORE [RFC8613] enables security following current best practices to devices and systems where current security protocols are impractical.

EDHOC is optimized for small message sizes and can therefore be sent over a small number of radio frames. The message size of a key exchange protocol may have a large impact on the performance of an IoT deployment, especially in noisy environments. For example, in a network bootstrapping setting a large number of devices turned on in a short period of time may result in large latencies caused by parallel key exchanges. Requirements on network formation time in constrained environments can be translated into key exchange overhead. In networks technologies with transmission back-off time, each additional frame significantly increases the latency even if no other devices are transmitting.

Power consumption for wireless devices is highly dependent on message transmission, listening, and reception. For devices that only send a few bytes occasionally, the battery lifetime may be significantly reduced by a heavy key exchange protocol. Moreover, a key exchange may need to be executed more than once, e.g. due to a device losing power or rebooting for other reasons.

EDHOC is adapted to primitives and protocols designed for the Internet of Things: EDHOC is built on CBOR and COSE which enables small message overhead and efficient parsing in constrained devices. EDHOC is not bound to a particular transport layer, but it is recommended to transport the EDHOC message in CoAP payloads. EDHOC is not bound to a particular communication security protocol but works off-the-shelf with OSCORE [RFC8613] providing the necessary input parameters with required properties. Maximum code complexity (ROM/Flash) is often a constraint in many devices and by reusing already existing libraries, the additional code footprint for EDHOC + OSCORE can be kept very low.

1.2. Terminology and 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.

The word "encryption" without qualification always refers to authenticated encryption, in practice implemented with an Authenticated Encryption with Additional Data (AEAD) algorithm, see [RFC5116].

Readers are expected to be familiar with the terms and concepts described in CBOR [I-D.ietf-cbor-7049bis], COSE [RFC8152], and CDDL [RFC8610]. The Concise Data Definition Language (CDDL) is used to express CBOR data structures [I-D.ietf-cbor-7049bis]. Examples of CBOR and CDDL are provided in Appendix A.1.

2. Background

SIGMA (SIGn-and-MAc) is a family of theoretical protocols with a large number of variants [SIGMA]. Like IKEv2 and (D)TLS 1.3 [RFC8446], EDHOC is built on a variant of the SIGMA protocol which provide identity protection of the initiator (SIGMA-I), and like (D)TLS 1.3, EDHOC implements the SIGMA-I variant as Sign-then-MAC. The SIGMA-I protocol using an authenticated encryption algorithm is shown in Figure 2.

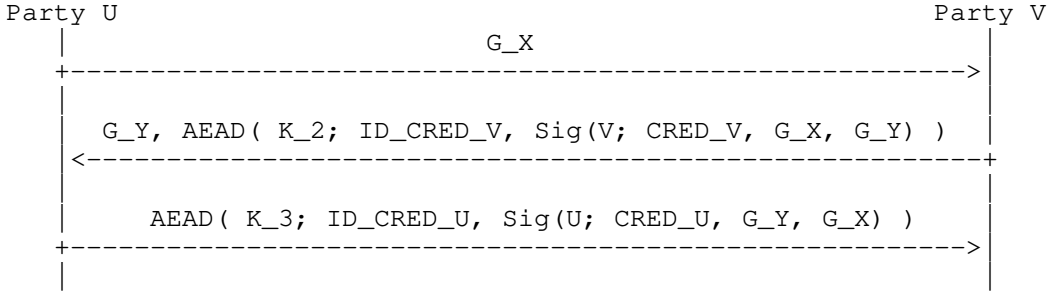

Figure 2: Authenticated encryption variant of the SIGMA-I protocol.

The parties exchanging messages are called "U" and "V". They exchange identities and ephemeral public keys, compute the shared secret, and derive symmetric application keys.

- G_X and G_Y are the ECDH ephemeral public keys of U and V, respectively.
- CRED_U and CRED_V are the credentials containing the public authentication keys of U and V, respectively.
- ID_CRED_U and ID_CRED_V are data enabling the recipient party to retrieve the credential of U and V, respectively.
- Sig(U; .) and S(V; .) denote signatures made with the private authentication key of U and V, respectively.
- AEAD(K; .) denotes authenticated encryption with additional data using the key K derived from the shared secret. The authenticated

encryption MUST NOT be replaced by plain encryption, see Section 8.

In order to create a "full-fledged" protocol some additional protocol elements are needed. EDHOC adds:

- Explicit connection identifiers C_U, C_V chosen by U and V, respectively, enabling the recipient to find the protocol state.
- Transcript hashes TH_2, TH_3, TH_4 used for key derivation and as additional authenticated data.
- Computationally independent keys derived from the ECDH shared secret and used for encryption of different messages.
- Verification of a common preferred cipher suite (AEAD algorithm, ECDH algorithm, ECDH curve, signature algorithm):
  - U lists supported cipher suites in order of preference
  - V verifies that the selected cipher suite is the first supported cipher suite
- Method types and error handling.
- Transport of opaque application defined data.

EDHOC is designed to encrypt and integrity protect as much information as possible, and all symmetric keys are derived using as much previous information as possible. EDHOC is furthermore designed to be as compact and lightweight as possible, in terms of message sizes, processing, and the ability to reuse already existing CBOR, COSE, and CoAP libraries.

To simplify for implementors, the use of CBOR in EDHOC is summarized in Appendix A and test vectors including CBOR diagnostic notation are given in Appendix C.

3. EDHOC Overview

EDHOC consists of three flights (message_1, message_2, message_3) that maps directly to the three messages in SIGMA-I, plus an EDHOC error message. EDHOC messages are CBOR Sequences [I-D.ietf-cbor-sequence], where the first data item of message_1 is an int (TYPE) specifying the method (asymmetric, symmetric) and the correlation properties of the transport used.

While EDHOC uses the COSE_Key, COSE_Sign1, and COSE_Encrypt0 structures, only a subset of the parameters is included in the EDHOC messages. After creating EDHOC message_3, Party U can derive symmetric application keys, and application protected data can therefore be sent in parallel with EDHOC message_3. The application may protect data using the algorithms (AEAD, HMAC, etc.) in the selected cipher suite and the connection identifiers (C_U, C_V). EDHOC may be used with the media type application/edhoc defined in Section 9.

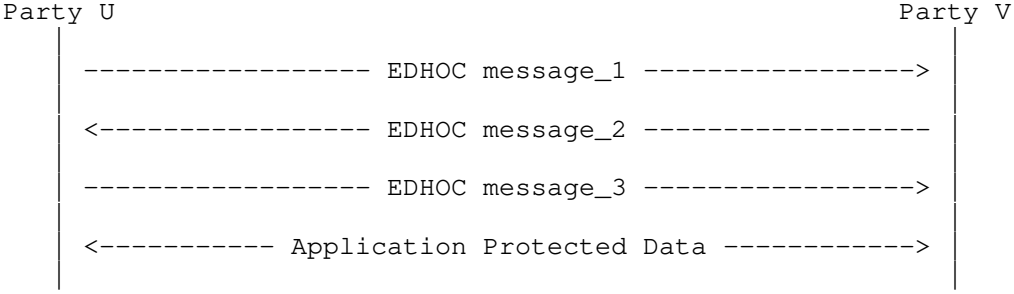

Figure 3: EDHOC message flow

The EDHOC message exchange may be authenticated using pre-shared keys (PSK), raw public keys (RPK), or public key certificates. EDHOC assumes the existence of mechanisms (certification authority, manual distribution, etc.) for binding identities with authentication keys (public or pre-shared). When a public key infrastructure is used, the identity is included in the certificate and bound to the authentication key by trust in the certification authority. When the credential is manually distributed (PSK, RPK, self-signed certificate), the identity and authentication key is distributed out-of-band and bound together by trust in the distribution method. EDHOC with symmetric key authentication is very similar to EDHOC with asymmetric key authentication, the difference being that information is only MACed, not signed, and that session keys are derived from the ECDH shared secret and the PSK.

EDHOC allows opaque application data (UAD and PAD) to be sent in the EDHOC messages. Unprotected Application Data (UAD_1, UAD_2) may be sent in message_1 and message_2 and can be e.g. be used to transfer access tokens that are protected outside of EDHOC. Protected application data (PAD_3) may be used to transfer any application data in message_3.

Cryptographically, EDHOC does not put requirements on the lower layers. EDHOC is not bound to a particular transport layer, and can be used in environments without IP. It is recommended to transport

the EDHOC message in CoAP payloads, see Section 7. An implementation may support only Party U or only Party V.

3.1. Cipher Suites

EDHOC cipher suites consist of an ordered set of COSE algorithms: an AEAD algorithm, an HMAC algorithm, an ECDH curve, a signature algorithm, and signature algorithm parameters. The signature algorithm is not used when EDHOC is authenticated with symmetric keys. Each cipher suite is either identified with a pre-defined int label or with an array of labels and values from the COSE Algorithms and Elliptic Curves registries.

```
suite = int / [ 4*4 algs: int / tstr, ? para: any ]
```

This document specifies two pre-defined cipher suites.

0. [10, 5, 4, -8, 6]
   (AES-CCM-16-64-128, HMAC 256/256, X25519, EdDSA, Ed25519)

1. [10, 5, 1, -7, 1]
   (AES-CCM-16-64-128, HMAC 256/256, P-256, ES256, P-256)

3.2. Ephemeral Public Keys

The ECDH ephemeral public keys are formatted as a COSE_Key of type EC2 or OKP according to Sections 13.1 and 13.2 of [RFC8152], but only the x-coordinate is included in the EDHOC messages. For Elliptic Curve Keys of type EC2, compact representation as per [RFC6090] MAY be used also in the COSE_Key. If the COSE implementation requires an y-coordinate, any of the possible values of the y-coordinate can be used, see Appendix C of [RFC6090]. COSE [RFC8152] always use compact output for Elliptic Curve Keys of type EC2.

3.3. Key Derivation

Key and IV derivation SHALL be performed with HKDF [RFC5869] following the specification in Section 11 of [RFC8152] using the HMAC algorithm in the selected cipher suite. The pseudorandom key (PRK) is derived using HKDF-Extract [RFC5869]

```
PRK = HKDF-Extract( salt, IKM )
```

with the following input:

- The salt SHALL be the PSK when EDHOC is authenticated with symmetric keys, and the empty byte string when EDHOC is authenticated with asymmetric keys. The PSK is used as 'salt' to

simplify implementation. Note that [RFC5869] specifies that if the salt is not provided, it is set to a string of zeros (see Section 2.2 of [RFC5869]). For implementation purposes, not providing the salt is the same as setting the salt to the empty byte string.

- The input keying material (IKM) SHALL be the ECDH shared secret G_XY as defined in Section 12.4.1 of [RFC8152]. When using the curve25519, the ECDH shared secret is the output of the X25519 function [RFC7748].

Example: Assuming use of HMAC 256/256 the extract phase of HKDF produces a PRK as follows:

```
PRK = HMAC-SHA-256( salt, G_XY )
```

where salt = 0x (the empty byte string) in the asymmetric case and salt = PSK in the symmetric case.

The keys and IVs used in EDHOC are derived from PRK using HKDF-Expand [RFC5869]

```
OKM = HKDF-Expand( PRK, info, L )
```

where L is the length of output keying material (OKM) in bytes and info is the CBOR encoding of a COSE_KDF_Context

```
info = [
  AlgorithmID,
  [ null, null, null ],
  [ null, null, null ],
  [ keyDataLength, h'', other ]
]
```

where

- AlgorithmID is an int or tstr, see below
- keyDataLength is a uint set to the length of output keying material in bits, see below
- other is a bstr set to one of the transcript hashes TH_2, TH_3, or TH_4 as defined in Sections 4.3.1, 4.4.1, and 3.3.1.

For message_2 and message_3, the keys K_2 and K_3 SHALL be derived using transcript hashes TH_2 and TH_3 respectively. The key SHALL be derived using AlgorithmID set to the integer value of the AEAD in the

selected cipher suite, and keyDataLength equal to the key length of the AEAD.

If the AEAD algorithm uses an IV, then IV_2 and IV_3 for message_2 and message_3 SHALL be derived using the transcript hashes TH_2 and TH_3 respectively. The IV SHALL be derived using AlgorithmID = "IV-GENERATION" as specified in Section 12.1.2. of [RFC8152], and keyDataLength equal to the IV length of the AEAD.

Assuming the output OKM length L is smaller than the hash function output size, the expand phase of HKDF consists of a single HMAC invocation

```
OKM = first L bytes of HMAC( PRK, info || 0x01 )
```

where || means byte string concatenation.

Example: Assuming use of the algorithm AES-CCM-16-64-128 and HMAC 256/256, K_i and IV_i are therefore the first 16 and 13 bytes, respectively, of

```
HMAC-SHA-256( PRK, info || 0x01 )
```

calculated with (AlgorithmID, keyDataLength) = (10, 128) and (AlgorithmID, keyDataLength) = ("IV-GENERATION", 104), respectively.

3.3.1. EDHOC-Exporter Interface

Application keys and other application specific data can be derived using the EDHOC-Exporter interface defined as:

```
EDHOC-Exporter( label, length ) = HKDF-Expand( PRK, info, length )
```

The output of the EDHOC-Exporter function SHALL be derived using AlgorithmID = label, keyDataLength = 8 * length, and other = TH_4 where label is a tstr defined by the application and length is a uint defined by the application. The label SHALL be different for each different exporter value. The transcript hash TH_4 is a CBOR encoded bstr and the input to the hash function is a CBOR Sequence.

```
TH_4 = H( TH_3, CIPHERTEXT_3 )
```

where H() is the hash function in the HMAC algorithm. Example use of the EDHOC-Exporter is given in Sections 3.3.2 and 7.1.1.

3.3.2. EDHOC PSK Chaining

An application using EDHOC may want to derive new PSKs to use for authentication in future EDHOC exchanges. In this case, the new PSK and the ID_PSK 'kid_value' parameter SHOULD be derived as follows where length is the key length (in bytes) of the AEAD Algorithm.

```
PSK    = EDHOC-Exporter( "EDHOC Chaining PSK", length )
ID_PSK = EDHOC-Exporter( "EDHOC Chaining ID_PSK", 4 )
```

4. EDHOC Authenticated with Asymmetric Keys

4.1. Overview

EDHOC supports authentication with raw public keys (RPK) and public key certificates with the requirements that:

- Only Party V SHALL have access to the private authentication key of Party V,
- Only Party U SHALL have access to the private authentication key of Party U,
- Party U is able to retrieve Party V's public authentication key using ID_CRED_V,
- Party V is able to retrieve Party U's public authentication key using ID_CRED_U,

where the identifiers ID_CRED_U and ID_CRED_V are COSE header_maps, i.e. a CBOR map containing COSE Common Header Parameters, see [RFC8152]). ID_CRED_U and ID_CRED_V need to contain parameters that can identify a public authentication key, see Appendix A.2. In the following we give some examples of possible COSE header parameters.

Raw public keys are most optimally stored as COSE_Key objects and identified with a 'kid' parameter (see [RFC8152]):

- ID_CRED_x = { 4 : kid_value }, where kid_value : bstr, for x = U or V.

Public key certificates can be identified in different ways. Several header parameters for identifying X.509 certificates are defined in [I-D.ietf-cose-x509] (the exact labels are TBD):

- by a hash value with the 'x5t' parameter;
  - ID_CRED_x = { TBD1 : COSE_CertHash }, for x = U or V,

- by a URL with the 'x5u' parameter;
  - ID_CRED_x = { TBD2 : uri }, for x = U or V,
- or by a bag of certificates with the 'x5bag' parameter;
  - ID_CRED_x = { TBD3 : COSE_X509 }, for x = U or V.
- by a certificate chain with the 'x5chain' parameter;
  - ID_CRED_x = { TBD4 : COSE_X509 }, for x = U or V,

In the latter two examples, ID_CRED_U and ID_CRED_V contain the actual credential used for authentication. The purpose of ID_CRED_U and ID_CRED_V is to facilitate retrieval of a public authentication key and when they do not contain the actual credential, they may be very short. It is RECOMMENDED that they uniquely identify the public authentication key as the recipient may otherwise have to try several keys. ID_CRED_U and ID_CRED_V are transported in the ciphertext, see Section 4.3.2 and Section 4.4.2.

The actual credentials CRED_U and CRED_V (e.g. a COSE_Key or a single X.509 certificate) are signed by party U and V, respectively to prevent duplicate-signature key selection (DSKS) attacks, see Section 4.4.1 and Section 4.3.1. Party U and Party V MAY use different types of credentials, e.g. one uses RPK and the other uses certificate. When included in the signature payload, COSE_Keys of type OKP SHALL only include the parameters 1 (kty), -1 (crv), and -2 (x-coordinate). COSE_Keys of type EC2 SHALL only include the parameters 1 (kty), -1 (crv), -2 (x-coordinate), and -3 (y-coordinate). The parameters SHALL be encoded in decreasing order.

The connection identifiers C_U and C_V do not have any cryptographic purpose in EDHOC. They contain information facilitating retrieval of the protocol state and may therefore be very short. The connection identifier MAY be used with an application protocol (e.g. OSCORE) for which EDHOC establishes keys, in which case the connection identifiers SHALL adhere to the requirements for that protocol. Each party choses a connection identifier it desires the other party to use in outgoing messages.

The first data item of message_1 is an int TYPE = 4 * method + corr specifying the method and the correlation properties of the transport used. corr = 0 is used when there is no external correlation mechanism. corr = 1 is used when there is an external correlation mechanism (e.g. the Token in CoAP) that enables Party U to correlate message_1 and message_2. corr = 2 is used when there is an external correlation mechanism that enables Party V to correlate message_2 and

message_3. corr = 3 is used when there is an external correlation mechanism that enables the parties to correlate all the messages. The use of the correlation parameter is exemplified in Section 7.1.

1 byte connection and credential identifiers are realistic in many scenarios as most constrained devices only have a few keys and connections. In cases where a node only has one connection or key, the identifiers may even be the empty byte string.

EDHOC with asymmetric key authentication is illustrated in Figure 4.

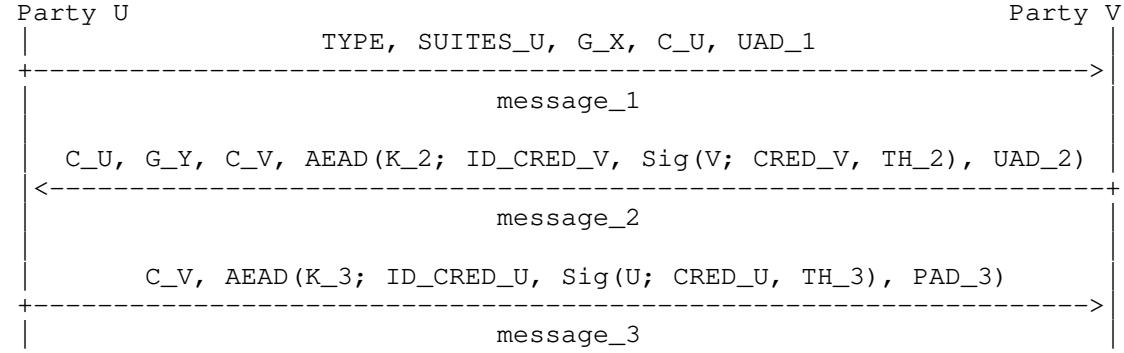

Figure 4: Overview of EDHOC with asymmetric key authentication.

4.2. EDHOC Message 1

4.2.1. Formatting of Message 1

message_1 SHALL be a CBOR Sequence (see Appendix A.1) as defined below

```
message_1 = (
  TYPE : int,
  SUITES_U : suite / [ index : uint, 2* suite ],
  G_X : bstr,
  C_U : bstr,
  ? UAD_1 : bstr,
)
```

where:

- TYPE = 4 * method + corr, where the method = 0 and the correlation parameter corr is chosen based on the transport and determines which connection identifiers that are omitted (see Section 4.1).

- SUITES_U - cipher suites which Party U supports in order of decreasing preference. One cipher suite is selected. If a single cipher suite is conveyed then that cipher suite is selected. If multiple cipher suites are conveyed then zero-based index (i.e. 0 for the first suite, 1 for the second suite, etc.) identifies the selected cipher suite out of the array elements listing the cipher suites (see Section 6).

- G_X - the x-coordinate of the ephemeral public key of Party U

- C_U - variable length connection identifier

- UAD_1 - bstr containing unprotected opaque application data

4.2.2. Party U Processing of Message 1

Party U SHALL compose message_1 as follows:

- The supported cipher suites and the order of preference MUST NOT be changed based on previous error messages. However, the list SUITES_U sent to Party V MAY be truncated such that cipher suites which are the least preferred are omitted. The amount of truncation MAY be changed between sessions, e.g. based on previous error messages (see next bullet), but all cipher suites which are more preferred than the least preferred cipher suite in the list MUST be included in the list.

- Determine the cipher suite to use with Party V in message_1. If Party U previously received from Party V an error message to message_1 with diagnostic payload identifying a cipher suite that U supports, then U SHALL use that cipher suite. Otherwise the first cipher suite in SUITES_U MUST be used.

- Generate an ephemeral ECDH key pair as specified in Section 5 of [SP-800-56A] using the curve in the selected cipher suite. Let G_X be the x-coordinate of the ephemeral public key.

- Choose a connection identifier C_U and store it for the length of the protocol.

- Encode message_1 as a sequence of CBOR encoded data items as specified in Section 4.2.1

4.2.3. Party V Processing of Message 1

Party V SHALL process message_1 as follows:

- Decode message_1 (see Appendix A.1).

- Verify that the selected cipher suite is supported and that no prior cipher suites in SUITES_U are supported.

- Validate that there is a solution to the curve definition for the given x-coordinate G_X.

- Pass UAD_1 to the application.

If any verification step fails, Party V MUST send an EDHOC error message back, formatted as defined in Section 6, and the protocol MUST be discontinued. If V does not support the selected cipher suite, then SUITES_V MUST include one or more supported cipher suites. If V does not support the selected cipher suite, but supports another cipher suite in SUITES_U, then SUITES_V MUST include the first supported cipher suite in SUITES_U.

4.3. EDHOC Message 2

4.3.1. Formatting of Message 2

message_2 and data_2 SHALL be CBOR Sequences (see Appendix A.1) as defined below

```
message_2 = (
  data_2,
  CIPHERTEXT_2 : bstr,
)

data_2 = (
  ? C_U : bstr,
  G_Y : bstr,
  C_V : bstr,
)
```

where:

- G_Y - the x-coordinate of the ephemeral public key of Party V

- C_V - variable length connection identifier

4.3.2. Party V Processing of Message 2

Party V SHALL compose message_2 as follows:

- If TYPE mod 4 equals 1 or 3, C_U is omitted, otherwise C_U is not omitted.

- Generate an ephemeral ECDH key pair as specified in Section 5 of [SP-800-56A] using the curve in the selected cipher suite. Let G_Y be the x-coordinate of the ephemeral public key.

- Choose a connection identifier C_V and store it for the length of the protocol.

- Compute the transcript hash TH_2 = H(message_1, data_2) where H() is the hash function in the HMAC algorithm. The transcript hash TH_2 is a CBOR encoded bstr and the input to the hash function is a CBOR Sequence.

- Compute COSE_Sign1 as defined in Section 4.4 of [RFC8152], using the signature algorithm in the selected cipher suite, the private authentication key of Party V, and the parameters below. Note that only 'signature' of the COSE_Sign1 object is used to create message_2, see next bullet. The unprotected header (not included in the EDHOC message) MAY contain parameters (e.g. 'alg').

  * protected = bstr .cbor ID_CRED_V

  * payload = CRED_V

  * external_aad = TH_2

  * ID_CRED_V - identifier to facilitate retrieval of CRED_V, see Section 4.1

  * CRED_V - bstr credential containing the credential of Party V, e.g. its public authentication key or X.509 certificate see Section 4.1. The public key must be a signature key. Note that if objects that are not bstr are used, such as COSE_Key for public authentication keys, these objects must be wrapped in a CBOR bstr.

  COSE constructs the input to the Signature Algorithm as follows:

  * The key is the private authentication key of V.

  * The message M to be signed is the CBOR encoding of:

    ["Signature1", << ID_CRED_V >>, TH_2, CRED_V]

- Compute COSE_Encrypt0 as defined in Section 5.3 of [RFC8152], with the AEAD algorithm in the selected cipher suite, K_2, IV_2, and the parameters below. Note that only 'ciphertext' of the COSE_Encrypt0 object is used to create message_2, see next bullet. The protected header SHALL be empty. The unprotected header (not

included in the EDHOC message) MAY contain parameters (e.g. 'alg').

* plaintext = (ID_CRED_V / kid_value, signature, ? UAD_2)

* external_aad = TH_2

* UAD_2 = bstr containing opaque unprotected application data

where signature is taken from the COSE_Sign1 object, ID_CRED_V is a COSE header_map (i.e. a CBOR map containing COSE Common Header Parameters, see [RFC8152]), and kid_value is a bstr. If ID_CRED_V contains a single 'kid' parameter, i.e., ID_CRED_V = { 4 : kid_value }, only kid_value is conveyed in the plaintext.

COSE constructs the input to the AEAD [RFC5116] as follows:

* Key K = K_2

* Nonce N = IV_2

* Plaintext P = (ID_CRED_V / kid_value, signature, ? UAD_2)

* Associated data A = ["Encrypt0", h'', TH_2]

- Encode message_2 as a sequence of CBOR encoded data items as specified in Section 4.3.1. CIPHERTEXT_2 is the COSE_Encrypt0 ciphertext.

4.3.3. Party U Processing of Message 2

Party U SHALL process message_2 as follows:

- Decode message_2 (see Appendix A.1).

- Retrieve the protocol state using the connection identifier C_U and/or other external information such as the CoAP Token and the 5-tuple.

- Validate that there is a solution to the curve definition for the given x-coordinate G_Y.

- Decrypt and verify COSE_Encrypt0 as defined in Section 5.3 of [RFC8152], with the AEAD algorithm in the selected cipher suite, K_2, and IV_2.

- Verify COSE_Sign1 as defined in Section 4.4 of [RFC8152], using the signature algorithm in the selected cipher suite and the public authentication key of Party V.

If any verification step fails, Party U MUST send an EDHOC error message back, formatted as defined in Section 6, and the protocol MUST be discontinued.

4.4. EDHOC Message 3

4.4.1. Formatting of Message 3

message_3 and data_3 SHALL be CBOR Sequences (see Appendix A.1) as defined below

```
message_3 = (
  data_3,
  CIPHERTEXT_3 : bstr,
)

data_3 = (
  ? C_V : bstr,
)
```

4.4.2. Party U Processing of Message 3

Party U SHALL compose message_3 as follows:

- If TYPE mod 4 equals 2 or 3, C_V is omitted, otherwise C_V is not omitted.

- Compute the transcript hash TH_3 = H(TH_2 , CIPHERTEXT_2, data_3) where H() is the hash function in the HMAC algorithm. The transcript hash TH_3 is a CBOR encoded bstr and the input to the hash function is a CBOR Sequence.

- Compute COSE_Sign1 as defined in Section 4.4 of [RFC8152], using the signature algorithm in the selected cipher suite, the private authentication key of Party U, and the parameters below. Note that only 'signature' of the COSE_Sign1 object is used to create message_3, see next bullet. The unprotected header (not included in the EDHOC message) MAY contain parameters (e.g. 'alg').

  * protected = bstr .cbor ID_CRED_U

  * payload = CRED_U

  * external_aad = TH_3

* ID_CRED_U - identifier to facilitate retrieval of CRED_U, see Section 4.1

* CRED_U - bstr credential containing the credential of Party U, e.g. its public authentication key or X.509 certificate see Section 4.1. The public key must be a signature key. Note that if objects that are not bstr are used, such as COSE_Key for public authentication keys, these objects must be wrapped in a CBOR bstr.

COSE constructs the input to the Signature Algorithm as follows:

* The key is the private authentication key of U.

* The message M to be signed is the CBOR encoding of:

  ["Signature1", << ID_CRED_U >>, TH_3, CRED_U]

o Compute COSE_Encrypt0 as defined in Section 5.3 of [RFC8152], with the AEAD algorithm in the selected cipher suite, K_3, and IV_3 and the parameters below. Note that only 'ciphertext' of the COSE_Encrypt0 object is used to create message_3, see next bullet. The protected header SHALL be empty. The unprotected header (not included in the EDHOC message) MAY contain parameters (e.g. 'alg').

  * plaintext = (ID_CRED_U / kid_value, signature, ? PAD_3)

  * external_aad = TH_3

  * PAD_3 = bstr containing opaque protected application data

  where signature is taken from the COSE_Sign1 object, ID_CRED_U is a COSE header_map (i.e. a CBOR map containing COSE Common Header Parameters, see [RFC8152]), and kid_value is a bstr. If ID_CRED_U contains a single 'kid' parameter, i.e., ID_CRED_U = { 4 : kid_value }, only kid_value is conveyed in the plaintext.

  COSE constructs the input to the AEAD [RFC5116] as follows:

  * Key K = K_3

  * Nonce N = IV_2

  * Plaintext P = (ID_CRED_U / kid_value, signature, ? PAD_3)

  * Associated data A = ["Encrypt0", h'', TH_3]

- Encode message_3 as a sequence of CBOR encoded data items as specified in Section 4.4.1. CIPHERTEXT_3 is the COSE_Encrypt0 ciphertext.

- Pass the connection identifiers (C_U, C_V) and the selected cipher suite to the application. The application can now derive application keys using the EDHOC-Exporter interface.

4.4.3. Party V Processing of Message 3

Party V SHALL process message_3 as follows:

- Decode message_3 (see Appendix A.1).

- Retrieve the protocol state using the connection identifier C_V and/or other external information such as the CoAP Token and the 5-tuple.

- Decrypt and verify COSE_Encrypt0 as defined in Section 5.3 of [RFC8152], with the AEAD algorithm in the selected cipher suite, K_3, and IV_3.

- Verify COSE_Sign1 as defined in Section 4.4 of [RFC8152], using the signature algorithm in the selected cipher suite and the public authentication key of Party U.

If any verification step fails, Party V MUST send an EDHOC error message back, formatted as defined in Section 6, and the protocol MUST be discontinued.

- Pass PAD_3, the connection identifiers (C_U, C_V), and the selected cipher suite to the application. The application can now derive application keys using the EDHOC-Exporter interface.

5. EDHOC Authenticated with Symmetric Keys

5.1. Overview

EDHOC supports authentication with pre-shared keys. Party U and V are assumed to have a pre-shared key (PSK) with a good amount of randomness and the requirement that:

- Only Party U and Party V SHALL have access to the PSK,

- Party V is able to retrieve the PSK using ID_PSK.

where the identifier ID_PSK is a COSE header_map (i.e. a CBOR map containing COSE Common Header Parameters, see [RFC8152]) containing

COSE header parameter that can identify a pre-shared key. Pre-shared keys are typically stored as COSE_Key objects and identified with a 'kid' parameter (see [RFC8152]):

o ID_PSK = { 4 : kid_value } , where kid_value : bstr

The purpose of ID_PSK is to facilitate retrieval of the PSK and in the case a 'kid' parameter is used it may be very short. It is RECOMMENDED that it uniquely identify the PSK as the recipient may otherwise have to try several keys.

EDHOC with symmetric key authentication is illustrated in Figure 5.

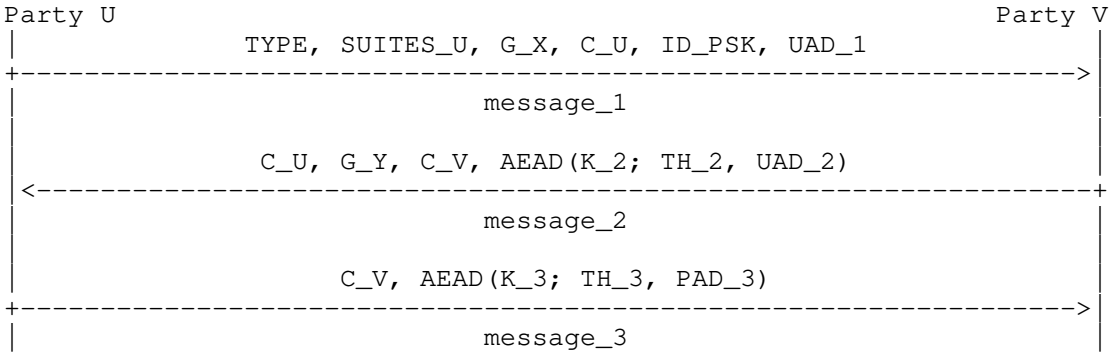

Figure 5: Overview of EDHOC with symmetric key authentication.

EDHOC with symmetric key authentication is very similar to EDHOC with asymmetric key authentication. In the following subsections the differences compared to EDHOC with asymmetric key authentication are described.

5.2. EDHOC Message 1

5.2.1. Formatting of Message 1

message_1 SHALL be a CBOR Sequence (see Appendix A.1) as defined below

```
message_1 = (
  TYPE : int,
  SUITES_U : suite / [ index : uint, 2* suite ],
  G_X : bstr,
  C_U : bstr,
  ID_PSK : header_map // kid_value : bstr,
  ? UAD_1 : bstr,
)
```

where:

- TYPE = 4 * method + corr, where the method = 1 and the connection parameter corr is chosen based on the transport and determines which connection identifiers that are omitted (see Section 4.1).

- ID_PSK - identifier to facilitate retrieval of the pre-shared key. If ID_PSK contains a single 'kid' parameter, i.e., ID_PSK = { 4 : kid_value }, with kid_value: bstr, only kid_value is conveyed.

5.3. EDHOC Message 2

5.3.1. Processing of Message 2

- COSE_Sign1 is not used.

- COSE_Encrypt0 is computed as defined in Section 5.3 of [RFC8152], with the AEAD algorithm in the selected cipher suite, K_2, IV_2, and the following parameters. The protected header SHALL be empty. The unprotected header MAY contain parameters (e.g. 'alg').

  * external_aad = TH_2

  * plaintext = ? UAD_2

  * UAD_2 = bstr containing opaque unprotected application data

5.4. EDHOC Message 3

5.4.1. Processing of Message 3

- COSE_Sign1 is not used.

- COSE_Encrypt0 is computed as defined in Section 5.3 of [RFC8152], with the AEAD algorithm in the selected cipher suite, K_3, IV_3, and the following parameters. The protected header SHALL be empty. The unprotected header MAY contain parameters (e.g. 'alg').

  * external_aad = TH_3

  * plaintext = ? PAD_3

  * PAD_3 = bstr containing opaque protected application data

6. Error Handling

6.1. EDHOC Error Message

This section defines a message format for the EDHOC error message, used during the protocol. An EDHOC error message can be sent by both parties as a reply to any non-error EDHOC message. After sending an error message, the protocol MUST be discontinued. Errors at the EDHOC layer are sent as normal successful messages in the lower layers (e.g. CoAP POST and 2.04 Changed). An advantage of using such a construction is to avoid issues created by usage of cross protocol proxies (e.g. UDP to TCP).

error SHALL be a CBOR Sequence (see Appendix A.1) as defined below

```
error = (
  ? C_x : bstr,
  ERR_MSG : tstr,
  ? SUITES_V : suite / [ 2* suite ],
)
```

where:

- C_x - if error is sent by Party V and TYPE mod 4 equals 0 or 2 then C_x is set to C_U, else if error is sent by Party U and TYPE mod 4 equals 0 or 1 then C_x is set to C_V, else C_x is omitted.

- ERR_MSG - text string containing the diagnostic payload, defined in the same way as in Section 5.5.2 of [RFC7252]. ERR_MSG MAY be a 0-length text string.

- SUITES_V - cipher suites from SUITES_U or the EDHOC cipher suites registry that V supports. Note that SUITES_V only contains the values from the EDHOC cipher suites registry and no index. SUITES_V MUST only be included in replies to message_1.

6.1.1. Example Use of EDHOC Error Message with SUITES_V

Assuming that Party U supports the five cipher suites {5, 6, 7, 8, 9} in decreasing order of preference, Figures 6 and 7 show examples of how Party U can truncate SUITES_U and how SUITES_V is used by Party V to give Party U information about the cipher suites that Party V supports. In Figure 6, Party V supports cipher suite 6 but not the selected cipher suite 5.

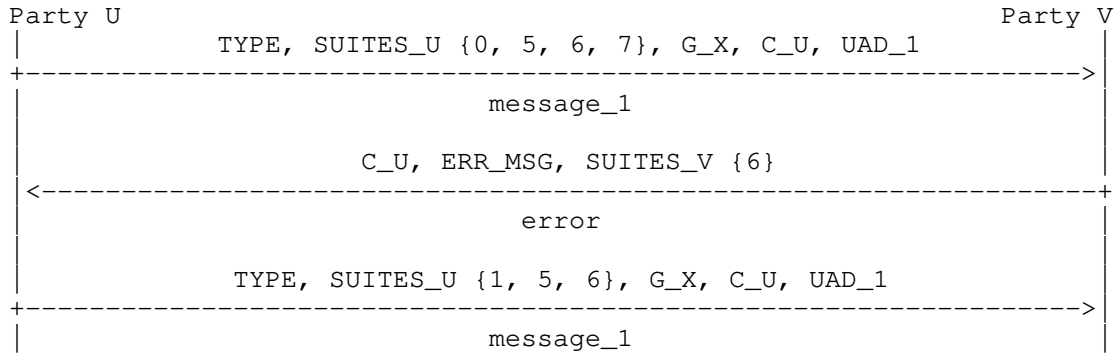

Figure 6: Example use of error message with SUITES_V.

In Figure 7, Party V supports cipher suite 7 but not cipher suites 5 and 6.

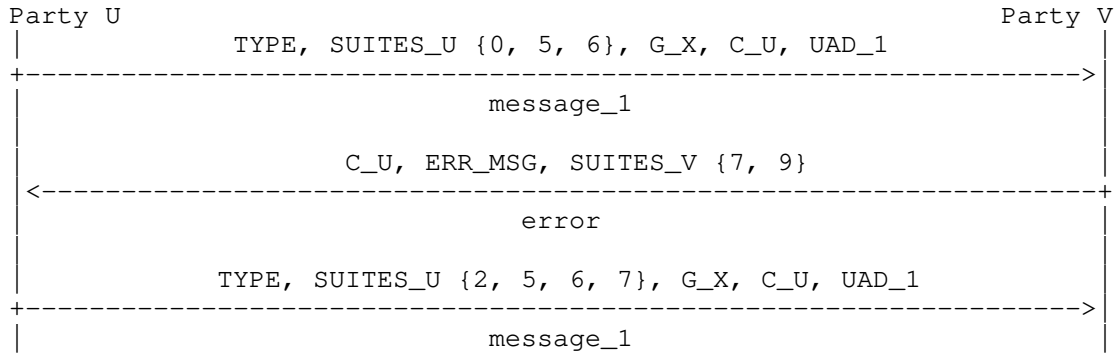

Figure 7: Example use of error message with SUITES_V.

As Party U's list of supported cipher suites and order of preference is fixed, and Party V only accepts message_1 if the selected cipher suite is the first cipher suite in SUITES_U that Party V supports, the parties can verify that the selected cipher suite is the most preferred (by Party U) cipher suite supported by both parties. If the selected cipher suite is not the first cipher suite in SUITES_U that Party V supports, Party V will discontinue the protocol.

7. Transferring EDHOC and Deriving Application Keys

7.1. Transferring EDHOC in CoAP

It is recommended to transport EDHOC as an exchange of CoAP [RFC7252] messages. CoAP is a reliable transport that can preserve packet ordering and handle message duplication. CoAP can also perform

fragmentation and protect against denial of service attacks. It is recommended to carry the EDHOC flights in Confirmable messages, especially if fragmentation is used.

By default, the CoAP client is Party U and the CoAP server is Party V, but the roles SHOULD be chosen to protect the most sensitive identity, see Section 8. By default, EDHOC is transferred in POST requests and 2.04 (Changed) responses to the Uri-Path: "/.well-known/edhoc", but an application may define its own path that can be discovered e.g. using resource directory [I-D.ietf-core-resource-directory].

By default, the message flow is as follows: EDHOC message_1 is sent in the payload of a POST request from the client to the server's resource for EDHOC. EDHOC message_2 or the EDHOC error message is sent from the server to the client in the payload of a 2.04 (Changed) response. EDHOC message_3 or the EDHOC error message is sent from the client to the server's resource in the payload of a POST request. If needed, an EDHOC error message is sent from the server to the client in the payload of a 2.04 (Changed) response.

An example of a successful EDHOC exchange using CoAP is shown in Figure 8. In this case the CoAP Token enables Party U to correlate message_1 and message_2 so the correlation parameter corr = 1.

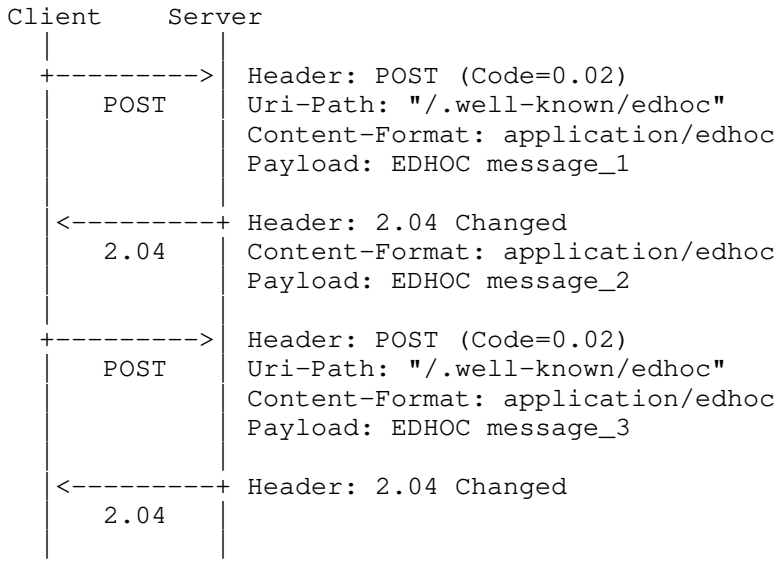

Figure 8: Transferring EDHOC in CoAP

The exchange in Figure 8 protects the client identity against active attackers and the server identity against passive attackers. An alternative exchange that protects the server identity against active attackers and the client identity against passive attackers is shown in Figure 9. In this case the CoAP Token enables Party V to correlate message_2 and message_3 so the correlation parameter corr = 2.

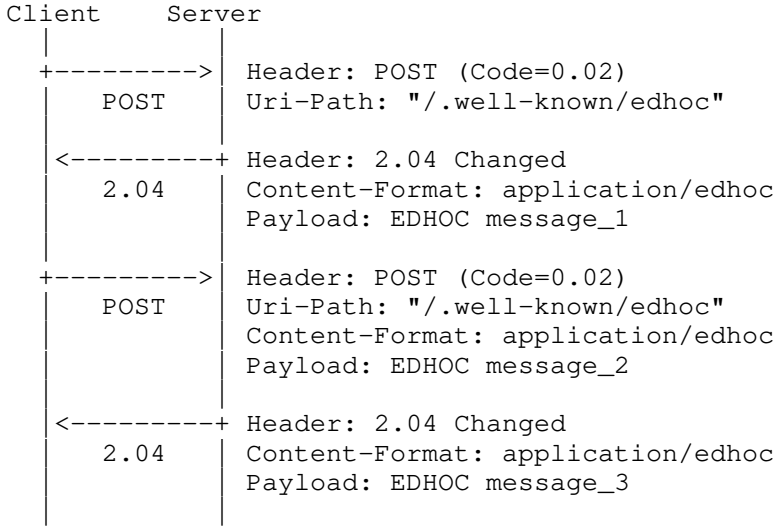

Figure 9: Transferring EDHOC in CoAP

To protect against denial-of-service attacks, the CoAP server MAY respond to the first POST request with a 4.01 (Unauthorized) containing an Echo option [I-D.ietf-core-echo-request-tag]. This forces the initiator to demonstrate its reachability at its apparent network address. If message fragmentation is needed, the EDHOC messages may be fragmented using the CoAP Block-Wise Transfer mechanism [RFC7959].

7.1.1. Deriving an OSCORE Context from EDHOC

When EDHOC is used to derive parameters for OSCORE [RFC8613], the parties must make sure that the EDHOC connection identifiers are unique, i.e. C_V MUST NOT be equal to C_U. The CoAP client and server MUST be able to retrieve the OSCORE protocol state using its chosen connection identifier and optionally other information such as the 5-tuple. In case that the CoAP client is party U and the CoAP server is party V:

- The client's OSCORE Sender ID is C_V and the server's OSCORE Sender ID is C_U, as defined in this document

- The AEAD Algorithm and the HMAC algorithms are the AEAD and HMAC algorithms in the selected cipher suite.

- The Master Secret and Master Salt are derived as follows where length is the key length (in bytes) of the AEAD Algorithm.

  ```
  Master Secret = EDHOC-Exporter( "OSCORE Master Secret", length )
  Master Salt   = EDHOC-Exporter( "OSCORE Master Salt", 8 )
  ```

7.2. Transferring EDHOC over Other Protocols

EDHOC may be transported over a different transport than CoAP. In this case the lower layers need to handle message loss, reordering, message duplication, fragmentation, and denial of service protection.

8. Security Considerations

8.1. Security Properties

EDHOC inherits its security properties from the theoretical SIGMA-I protocol [SIGMA]. Using the terminology from [SIGMA], EDHOC provides perfect forward secrecy, mutual authentication with aliveness, consistency, peer awareness, and identity protection. As described in [SIGMA], peer awareness is provided to Party V, but not to Party U. EDHOC also inherits Key Compromise Impersonation (KCI) resistance from SIGMA-I.

EDHOC with asymmetric authentication offers identity protection of Party U against active attacks and identity protection of Party V against passive attacks. The roles should be assigned to protect the most sensitive identity, typically that which is not possible to infer from routing information in the lower layers.

Compared to [SIGMA], EDHOC adds an explicit method type and expands the message authentication coverage to additional elements such as algorithms, application data, and previous messages. This protects against an attacker replaying messages or injecting messages from another session.

EDHOC also adds negotiation of connection identifiers and downgrade protected negotiation of cryptographic parameters, i.e. an attacker cannot affect the negotiated parameters. A single session of EDHOC does not include negotiation of cipher suites, but it enables Party V to verify that the selected cipher suite is the most preferred cipher suite by U which is supported by both U and V.

As required by [RFC7258], IETF protocols need to mitigate pervasive monitoring when possible. One way to mitigate pervasive monitoring is to use a key exchange that provides perfect forward secrecy. EDHOC therefore only supports methods with perfect forward secrecy. To limit the effect of breaches, it is important to limit the use of symmetrical group keys for bootstrapping. EDHOC therefore strives to make the additional cost of using raw public keys and self-signed certificates as small as possible. Raw public keys and self-signed certificates are not a replacement for a public key infrastructure, but SHOULD be used instead of symmetrical group keys for bootstrapping.

Compromise of the long-term keys (PSK or private authentication keys) does not compromise the security of completed EDHOC exchanges. Compromising the private authentication keys of one party lets the attacker impersonate that compromised party in EDHOC exchanges with other parties, but does not let the attacker impersonate other parties in EDHOC exchanges with the compromised party. Compromising the PSK lets the attacker impersonate Party U in EDHOC exchanges with Party V and impersonate Party V in EDHOC exchanges with Party U. Compromise of the HDKF input parameters (ECDH shared secret and/or PSK) leads to compromise of all session keys derived from that compromised shared secret. Compromise of one session key does not compromise other session keys.

8.2. Cryptographic Considerations

The security of the SIGMA protocol requires the MAC to be bound to the identity of the signer. Hence the message authenticating functionality of the authenticated encryption in EDHOC is critical: authenticated encryption MUST NOT be replaced by plain encryption only, even if authentication is provided at another level or through a different mechanism. EDHOC implements SIGMA-I using the same Sign-then-MAC approach as TLS 1.3.

To reduce message overhead EDHOC does not use explicit nonces and instead rely on the ephemeral public keys to provide randomness to each session. A good amount of randomness is important for the key generation, to provide liveness, and to protect against interleaving attacks. For this reason, the ephemeral keys MUST NOT be reused, and both parties SHALL generate fresh random ephemeral key pairs.

The choice of key length used in the different algorithms needs to be harmonized, so that a sufficient security level is maintained for certificates, EDHOC, and the protection of application data. Party U and V should enforce a minimum security level.

The data rates in many IoT deployments are very limited. Given that the application keys are protected as well as the long-term authentication keys they can often be used for years or even decades before the cryptographic limits are reached. If the application keys established through EDHOC need to be renewed, the communicating parties can derive application keys with other labels or run EDHOC again.

8.3. Cipher Suites

Cipher suite number 0 (AES-CCM-64-64-128, ECDH-SS + HKDF-256, X25519, Ed25519) is mandatory to implement. For many constrained IoT devices it is problematic to support more than one cipher suites, so some deployments with P-256 may not support the mandatory cipher suite. This is not a problem for local deployments.

The HMAC algorithm HMAC 256/64 (HMAC w/ SHA-256 truncated to 64 bits) SHALL NOT be supported for use in EDHOC.

8.4. Unprotected Data

Party U and V must make sure that unprotected data and metadata do not reveal any sensitive information. This also applies for encrypted data sent to an unauthenticated party. In particular, it applies to UAD_1, ID_CRED_V, UAD_2, and ERR_MSG in the asymmetric case, and ID_PSK, UAD_1, and ERR_MSG in the symmetric case. Using the same ID_PSK or UAD_1 in several EDHOC sessions allows passive eavesdroppers to correlate the different sessions. The communicating parties may therefore anonymize ID_PSK. Another consideration is that the list of supported cipher suites may be used to identify the application.

Party U and V must also make sure that unauthenticated data does not trigger any harmful actions. In particular, this applies to UAD_1 and ERR_MSG in the asymmetric case, and ID_PSK, UAD_1, and ERR_MSG in the symmetric case.

8.5. Denial-of-Service

EDHOC itself does not provide countermeasures against Denial-of-Service attacks. By sending a number of new or replayed message_1 an attacker may cause Party V to allocate state, perform cryptographic operations, and amplify messages. To mitigate such attacks, an implementation SHOULD rely on lower layer mechanisms such as the Echo option in CoAP [I-D.ietf-core-echo-request-tag] that forces the initiator to demonstrate reachability at its apparent network address.

8.6. Implementation Considerations

The availability of a secure pseudorandom number generator and truly random seeds are essential for the security of EDHOC. If no true random number generator is available, a truly random seed must be provided from an external source. As each pseudoranom number must only be used once, an implementation need to get a new truly random seed after reboot, or continously store state in nonvolatile memory, see ([RFC8613], Appendix B.1.1) for issues and solution approaches for writing to nonvolatile memory. If ECDSA is supported, "deterministic ECDSA" as specified in [RFC6979] is RECOMMENDED.

The referenced processing instructions in [SP-800-56A] must be complied with, including deleting the intermediate computed values along with any ephemeral ECDH secrets after the key derivation is completed. The ECDH shared secret, keys (K_2, K_3), and IVs (IV_2, IV_3) MUST be secret. Implementations should provide countermeasures to side-channel attacks such as timing attacks.

Party U and V are responsible for verifying the integrity of certificates. The selection of trusted CAs should be done very carefully and certificate revocation should be supported. The private authentication keys and the PSK (even though it is used as salt) MUST be kept secret.

Party U and V are allowed to select the connection identifiers C_U and C_V, respectively, for the other party to use in the ongoing EDHOC protocol as well as in a subsequent application protocol (e.g. OSCORE [RFC8613]). The choice of connection identifier is not security critical in EDHOC but intended to simplify the retrieval of the right security context in combination with using short identifiers. If the wrong connection identifier of the other party is used in a protocol message it will result in the receiving party not being able to retrieve a security context (which will terminate the protocol) or retrieve the wrong security context (which also terminates the protocol as the message cannot be verified).

Party V MUST finish the verification step of message_3 before passing PAD_3 to the application.

If two nodes unintentionally initiate two simultaneous EDHOC message exchanges with each other even if they only want to complete a single EDHOC message exchange, they MAY terminate the exchange with the lexicographically smallest G_X. If the two G_X values are equal, the received message_1 MUST be discarded to mitigate reflection attacks. Note that in the case of two simultaneous EDHOC exchanges where the nodes only complete one and where the nodes have different preferred

cipher suites, an attacker can affect which of the two nodes' preferred cipher suites will be used by blocking the other exchange.

8.7. Other Documents Referencing EDHOC

EDHOC has been analyzed in several other documents. A formal verification of EDHOC was done in [SSR18], an analysis of EDHOC for certificate enrollment was done in [Kron18], the use of EDHOC in LoRaWAN is analyzed in [LoRa1] and [LoRa2], the use of EDHOC in IoT bootstrapping is analyzed in [Perez18], and the use of EDHOC in 6TiSCH is described in [I-D.ietf-6tisch-dtsecurity-zerotouch-join].

9. IANA Considerations

9.1. EDHOC Cipher Suites Registry

IANA has created a new registry titled "EDHOC Cipher Suites" under the new heading "EDHOC". The registration procedure is "Expert Review". The columns of the registry are Value, Array, Description, and Reference, where Value is an integer and the other columns are text strings. The initial contents of the registry are:

Value: 1
Array: [10, 5, 1, -7, 1]
Desc: AES-CCM-16-64-128, HMAC 256/256, P-256, ES256, P-256
Reference: [[this document]]

Value: 0
Array: [10, 5, 4, -8, 6]
Desc: AES-CCM-16-64-128, HMAC 256/256, X25519, EdDSA, Ed25519
Reference: [[this document]]

Value: -5
Array:
Desc: Reserved for Private Use
Reference: [[this document]]

Value: -6
Array:
Desc: Reserved for Private Use
Reference: [[this document]]

9.2. EDHOC Method Type Registry

IANA has created a new registry titled "EDHOC Method Type" under the new heading "EDHOC". The registration procedure is "Expert Review". The columns of the registry are Value, Description, and Reference,

where Value is an integer and the other columns are text strings. The initial contents of the registry are:

Value	Specification	Reference
0	EDHOC Authenticated with Asymmetric Keys	[[this document]]
1	EDHOC Authenticated with Symmetric Keys	[[this document]]

9.3. The Well-Known URI Registry

IANA has added the well-known URI 'edhoc' to the Well-Known URIs registry.

- URI suffix: edhoc
- Change controller: IETF
- Specification document(s): [[this document]]
- Related information: None

9.4. Media Types Registry

IANA has added the media type 'application/edhoc' to the Media Types registry.

- Type name: application
- Subtype name: edhoc
- Required parameters: N/A
- Optional parameters: N/A
- Encoding considerations: binary
- Security considerations: See Section 7 of this document.
- Interoperability considerations: N/A
- Published specification: [[this document]] (this document)
- Applications that use this media type: To be identified
- Fragment identifier considerations: N/A

- Additional information:
  - Magic number(s): N/A
  - File extension(s): N/A
  - Macintosh file type code(s): N/A
- Person & email address to contact for further information: See "Authors' Addresses" section.
- Intended usage: COMMON
- Restrictions on usage: N/A
- Author: See "Authors' Addresses" section.
- Change Controller: IESG

9.5. CoAP Content-Formats Registry

IANA has added the media type 'application/edhoc' to the CoAP Content-Formats registry.

- Media Type: application/edhoc
- Encoding:
- ID: TBD42
- Reference: [[this document]]

9.6. Expert Review Instructions

The IANA Registries established in this document is defined as "Expert Review". This section gives some general guidelines for what the experts should be looking for, but they are being designated as experts for a reason so they should be given substantial latitude.

Expert reviewers should take into consideration the following points:

- Clarity and correctness of registrations. Experts are expected to check the clarity of purpose and use of the requested entries. Expert needs to make sure the values of algorithms are taken from the right registry, when that's required. Expert should consider requesting an opinion on the correctness of registered parameters from relevant IETF working groups. Encodings that do not meet

these objective of clarity and completeness should not be registered.

- Experts should take into account the expected usage of fields when approving point assignment. The length of the encoded value should be weighed against how many code points of that length are left, the size of device it will be used on, and the number of code points left that encode to that size.

- Specifications are recommended. When specifications are not provided, the description provided needs to have sufficient information to verify the points above.

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Appendix A. Use of CBOR, CDDL and COSE in EDHOC

This Appendix is intended to simplify for implementors not familiar with CBOR [I-D.ietf-cbor-7049bis], CDDL [RFC8610], COSE [RFC8152], and HKDF [RFC5869].

A.1. CBOR and CDDL

The Concise Binary Object Representation (CBOR) [I-D.ietf-cbor-7049bis] is a data format designed for small code size and small message size. CBOR builds on the JSON data model but extends it by e.g. encoding binary data directly without base64 conversion. In addition to the binary CBOR encoding, CBOR also has a diagnostic notation that is readable and editable by humans. The Concise Data Definition Language (CDDL) [RFC8610] provides a way to express structures for protocol messages and APIs that use CBOR. [RFC8610] also extends the diagnostic notation.

CBOR data items are encoded to or decoded from byte strings using a type-length-value encoding scheme, where the three highest order bits of the initial byte contain information about the major type. CBOR supports several different types of data items, in addition to integers (int, uint), simple values (e.g. null), byte strings (bstr), and text strings (tstr), CBOR also supports arrays [] of data items, maps {} of pairs of data items, and sequences [I-D.ietf-cbor-sequence] of data items. Some examples are given below. For a complete specification and more examples, see [I-D.ietf-cbor-7049bis] and [RFC8610]. We recommend implementors to get used to CBOR by using the CBOR playground [CborMe].

Diagnostic	Encoded	Type
1	0x01	unsigned integer
24	0x1818	unsigned integer
-24	0x37	negative integer
-25	0x3818	negative integer
null	0xf6	simple value
h'12cd'	0x4212cd	byte string
'12cd'	0x4431326364	byte string
"12cd"	0x6431326364	text string
{ 4 : h'cd' }	0xa10441cd	map
<< 1, 2, null >>	0x430102f6	byte string
[1, 2, null]	0x830102f6	array
(1, 2, null)	0x0102f6	sequence
1, 2, null	0x0102f6	sequence

EDHOC messages are CBOR Sequences [I-D.ietf-cbor-sequence]. The message format specification uses the construct '.cbor' enabling conversion between different CDDL types matching different CBOR items with different encodings. Some examples are given below.

A type (e.g. an uint) may be wrapped in a byte string (bstr):

CDDL Type	Diagnostic	Encoded
uint	24	0x1818
bstr .cbor uint	<< 24 >>	0x421818

A.2. COSE

CBOR Object Signing and Encryption (COSE) [RFC8152] describes how to create and process signatures, message authentication codes, and encryption using CBOR. COSE builds on JOSE, but is adapted to allow more efficient processing in constrained devices. EDHOC makes use of COSE_Key, COSE_Encrypt0, COSE_Sign1, and COSE_KDF_Context objects.

Appendix B. EDHOC Authenticated withDiffie-Hellman Keys

The SIGMA protocol is mainly optimized for PKI and certificates. The OPTLS protocol [OPTLS] shows how authentication can be provided by a MAC computed from an ephemeral-static ECDH shared secret. Instead of signature authentication keys, U and V would have Diffie-Hellman authentication keys G_U and G_V, respectively. This type of authentication keys could easily be used with RPK and would provide significant reductions in message sizes as the 64 bytes signature would be replaced by an 8 bytes MAC.

EDHOC authenticated with asymmetric Diffie-Hellman keys should have similar security properties as EDHOC authenticated with asymmetric signature keys with a few differences:

- Repudiation: In EDHOC authenticated with asymmetric signature keys, Party U could theoretically prove that Party V performed a run of the protocol by presenting the private ephemeral key, and vice versa. Note that storing the private ephemeral keys violates the protocol requirements. With asymmetric Diffie-Hellman key authentication, both parties can always deny having participated in the protocol, this is similar to EDHOC with symmetric key authentication.

- Key compromise impersonation (KCI): In EDHOC authenticated with asymmetric signature keys, EDHOC provides KCI protection against an attacker having access to the long term key or the ephemeral secret key. In EDHOC authenticated with symmetric keys, EDHOC provides KCI protection against an attacker having access to the ephemeral secret key, but not against an attacker having access to the long-term PSK. With asymmetric Diffie-Hellman key authentication, KCI protection would be provided against an attacker having access to the long-term Diffie-Hellman key, but not to an attacker having access to the ephemeral secret key. Note that the term KCI has typically been used for compromise of long-term keys, and that an attacker with access to the ephemeral secret key can only attack that specific protocol run.

TODO: Initial suggestion for key derivation, message formats, and processing

Appendix C. Test Vectors

This appendix provides detailed test vectors to ease implementation and ensure interoperability. In addition to hexadecimal, all CBOR data items and sequences are given in CBOR diagnostic notation. The test vectors use 1 byte key identifiers, 1 byte connection IDs, and the default mapping to CoAP where Party U is CoAP client (this means that corr = 1).

C.1. Test Vectors for EDHOC Authenticated with Asymmetric Keys (RPK)

Asymmetric EDHOC is used:

method (Asymmetric Authentication)
0

CoAP is used as transport:

corr (Party U is CoAP client)
1

No unprotected opaque application data is sent in the message exchanges.

The pre-defined Cipher Suite 0 is in place both on Party U and Party V, see Section 3.1.

C.1.1. Input for Party U

The following are the parameters that are set in Party U before the first message exchange.

Party U's private authentication key (32 bytes)
53 21 fc 01 c2 98 20 06 3a 72 50 8f c6 39 25 1d c8 30 e2 f7 68 3e b8 e3 8a f1 64 a5 b9 af 9b e3

Party U's public authentication key (32 bytes)
42 4c 75 6a b7 7c c6 fd ec f0 b3 ec fc ff b7 53 10 c0 15 bf 5c ba 2e c0 a2 36 e6 65 0c 8a b9 c7

kid value to identify U's public authentication key (1 bytes)
a2

This test vector uses COSE_Key objects to store the raw public keys. Moreover, EC2 keys with curve Ed25519 are used. That is in agreement with the Cipher Suite 0.

```
CRED_U =
<< {
  1:  1,
 -1:  6,
 -2:  h'424c756ab77cc6fdecf0b3ecfcffb75310c015bf5cba2ec0a236e6650c8ab9c7'
} >>
```

CRED_U (COSE_Key) (CBOR-encoded) (42 bytes)
58 28 a3 01 01 20 06 21 58 20 42 4c 75 6a b7 7c c6 fd ec f0 b3 ec fc ff b7 53 10 c0 15 bf 5c ba 2e c0 a2 36 e6 65 0c 8a b9 c7

Because COSE_Keys are used, and because kid = h'a2':

```
ID_CRED_U =
{
  4:  h'a2'
}
```

Note that since the map for ID_CRED_U contains a single 'kid' parameter, ID_CRED_U is used when transported in the protected header of the COSE Object, but only the kid_value is used when added to the plaintext (see Section 4.4.2):

ID_CRED_U (in protected header) (CBOR-encoded) (4 bytes)
a1 04 41 a2

kid_value (in plaintext) (CBOR-encoded) (2 bytes)
41 a2

C.1.2. Input for Party V

The following are the parameters that are set in Party V before the first message exchange.

Party V's private authentication key (32 bytes)
74 56 b3 a3 e5 8d 8d 26 dd 36 bc 75 d5 5b 88 63 a8 5d 34 72 f4 a0 1f 02 24 62 1b 1c b8 16 6d a9

Party V's public authentication key (32 bytes)
1b 66 1e e5 d5 ef 16 72 a2 d8 77 cd 5b c2 0f 46 30 dc 78 a1 14 de 65 9c 7e 50 4d 0f 52 9a 6b d3

kid value to identify U's public authentication key (1 bytes)
a3

This test vector uses COSE_Key objects to store the raw public keys. Moreover, EC2 keys with curve Ed25519 are used. That is in agreement with the Cipher Suite 0.

```
CRED_V =
<< {
  1:  1,
 -1:  6,
 -2:  h'1b661ee5d5ef1672a2d877cd5bc20f4630dc78a114de659c7e504d0f529a6bd3'
} >>
```

CRED_V (COSE_Key) (CBOR-encoded) (42 bytes)
58 28 a3 01 01 20 06 21 58 20 1b 66 1e e5 d5 ef 16 72 a2 d8 77 cd 5b c2 0f 46 30 dc 78 a1 14 de 65 9c 7e 50 4d 0f 52 9a 6b d3

Because COSE_Keys are used, and because kid = h'a3':

```
ID_CRED_V =
{
  4:  h'a3'
}
```

Note that since the map for ID_CRED_U contains a single 'kid' parameter, ID_CRED_U is used when transported in the protected header of the COSE Object, but only the kid_value is used when added to the plaintext (see Section 4.4.2):

ID_CRED_V (in protected header) (CBOR-encoded) (4 bytes)
a1 04 41 a3

kid_value (in plaintext) (CBOR-encoded) (2 bytes)
41 a3

C.1.3. Message 1

From the input parameters (in Appendix C.1.1):

TYPE (4 * method + corr)
1

suite
0

SUITES_U : suite
0

G_X (X-coordinate of the ephemeral public key of Party U) (32 bytes)
b1 a3 e8 94 60 e8 8d 3a 8d 54 21 1d c9 5f 0b 90 3f f2 05 eb 71 91 2d 6d b8 f4 af 98 0d 2d b8 3a

C_U (Connection identifier chosen by U) (1 bytes)
c3

No UAD_1 is provided, so UAD_1 is absent from message_1.

Message_1 is constructed, as the CBOR Sequence of the CBOR data items above.

```
message_1 =
(
  1,
  0,
  h'b1a3e89460e88d3a8d54211dc95f0b903ff205eb71912d6db8f4af980d2db83a',
  h'c3'
)
```

message_1 (CBOR Sequence) (38 bytes)
01 00 58 20 b1 a3 e8 94 60 e8 8d 3a 8d 54 21 1d c9 5f 0b 90 3f f2 05 eb 71 91 2d 6d b8 f4 af 98 0d 2d b8 3a 41 c3

C.1.4. Message 2

Since TYPE mod 4 equals 1, C_U is omitted from data_2.

G_Y (X-coordinate of the ephemeral public key of Party V) (32 bytes)
8d b5 77 f9 b9 c2 74 47 98 98 7d b5 57 bf 31 ca 48 ac d2 05 a9 db 8c 32 0e
5d 49 f3 02 a9 64 74

C_V (Connection identifier chosen by V) (1 bytes)
c4

Data_2 is constructed, as the CBOR Sequence of the CBOR data items above.

```
data_2 =
(
  h'8db577f9b9c2744798987db557bf31ca48acd205a9db8c320e5d49f302a96474',
  h'c4'
)
```

data_2 (CBOR Sequence) (36 bytes)
58 20 8d b5 77 f9 b9 c2 74 47 98 98 7d b5 57 bf 31 ca 48 ac d2 05 a9 db 8c
32 0e 5d 49 f3 02 a9 64 74 41 c4

From data_2 and message_1 (from Appendix C.1.3), compute the input to the transcript hash TH_2 = H(message_1, data_2), as a CBOR Sequence of these 2 data items.

(message_1, data_2) (CBOR Sequence)
(74 bytes)
01 00 58 20 b1 a3 e8 94 60 e8 8d 3a 8d 54 21 1d c9 5f 0b 90 3f f2 05 eb 71
91 2d 6d b8 f4 af 98 0d 2d b8 3a 41 c3 58 20 8d b5 77 f9 b9 c2 74 47 98 98
7d b5 57 bf 31 ca 48 ac d2 05 a9 db 8c 32 0e 5d 49 f3 02 a9 64 74 41 c4

And from there, compute the transcript hash TH_2 = SHA-256(message_1, data_2)

TH_2 value (32 bytes)
55 50 b3 dc 59 84 b0 20 9a e7 4e a2 6a 18 91 89 57 50 8e 30 33 2b 11 da 68
1d c2 af dd 87 03 55

When encoded as a CBOR bstr, that gives:

TH_2 (CBOR-encoded) (34 bytes)
58 20 55 50 b3 dc 59 84 b0 20 9a e7 4e a2 6a 18 91 89 57 50 8e 30 33 2b 11
da 68 1d c2 af dd 87 03 55

C.1.4.1. Signature Computation

COSE_Sign1 is computed with the following parameters. From Appendix C.1.2:

- protected = bstr .cbor ID_CRED_V
- payload = CRED_V

And from Appendix C.1.4:

- external_aad = TH_2

The Sig_structure M_V to be signed is: ["Signature1", << ID_CRED_V >>, TH_2, CRED_V] , as defined in Section 4.3.2:

```
M_V =
[
  "Signature1",
  << { 4: h'a3' } >>,
  h'5550b3dc5984b0209ae74ea26a18918957508e30332b11da681dc2afdd870355',
  << {
    1:  1,
   -1:  6,
   -2:  h'1b661ee5d5ef1672a2d877cd5bc20f4630dc78a114de659c7e504d0f529a6b
          d3'
  } >>
]
```

Which encodes to the following byte string ToBeSigned:

```
M_V (message to be signed with Ed25519) (CBOR-encoded) (93 bytes)
84 6a 53 69 67 6e 61 74 75 72 65 31 44 a1 04 41 a3 58 20 55 50 b3 dc 59 84
b0 20 9a e7 4e a2 6a 18 91 89 57 50 8e 30 33 2b 11 da 68 1d c2 af dd 87 03
55 58 28 a3 01 01 20 06 21 58 20 1b 66 1e e5 d5 ef 16 72 a2 d8 77 cd 5b c2
0f 46 30 dc 78 a1 14 de 65 9c 7e 50 4d 0f 52 9a 6b d3
```

The message is signed using the private authentication key of V, and produces the following signature:

```
V's signature (64 bytes)
52 3d 99 6d fd 9e 2f 77 c7 68 71 8a 30 c3 48 77 8c 5e b8 64 dd 53 7e 55 5e
4a 00 05 e2 09 53 07 13 ca 14 62 0d e8 18 7e 81 99 6e e8 04 d1 53 b8 a1 f6
08 49 6f dc d9 3d 30 fc 1c 8b 45 be cc 06
```

C.1.4.2. Key and Nonce Computation

The key and nonce for calculating the ciphertext are calculated as follows, as specified in Section 3.3.

HKDF SHA-256 is the HKDF used (as defined by cipher suite 0).

PRK = HMAC-SHA-256(salt, G_XY)

Since this is the asymmetric case, salt is the empty byte string.

G_XY is the shared secret, and since the curve25519 is used, the ECDH shared secret is the output of the X25519 function.

```
G_XY (32 bytes)
c6 1e 09 09 a1 9d 64 24 01 63 ec 26 2e 9c c4 f8 8c e7 7b e1 23 c5 ab 53 8d
26 b0 69 22 a5 20 67
```

From there, PRK is computed:

```
PRK (32 bytes)
ba 9c 2c a1 c5 62 14 a6 e0 f6 13 ed a8 91 86 8a 4c a3 e3 fa bc c7 79 8f dc
01 60 80 07 59 16 71
```

Key K_2 is the output of HKDF-Expand(PRK, info, L).

info is defined as follows:

```
info for K_2
[
  10,
  [ null, null, null ],
  [ null, null, null ],
  [ 128, h'', h'5550b3dc5984b0209ae74ea26a18918957508e30332b11da681dc2afdd
                870355' ]
]
```

Which as a CBOR encoded data item is:

```
info (K_2) (CBOR-encoded) (48 bytes)
84 0a 83 f6 f6 f6 83 f6 f6 f6 83 18 80 40 58 20 55 50 b3 dc 59 84 b0 20 9a
e7 4e a2 6a 18 91 89 57 50 8e 30 33 2b 11 da 68 1d c2 af dd 87 03 55
```

L is the length of K_2, so 16 bytes.

From these parameters, K_2 is computed:

K_2 (16 bytes)
da d7 44 af 07 c4 da 27 d1 f0 a3 8a 0c 4b 87 38

Nonce IV_2 is the output of HKDF-Expand(PRK, info, L).

info is defined as follows:

```
info for IV_2
[
  "IV-GENERATION",
  [ null, null, null ],
  [ null, null, null ],
  [ 104, h'', h'5550b3dc5984b0209ae74ea26a18918957508e30332b11da681dc2afdd
                870355' ]
]
```

Which as a CBOR encoded data item is:

```
info (IV_2) (CBOR-encoded) (61 bytes)
84 6d 49 56 2d 47 45 4e 45 52 41 54 49 4f 4e 83 f6 f6 f6 83 f6 f6 f6 83 18
68 40 58 20 55 50 b3 dc 59 84 b0 20 9a e7 4e a2 6a 18 91 89 57 50 8e 30 33
2b 11 da 68 1d c2 af dd 87 03 55
```

L is the length of IV_2, so 13 bytes.

From these parameters, IV_2 is computed:

IV_2 (13 bytes)
fb a1 65 d9 08 da a7 8e 4f 84 41 42 d0

C.1.4.3. Ciphertext Computation

COSE_Encrypt0 is computed with the following parameters. Note that UAD_2 is omitted.

- empty protected header
- external_aad = TH_2
- plaintext = CBOR Sequence of the items kid_value, signature, in this order.

with kid_value taken from Appendix C.1.2, and signature as calculated in Appendix C.1.4.1.

The plaintext is the following:

```
P_2 (68 bytes)
41 a3 58 40 52 3d 99 6d fd 9e 2f 77 c7 68 71 8a 30 c3 48 77 8c 5e b8 64 dd
53 7e 55 5e 4a 00 05 e2 09 53 07 13 ca 14 62 0d e8 18 7e 81 99 6e e8 04 d1
53 b8 a1 f6 08 49 6f dc d9 3d 30 fc 1c 8b 45 be cc 06
```

From the parameters above, the Enc_structure A_2 is computed.

```
A_2 =
[
  "Encrypt0",
  h'',
  h'5550b3dc5984b0209ae74ea26a18918957508e30332b11da681dc2afdd870355'
]
```

Which encodes to the following byte string to be used as Additional Authenticated Data:

```
A_2 (CBOR-encoded) (45 bytes)
83 68 45 6e 63 72 79 70 74 30 40 58 20 55 50 b3 dc 59 84 b0 20 9a e7 4e a2
6a 18 91 89 57 50 8e 30 33 2b 11 da 68 1d c2 af dd 87 03 55
```

The key and nonce used are defined in Appendix C.1.4.2:

- key = K_2

- nonce = IV_2

Using the parameters above, the ciphertext CIPHERTEXT_2 can be computed:

```
CIPHERTEXT_2 (76 bytes)
1e 6b fe 0e 77 99 ce f0 66 a3 4f 08 ef aa 90 00 6d b4 4c 90 1c f7 9b 23 85
3a b9 7f d8 db c8 53 39 d5 ed 80 87 78 3c f7 a4 a7 e0 ea 38 c2 21 78 9f a3
71 be 64 e9 3c 43 a7 db 47 d1 e3 fb 14 78 8e 96 7f dd 78 d8 80 78 e4 9b 78
bf
```

C.1.4.4. message_2

From the parameter computed in Appendix C.1.4 and Appendix C.1.4.3, message_2 is computed, as the CBOR Sequence of the following items: (G_Y, C_V, CIPHERTEXT_2).

```
message_2 =
(
  h'8db577f9b9c2744798987db557bf31ca48acd205a9db8c320e5d49f302a96474',
  h'c4',
  h'1e6bfe0e7799cef066a34f08efaa90006db44c901cf79b23853ab97fd8dbc85339d5ed
  8087783cf7a4a7e0ea38c221789fa371be64e93c43a7db47d1e3fb14788e967fdd78d880
  78e49b78bf'
)
```

Which encodes to the following byte string:

```
message_2 (CBOR Sequence) (114 bytes)
58 20 8d b5 77 f9 b9 c2 74 47 98 98 7d b5 57 bf 31 ca 48 ac d2 05 a9 db 8c
32 0e 5d 49 f3 02 a9 64 74 41 c4 58 4c 1e 6b fe 0e 77 99 ce f0 66 a3 4f 08
ef aa 90 00 6d b4 4c 90 1c f7 9b 23 85 3a b9 7f d8 db c8 53 39 d5 ed 80 87
78 3c f7 a4 a7 e0 ea 38 c2 21 78 9f a3 71 be 64 e9 3c 43 a7 db 47 d1 e3 fb
14 78 8e 96 7f dd 78 d8 80 78 e4 9b 78 bf
```

C.1.5. Message 3

Since TYPE mod 4 equals 1, C_V is not omitted from data_3.

```
C_V (1 bytes)
c4
```

Data_3 is constructed, as the CBOR Sequence of the CBOR data item above.

```
data_3 =
(
  h'c4'
)

data_3 (CBOR Sequence) (2 bytes)
41 c4
```

From data_3, CIPHERTEXT_2 (Appendix C.1.4.3), and TH_2 (Appendix C.1.4), compute the input to the transcript hash TH_2 = H(TH_2 , CIPHERTEXT_2, data_3), as a CBOR Sequence of these 3 data items.

```
( TH_2, CIPHERTEXT_2, data_3 )
(CBOR Sequence) (114 bytes)
58 20 55 50 b3 dc 59 84 b0 20 9a e7 4e a2 6a 18 91 89 57 50 8e 30 33 2b 11
da 68 1d c2 af dd 87 03 55 58 4c 1e 6b fe 0e 77 99 ce f0 66 a3 4f 08 ef aa
90 00 6d b4 4c 90 1c f7 9b 23 85 3a b9 7f d8 db c8 53 39 d5 ed 80 87 78 3c
f7 a4 a7 e0 ea 38 c2 21 78 9f a3 71 be 64 e9 3c 43 a7 db 47 d1 e3 fb 14 78
8e 96 7f dd 78 d8 80 78 e4 9b 78 bf 41 c4
```

And from there, compute the transcript hash TH_3 = SHA-256(TH_2 , CIPHERTEXT_2, data_3)

```
TH_3 value (32 bytes)
21 cc b6 78 b7 91 14 96 09 55 88 5b 90 a2 b8 2e 3b 2c a2 7e 8e 37 4a 79 07
f3 e7 85 43 67 fc 22
```

When encoded as a CBOR bstr, that gives:

```
TH_3 (CBOR-encoded) (34 bytes)
58 20 21 cc b6 78 b7 91 14 96 09 55 88 5b 90 a2 b8 2e 3b 2c a2 7e 8e 37 4a
79 07 f3 e7 85 43 67 fc 22
```

C.1.5.1. Signature Computation

COSE_Sign1 is computed with the following parameters. From Appendix C.1.2:

- protected = bstr .cbor ID_CRED_U
- payload = CRED_U

And from Appendix C.1.4:

- external_aad = TH_3

The Sig_structure M_V to be signed is: ["Signature1", << ID_CRED_U >>, TH_3, CRED_U] , as defined in Section 4.4.2:

```
M_U =
[
  "Signature1",
  << { 4: h'a2' } >>,
  h'734bef323d867a12956127c2e62ade42c0f119e5487750c0c31fd093376dceed',
  << {
    1:  1,
   -1:  6,
   -2:  h'424c756ab77cc6fdecf0b3ecfcffb75310c015bf5cba2ec0a236e6650c8ab9
   c7'
  } >>
]
```

Which encodes to the following byte string ToBeSigned:

M_U (message to be signed with Ed25519) (CBOR-encoded) (93 bytes)
84 6a 53 69 67 6e 61 74 75 72 65 31 44 a1 04 41 a2 58 20 73 4b ef 32 3d 86
7a 12 95 61 27 c2 e6 2a de 42 c0 f1 19 e5 48 77 50 c0 c3 1f d0 93 37 6d ce
ed 58 28 a3 01 01 20 06 21 58 20 42 4c 75 6a b7 7c c6 fd ec f0 b3 ec fc ff
b7 53 10 c0 15 bf 5c ba 2e c0 a2 36 e6 65 0c 8a b9 c7

The message is signed using the private authentication key of U, and produces the following signature:

U's signature (64 bytes)
5c 7d 7d 64 c9 61 c5 f5 2d cf 33 91 25 92 a1 af f0 2c 33 62 b0 e7 55 0e 4b
c5 66 b7 0c 20 61 f3 c5 f6 49 e5 ed 32 3d 30 a2 6c 61 2f bb 5c bd 25 f3 1c
27 22 8c ea ec 64 29 31 95 41 fe 07 8e 0e

C.1.5.2. Key and Nonce Computation

The key and nonce for calculating the ciphertext are calculated as follows, as specified in Section 3.3.

HKDF SHA-256 is the HKDF used (as defined by cipher suite 0).

PRK = HMAC-SHA-256(salt, G_XY)

Since this is the asymmetric case, salt is the empty byte string.

G_XY is the shared secret, and since the curve25519 is used, the ECDH shared secret is the output of the X25519 function.

G_XY (32 bytes)
c6 1e 09 09 a1 9d 64 24 01 63 ec 26 2e 9c c4 f8 8c e7 7b e1 23 c5 ab 53 8d
26 b0 69 22 a5 20 67

From there, PRK is computed:

PRK (32 bytes)
ba 9c 2c a1 c5 62 14 a6 e0 f6 13 ed a8 91 86 8a 4c a3 e3 fa bc c7 79 8f dc
01 60 80 07 59 16 71

Key K_3 is the output of HKDF-Expand(PRK, info, L).

info is defined as follows:

```
info for K_3
[
  10,
  [ null, null, null ],
  [ null, null, null ],
  [ 128, h'', h'21ccb678b79114960955885b90a2b82e3b2ca27e8e374a7907f3e78543
  67fc22' ]
]
```

Which as a CBOR encoded data item is:

```
info (K_3) (CBOR-encoded) (48 bytes)
84 0a 83 f6 f6 f6 83 f6 f6 f6 83 18 80 40 58 20 21 cc b6 78 b7 91 14 96 09
55 88 5b 90 a2 b8 2e 3b 2c a2 7e 8e 37 4a 79 07 f3 e7 85 43 67 fc 22
```

L is the length of K_3, so 16 bytes.

From these parameters, K_3 is computed:

```
K_3 (16 bytes)
e1 ac d4 76 f5 96 a4 60 72 44 a8 da 8c ff 49 df
```

Nonce IV_3 is the output of HKDF-Expand(PRK, info, L).

info is defined as follows:

```
info for IV_3
[
  "IV-GENERATION",
  [ null, null, null ],
  [ null, null, null ],
  [ 104, h'', h'21ccb678b79114960955885b90a2b82e3b2ca27e8e374a7907f3e78543
  67fc22' ]
]
```

Which as a CBOR encoded data item is:

```
info (IV_3) (CBOR-encoded) (61 bytes)
84 6d 49 56 2d 47 45 4e 45 52 41 54 49 4f 4e 83 f6 f6 f6 83 f6 f6 f6 83 18
68 40 58 20 21 cc b6 78 b7 91 14 96 09 55 88 5b 90 a2 b8 2e 3b 2c a2 7e 8e
37 4a 79 07 f3 e7 85 43 67 fc 22
```

L is the length of IV_3, so 13 bytes.

From these parameters, IV_3 is computed:

```
IV_3 (13 bytes)
de 53 02 13 ab a2 6a 47 1a 51 f3 d6 fb
```

C.1.5.3. Ciphertext Computation

COSE_Encrypt0 is computed with the following parameters. Note that PAD_3 is omitted.

- empty protected header
- external_aad = TH_3
- plaintext = CBOR Sequence of the items kid_value, signature, in this order.

with kid_value taken from Appendix C.1.1, and signature as calculated in Appendix C.1.5.1.

The plaintext is the following:

```
P_3 (68 bytes)
41 a2 58 40 5c 7d 7d 64 c9 61 c5 f5 2d cf 33 91 25 92 a1 af f0 2c 33 62 b0
e7 55 0e 4b c5 66 b7 0c 20 61 f3 c5 f6 49 e5 ed 32 3d 30 a2 6c 61 2f bb 5c
bd 25 f3 1c 27 22 8c ea ec 64 29 31 95 41 fe 07 8e 0e
```

From the parameters above, the Enc_structure A_3 is computed.

```
A_3 =
[
  "Encrypt0",
  h'',
  h'21ccb678b79114960955885b90a2b82e3b2ca27e8e374a7907f3e7854367fc22'
]
```

Which encodes to the following byte string to be used as Additional Authenticated Data:

```
A_2 (CBOR-encoded) (45 bytes)
83 68 45 6e 63 72 79 70 74 30 40 58 20 21 cc b6 78 b7 91 14 96 09 55 88 5b
90 a2 b8 2e 3b 2c a2 7e 8e 37 4a 79 07 f3 e7 85 43 67 fc 22
```

The key and nonce used are defined in Appendix C.1.4.2:

- key = K_3
- nonce = IV_3

Using the parameters above, the ciphertext CIPHERTEXT_3 can be computed:

CIPHERTEXT_3 (76 bytes)
```
de 4a 83 3d 48 b6 64 74 14 2c c9 bd ce 87 d9 3a f8 35 57 9c 2d bf 1b 9e 2f
b4 dc 66 60 0d ba c6 bb 3c c0 5c 29 0e f3 5d 51 5b 4d 7d 64 83 f5 09 61 43
b5 56 44 cf af d1 ff aa 7f 2b a3 86 36 57 83 1d d2 e5 bd 04 04 38 60 14 0d
c8
```

C.1.5.4. message_3

From the parameter computed in Appendix C.1.5 and Appendix C.1.5.3, message_3 is computed, as the CBOR Sequence of the following items: (C_V, CIPHERTEXT_3).

```
message_3 =
(
  h'c4',
  h'de4a833d48b66474142cc9bdce87d93af835579c2dbf1b9e2fb4dc66600dbac6bb3cc0
  5c290ef35d515b4d7d6483f5096143b55644cfafd1ffaa7f2ba3863657831dd2e5bd0404
  3860140dc8'
)
```

Which encodes to the following byte string:

message_3 (CBOR Sequence) (80 bytes)
```
41 c4 58 4c de 4a 83 3d 48 b6 64 74 14 2c c9 bd ce 87 d9 3a f8 35 57 9c 2d bf 1b
 9e 2f b4 dc 66 60 0d ba c6 bb 3c c0 5c 29 0e f3 5d 51 5b 4d 7d 64 83 f5 09 61 4
3 b5 56 44 cf af d1 ff aa 7f 2b a3 86 36 57 83 1d d2 e5 bd 04 04 38 60 14 0d c8
```

C.1.5.5. OSCORE Security Context Derivation

From the previous message exchange, the Common Security Context for OSCORE [RFC8613] can be derived, as specified in Section 3.3.1.

First af all, TH_4 is computed: TH_4 = H(TH_3, CIPHERTEXT_3), where the input to the hash function is the CBOR Sequence of TH_3 and CIPHERTEXT_3

(TH_3, CIPHERTEXT_3)
(CBOR Sequence) (112 bytes)
```
58 20 21 cc b6 78 b7 91 14 96 09 55 88 5b 90 a2 b8 2e 3b 2c a2 7e 8e 37 4a
79 07 f3 e7 85 43 67 fc 22 58 4c de 4a 83 3d 48 b6 64 74 14 2c c9 bd ce 87
d9 3a f8 35 57 9c 2d bf 1b 9e 2f b4 dc 66 60 0d ba c6 bb 3c c0 5c 29 0e f3
5d 51 5b 4d 7d 64 83 f5 09 61 43 b5 56 44 cf af d1 ff aa 7f 2b a3 86 36 57
83 1d d2 e5 bd 04 04 38 60 14 0d c8
```

And from there, compute the transcript hash TH_4 = SHA-256(TH_3, CIPHERTEXT_3)

TH_4 value (32 bytes)
```
51 ed 39 32 bc ba e8 90 1c 1d 4d eb 94 bd 67 3a b4 d3 8c 34 81 96 09 ee 0d
5c 9d a6 e9 80 7f e5
```

When encoded as a CBOR bstr, that gives:

```
TH_4 (CBOR-encoded) (34 bytes)
58 20 51 ed 39 32 bc ba e8 90 1c 1d 4d eb 94 bd 67 3a b4 d3 8c 34 81 96 09
ee 0d 5c 9d a6 e9 80 7f e5
```

To derive the Master Secret and Master Salt the same HKDF-Expand (PRK, info, L) is used, with different info and L.

For Master Secret:

L for Master Secret = 16

```
Info for Master Secret =
[
  "OSCORE Master Secret",
  [ null, null, null ],
  [ null, null, null ],
  [ 128, h'', h'51ed3932bcbae8901c1d4deb94bd673ab4d38c34819609ee0d5c9da6e9
  807fe5' ]
]
```

When encoded as a CBOR bstr, that gives:

```
info (OSCORE Master Secret) (CBOR-encoded) (68 bytes)
84 74 4f 53 43 4f 52 45 20 4d 61 73 74 65 72 20 53 65 63 72 65 74 83 f6 f6
f6 83 f6 f6 f6 83 18 80 40 58 20 51 ed 39 32 bc ba e8 90 1c 1d 4d eb 94 bd
67 3a b4 d3 8c 34 81 96 09 ee 0d 5c 9d a6 e9 80 7f e5
```

Finally, the Master Secret value computed is:

```
OSCORE Master Secret (16 bytes)
09 02 9d b0 0c 3e 01 27 42 c3 a8 69 04 07 4c 0e
```

For Master Salt:

L for Master Secret = 8

```
Info for Master Salt =
[
  "OSCORE Master Salt",
  [ null, null, null ],
  [ null, null, null ],
  [ 64, h'', h'51ed3932bcbae8901c1d4deb94bd673ab4d38c34819609ee0d5c9da6e98
  07fe5' ]
]
```

When encoded as a CBOR bstr, that gives:

info (OSCORE Master Salt) (CBOR-encoded) (66 bytes)
84 72 4f 53 43 4f 52 45 20 4d 61 73 74 65 72 20 53 61 6c 74 83 f6 f6 f6 83
f6 f6 f6 83 18 40 40 58 20 51 ed 39 32 bc ba e8 90 1c 1d 4d eb 94 bd 67 3a
b4 d3 8c 34 81 96 09 ee 0d 5c 9d a6 e9 80 7f e5

Finally, the Master Secret value computed is:

OSCORE Master Salt (8 bytes)
81 02 97 22 a2 30 4a 06

The Client's Sender ID takes the value of C_V:

Client's OSCORE Sender ID (1 bytes)
c4

The Server's Sender ID takes the value of C_U:

Server's OSCORE Sender ID (1 bytes)
c3

The algorithms are those negociated in the cipher suite:

AEAD Algorithm
10

HMAC Algorithm
5

C.2. Test Vectors for EDHOC Authenticated with Symmetric Keys (PSK)

Symmetric EDHOC is used:

method (Symmetric Authentication)
1

CoAP is used as transport:

corr (Party U is CoAP client)
1

No unprotected opaque application data is sent in the message exchanges.

The pre-defined Cipher Suite 0 is in place both on Party U and Party V, see Section 3.1.

C.2.1. Input for Party U

The following are the parameters that are set in Party U before the first message exchange.

Party U's ephemeral private key (32 bytes)
f4 0c ea f8 6e 57 76 92 33 32 b8 d8 fd 3b ef 84 9c ad b1 9c 69 96 bc 27 2a f1 f6 48 d9 56 6a 4c

Party U's ephemeral public key (value of X_U) (32 bytes)
ab 2f ca 32 89 83 22 c2 08 fb 2d ab 50 48 bd 43 c3 55 c6 43 0f 58 88 97 cb 57 49 61 cf a9 80 6f

Connection identifier chosen by U (value of C_U) (1 bytes)
c1

Pre-shared Key (PSK) (16 bytes)
a1 1f 8f 12 d0 87 6f 73 6d 2d 8f d2 6e 14 c2 de

kid value to identify PSK (1 bytes)
a1

So ID_PSK is defined as the following:

```
ID_PSK =
{
  4:  h'a1'
}
```

This test vector uses COSE_Key objects to store the pre-shared key.

Note that since the map for ID_PSK contains a single 'kid' parameter, ID_PSK is used when transported in the protected header of the COSE Object, but only the kid_value is used when added to the plaintext (see Section 5.1):

ID_PSK (in protected header) (CBOR-encoded) (4 bytes)
a1 04 41 a1

kid_value (in plaintext) (CBOR-encoded) (2 bytes)
41 a1

C.2.2. Input for Party V

The following are the parameters that are set in Party U before the first message exchange.

Party V's ephemeral private key (32 bytes)
d9 81 80 87 de 72 44 ab c1 b5 fc f2 8e 55 e4 2c 7f f9 c6 78 c0 60 51 81 f3
7a c5 d7 41 4a 7b 95

Party V's ephemeral public key (value of X_V) (32 bytes)
fc 3b 33 93 67 a5 22 5d 53 a9 2d 38 03 23 af d0 35 d7 81 7b 6d 1b e4 7d 94
6f 6b 09 a9 cb dc 06

Connection identifier chosen by V (value of C_V) (1 bytes)
c2

Pre-shared Key (PSK) (16 bytes)
a1 1f 8f 12 d0 87 6f 73 6d 2d 8f d2 6e 14 c2 de

kid value to identify PSK (1 bytes)
a1

So ID_PSK is defined as the following:

```
ID_PSK =
{
  4:  h'a1'
}
```

This test vector uses COSE_Key objects to store the pre-shared key.

Note that since the map for ID_PSK contains a single 'kid' parameter, ID_PSK is used when transported in the protected header of the COSE Object, but only the kid_value is used when added to the plaintext (see Section 5.1):

ID_PSK (in protected header) (CBOR-encoded) (4 bytes)
a1 04 41 a1

kid_value (in plaintext) (CBOR-encoded) (2 bytes)
41 a1

C.2.3. Message 1

From the input parameters (in Appendix C.2.1):

TYPE (4 * method + corr)
5

suite
0

SUITES_U : suite
0

G_X (X-coordinate of the ephemeral public key of Party U) (32 bytes)
ab 2f ca 32 89 83 22 c2 08 fb 2d ab 50 48 bd 43 c3 55 c6 43 0f 58 88 97 cb
57 49 61 cf a9 80 6f

C_U (Connection identifier chosen by U) (CBOR encoded) (2 bytes)
41 c1

kid_value of ID_PSK (CBOR encoded) (2 bytes)
41 a1

No UAD_1 is provided, so UAD_1 is absent from message_1.

Message_1 is constructed, as the CBOR Sequence of the CBOR data items above.

```
message_1 =
(
  5,
  0,
  h'ab2fca32898322c208fb2dab5048bd43c355c6430f588897cb574961cfa9806f',
  h'c1',
  h'a1'
)
```

message_1 (CBOR Sequence) (40 bytes)
05 00 58 20 ab 2f ca 32 89 83 22 c2 08 fb 2d ab 50 48 bd 43 c3 55 c6 43 0f
58 88 97 cb 57 49 61 cf a9 80 6f 41 c1 41 a1

C.2.4. Message 2

Since TYPE mod 4 equals 1, C_U is omitted from data_2.

G_Y (X-coordinate of the ephemeral public key of Party V) (32 bytes)
fc 3b 33 93 67 a5 22 5d 53 a9 2d 38 03 23 af d0 35 d7 81 7b 6d 1b e4 7d 94
6f 6b 09 a9 cb dc 06

C_V (Connection identifier chosen by V) (1 bytes)
c2

Data_2 is constructed, as the CBOR Sequence of the CBOR data items above.

```
  data_2 =
  (
    h'fc3b339367a5225d53a92d380323afd035d7817b6d1be47d946f6b09a9cbdc06',
    h'c2'
  )

data_2 (CBOR Sequence) (36 bytes)
58 20 fc 3b 33 93 67 a5 22 5d 53 a9 2d 38 03 23 af d0 35 d7 81 7b 6d 1b e4
7d 94 6f 6b 09 a9 cb dc 06 41 c2
```

From data_2 and message_1 (from Appendix C.2.3), compute the input to the transcript hash TH_2 = H(message_1, data_2), as a CBOR Sequence of these 2 data items.

```
( message_1, data_2 ) (CBOR Sequence)
(76 bytes)
05 00 58 20 ab 2f ca 32 89 83 22 c2 08 fb 2d ab 50 48 bd 43 c3 55 c6 43 0f
58 88 97 cb 57 49 61 cf a9 80 6f 41 c1 41 a1 58 20 fc 3b 33 93 67 a5 22 5d
53 a9 2d 38 03 23 af d0 35 d7 81 7b 6d 1b e4 7d 94 6f 6b 09 a9 cb dc 06 41
c2
```

And from there, compute the transcript hash TH_2 = SHA-256(message_1, data_2)

```
TH_2 value (32 bytes)
16 4f 44 d8 56 dd 15 22 2f a4 63 f2 02 d9 c6 0b e3 c6 9b 40 f7 35 8d 34 1c
db 7b 07 de e1 70 ca
```

When encoded as a CBOR bstr, that gives:

```
TH_2 (CBOR-encoded) (34 bytes)
58 20 16 4f 44 d8 56 dd 15 22 2f a4 63 f2 02 d9 c6 0b e3 c6 9b 40 f7 35 8d
34 1c db 7b 07 de e1 70 ca
```

C.2.4.1. Key and Nonce Computation

The key and nonce for calculating the ciphertext are calculated as follows, as specified in Section 3.3.

HKDF SHA-256 is the HKDF used (as defined by cipher suite 0).

PRK = HMAC-SHA-256(salt, G_XY)

Since this is the symmetric case, salt is the PSK:

```
salt (16 bytes)
a1 1f 8f 12 d0 87 6f 73 6d 2d 8f d2 6e 14 c2 de
```

G_XY is the shared secret, and since the curve25519 is used, the ECDH shared secret is the output of the X25519 function.

```
G_XY (32 bytes)
d5 75 05 50 6d 8f 30 a8 60 a0 63 d0 1b 5b 7a d7 6a 09 4f 70 61 3b 4a e6 6c
5a 90 e5 c2 1f 23 11
```

From there, PRK is computed:

```
PRK (32 bytes)
aa b2 f1 3c cb 1a 4f f7 96 a9 7a 32 a4 d2 fb 62 47 ef 0b 6b 06 da 04 d3 d1
06 39 4b 28 76 e2 8c
```

Key K_2 is the output of HKDF-Expand(PRK, info, L).

info is defined as follows:

```
info for K_2
[
  10,
  [ null, null, null ],
  [ null, null, null ],
  [ 128, h'', h'164f44d856dd15222fa463f202d9c60be3c69b40f7358d341cdb7b07de
  e170ca' ]
]
```

Which as a CBOR encoded data item is:

```
info (K_2) (CBOR-encoded) (48 bytes)
84 0a 83 f6 f6 f6 83 f6 f6 f6 83 18 80 40 58 20 16 4f 44 d8 56 dd 15 22 2f
a4 63 f2 02 d9 c6 0b e3 c6 9b 40 f7 35 8d 34 1c db 7b 07 de e1 70 ca
```

L is the length of K_2, so 16 bytes.

From these parameters, K_2 is computed:

```
K_2 (16 bytes)
ac 42 6e 5e 7d 7a d6 ae 3b 19 aa bd e0 f6 25 57
```

Nonce IV_2 is the output of HKDF-Expand(PRK, info, L).

info is defined as follows:

```
info for IV_2
[
  "IV-GENERATION",
  [ null, null, null ],
  [ null, null, null ],
  [ 104, h'', h'164f44d856dd15222fa463f202d9c60be3c69b40f7358d341cdb7b07de
  e170ca' ]
]
```

Which as a CBOR encoded data item is:

```
info (IV_2) (CBOR-encoded) (61 bytes)
84 6d 49 56 2d 47 45 4e 45 52 41 54 49 4f 4e 83 f6 f6 f6 83 f6 f6 f6 83 18
68 40 58 20 16 4f 44 d8 56 dd 15 22 2f a4 63 f2 02 d9 c6 0b e3 c6 9b 40 f7
35 8d 34 1c db 7b 07 de e1 70 ca
```

L is the length of IV_2, so 13 bytes.

From these parameters, IV_2 is computed:

```
IV_2 (13 bytes)
ff 11 2e 1c 26 8a a2 a7 7c c3 ee 6c 4d
```

C.2.4.2. Ciphertext Computation

COSE_Encrypt0 is computed with the following parameters. Note that UAD_2 is omitted.

- empty protected header
- external_aad = TH_2
- empty plaintext, since UAD_2 is omitted

From the parameters above, the Enc_structure A_2 is computed.

```
A_2 =
[
  "Encrypt0",
  h'',
  h'164f44d856dd15222fa463f202d9c60be3c69b40f7358d341cdb7b07dee170ca'
]
```

Which encodes to the following byte string to be used as Additional Authenticated Data:

A_2 (CBOR-encoded) (45 bytes)
83 68 45 6e 63 72 79 70 74 30 40 58 20 16 4f 44 d8 56 dd 15 22 2f a4 63 f2
02 d9 c6 0b e3 c6 9b 40 f7 35 8d 34 1c db 7b 07 de e1 70 ca

The key and nonce used are defined in Appendix C.2.4.1:

- key = K_2

- nonce = IV_2

Using the parameters above, the ciphertext CIPHERTEXT_2 can be computed:

CIPHERTEXT_2 (8 bytes)
ba 38 b9 a3 fc 1a 58 e9

C.2.4.3. message_2

From the parameter computed in Appendix C.2.4 and Appendix C.2.4.2, message_2 is computed, as the CBOR Sequence of the following items: (G_Y, C_V, CIPHERTEXT_2).

```
message_2 =
(
  h'fc3b339367a5225d53a92d380323afd035d7817b6d1be47d946f6b09a9cbdc06',
  h'c2',
  h'ba38b9a3fc1a58e9'
)
```

Which encodes to the following byte string:

message_2 (CBOR Sequence) (45 bytes)
58 20 fc 3b 33 93 67 a5 22 5d 53 a9 2d 38 03 23 af d0 35 d7 81 7b 6d 1b e4
7d 94 6f 6b 09 a9 cb dc 06 41 c2 48 ba 38 b9 a3 fc 1a 58 e9

C.2.5. Message 3

Since TYPE mod 4 equals 1, C_V is not omitted from data_3.

C_V (1 bytes)
c2

Data_3 is constructed, as the CBOR Sequence of the CBOR data item above.

```
data_3 =
(
  h'c2'
)

data_3 (CBOR Sequence) (2 bytes)
41 c2
```

From data_3, CIPHERTEXT_2 (Appendix C.2.4.2), and TH_2 (Appendix C.2.4), compute the input to the transcript hash TH_2 = H(TH_2 , CIPHERTEXT_2, data_3), as a CBOR Sequence of these 3 data items.

```
( TH_2, CIPHERTEXT_2, data_3 ) (CBOR Sequence) (45 bytes)
58 20 16 4f 44 d8 56 dd 15 22 2f a4 63 f2 02 d9 c6 0b e3 c6 9b 40 f7 35 8d
34 1c db 7b 07 de e1 70 ca 48 ba 38 b9 a3 fc 1a 58 e9 41 c2
```

And from there, compute the transcript hash TH_3 = SHA-256(TH_2 , CIPHERTEXT_2, data_3)

```
TH_3 value (32 bytes)
11 98 aa b3 ed db 61 b8 a1 b1 93 a9 e5 60 2b 5d 5f ea 76 bc 28 52 89 54 81
b5 2b 8a f5 66 d7 fe
```

When encoded as a CBOR bstr, that gives:

```
TH_3 (CBOR-encoded) (34 bytes)
58 20 11 98 aa b3 ed db 61 b8 a1 b1 93 a9 e5 60 2b 5d 5f ea 76 bc 28 52 89
54 81 b5 2b 8a f5 66 d7 fe
```

C.2.5.1. Key and Nonce Computation

The key and nonce for calculating the ciphertext are calculated as follows, as specified in Section 3.3.

HKDF SHA-256 is the HKDF used (as defined by cipher suite 0).

PRK = HMAC-SHA-256(salt, G_XY)

Since this is the symmetric case, salt is the PSK:

```
salt (16 bytes)
a1 1f 8f 12 d0 87 6f 73 6d 2d 8f d2 6e 14 c2 de
```

G_XY is the shared secret, and since the curve25519 is used, the ECDH shared secret is the output of the X25519 function.

```
G_XY (32 bytes)
d5 75 05 50 6d 8f 30 a8 60 a0 63 d0 1b 5b 7a d7 6a 09 4f 70 61 3b 4a e6 6c
5a 90 e5 c2 1f 23 11
```

From there, PRK is computed:

```
PRK (32 bytes)
aa b2 f1 3c cb 1a 4f f7 96 a9 7a 32 a4 d2 fb 62 47 ef 0b 6b 06 da 04 d3 d1
06 39 4b 28 76 e2 8c
```

Key K_3 is the output of HKDF-Expand(PRK, info, L).

info is defined as follows:

```
info for K_3
[
  10,
  [ null, null, null ],
  [ null, null, null ],
  [ 128, h'', h'1198aab3eddb61b8a1b193a9e5602b5d5fea76bc2852895481b52b8af5
  66d7fe' ]
]
```

Which as a CBOR encoded data item is:

```
info (K_3) (CBOR-encoded) (48 bytes)
84 0a 83 f6 f6 f6 83 f6 f6 f6 83 18 80 40 58 20 11 98 aa b3 ed db 61 b8 a1
b1 93 a9 e5 60 2b 5d 5f ea 76 bc 28 52 89 54 81 b5 2b 8a f5 66 d7 fe
```

L is the length of K_3, so 16 bytes.

From these parameters, K_3 is computed:

```
K_3 (16 bytes)
fe 75 e3 44 27 f8 3a ad 84 16 83 c6 6f a3 8a 62
```

Nonce IV_3 is the output of HKDF-Expand(PRK, info, L).

info is defined as follows:

```
info for IV_3
[
  "IV-GENERATION",
  [ null, null, null ],
  [ null, null, null ],
  [ 104, h'', h'1198aab3eddb61b8a1b193a9e5602b5d5fea76bc2852895481b52b8af5
  66d7fe' ]
]
```

Which as a CBOR encoded data item is:

```
info (IV_3) (CBOR-encoded) (61 bytes)
84 6d 49 56 2d 47 45 4e 45 52 41 54 49 4f 4e 83 f6 f6 f6 83 f6 f6 f6 83 18
68 40 58 20 11 98 aa b3 ed db 61 b8 a1 b1 93 a9 e5 60 2b 5d 5f ea 76 bc 28
52 89 54 81 b5 2b 8a f5 66 d7 fe
```

L is the length of IV_3, so 13 bytes.

From these parameters, IV_3 is computed:

```
IV_3 (13 bytes)
60 0a 33 b4 16 de 08 23 52 67 71 ec 8a
```

C.2.5.2. Ciphertext Computation

COSE_Encrypt0 is computed with the following parameters. Note that PAD_2 is omitted.

- empty protected header
- external_aad = TH_3
- empty plaintext, since PAD_2 is omitted

From the parameters above, the Enc_structure A_3 is computed.

```
A_3 =
[
  "Encrypt0",
  h'',
  h'1198aab3eddb61b8a1b193a9e5602b5d5fea76bc2852895481b52b8af566d7fe'
]
```

Which encodes to the following byte string to be used as Additional Authenticated Data:

```
A_3 (CBOR-encoded) (45 bytes)
83 68 45 6e 63 72 79 70 74 30 40 58 20 11 98 aa b3 ed db 61 b8 a1 b1 93 a9
e5 60 2b 5d 5f ea 76 bc 28 52 89 54 81 b5 2b 8a f5 66 d7 fe
```

The key and nonce used are defined in Appendix C.2.5.1:

- key = K_3
- nonce = IV_3

Using the parameters above, the ciphertext CIPHERTEXT_3 can be computed:

CIPHERTEXT_3 (8 bytes)
51 29 07 92 61 45 40 04

C.2.5.3. message_3

From the parameter computed in Appendix C.2.5 and Appendix C.2.5.2, message_3 is computed, as the CBOR Sequence of the following items: (C_V, CIPHERTEXT_3).

```
message_3 =
(
  h'c2',
  h'5129079261454004'
)
```

Which encodes to the following byte string:

message_3 (CBOR Sequence) (11 bytes)
41 c2 48 51 29 07 92 61 45 40 04

C.2.5.4. OSCORE Security Context Derivation

From the previous message exchange, the Common Security Context for OSCORE [RFC8613] can be derived, as specified in Section 3.3.1.

First af all, TH_4 is computed: TH_4 = H(TH_3, CIPHERTEXT_3), where the input to the hash function is the CBOR Sequence of TH_3 and CIPHERTEXT_3

(TH_3, CIPHERTEXT_3)
(CBOR Sequence) (43 bytes)
58 20 11 98 aa b3 ed db 61 b8 a1 b1 93 a9 e5 60 2b 5d 5f ea 76 bc 28 52 89
54 81 b5 2b 8a f5 66 d7 fe 48 51 29 07 92 61 45 40 04

And from there, compute the transcript hash TH_4 = SHA-256(TH_3, CIPHERTEXT_3)

TH_4 value (32 bytes)
df 7c 9b 06 f5 dc 0e e8 86 0b 39 6c 78 c5 be b7 57 41 3f a7 b6 a9 cf 28 3d
db 4c d4 c1 fd e4 3c

When encoded as a CBOR bstr, that gives:

```
TH_4 (CBOR-encoded) (34 bytes)
58 20 df 7c 9b 06 f5 dc 0e e8 86 0b 39 6c 78 c5 be b7 57 41 3f a7 b6 a9 cf
28 3d db 4c d4 c1 fd e4 3c
```

To derive the Master Secret and Master Salt the same HKDF-Expand (PRK, info, L) is used, with different info and L.

For Master Secret:

L for Master Secret = 16

```
Info for Master Secret =
[
  "OSCORE Master Secret",
  [ null, null, null ],
  [ null, null, null ],
  [ 128, h'', h'df7c9b06f5dc0ee8860b396c78c5beb757413fa7b6a9cf283ddb4cd4c1
  fde43c' ]
]
```

When encoded as a CBOR bstr, that gives:

```
info (OSCORE Master Secret) (CBOR-encoded) (68 bytes)
84 74 4f 53 43 4f 52 45 20 4d 61 73 74 65 72 20 53 65 63 72 65 74 83 f6 f6
f6 83 f6 f6 f6 83 18 80 40 58 20 df 7c 9b 06 f5 dc 0e e8 86 0b 39 6c 78 c5
be b7 57 41 3f a7 b6 a9 cf 28 3d db 4c d4 c1 fd e4 3c
```

Finally, the Master Secret value computed is:

```
OSCORE Master Secret (16 bytes)
8d 36 8f 09 26 2d c5 52 7f e7 19 e6 6c 91 63 75
```

For Master Salt:

L for Master Secret = 8

```
Info for Master Salt =
[
  "OSCORE Master Salt",
  [ null, null, null ],
  [ null, null, null ],
  [ 64, h'', h'df7c9b06f5dc0ee8860b396c78c5beb757413fa7b6a9cf283ddb4cd4c1f
  de43c' ]
]
```

When encoded as a CBOR bstr, that gives:

info (OSCORE Master Salt) (CBOR-encoded) (66 bytes)
84 72 4f 53 43 4f 52 45 20 4d 61 73 74 65 72 20 53 61 6c 74 83 f6 f6 f6 83
f6 f6 f6 83 18 40 40 58 20 df 7c 9b 06 f5 dc 0e e8 86 0b 39 6c 78 c5 be b7
57 41 3f a7 b6 a9 cf 28 3d db 4c d4 c1 fd e4 3c

Finally, the Master Secret value computed is:

OSCORE Master Salt (8 bytes)
4d b7 06 58 c5 e9 9f b6

The Client's Sender ID takes the value of C_V:

Client's OSCORE Sender ID (1 bytes)
c2

The Server's Sender ID takes the value of C_U:

Server's OSCORE Sender ID (1 bytes)
c1

The algorithms are those negociated in the cipher suite:

AEAD Algorithm
10

HMAC Algorithm
5

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Authors' Addresses

Goeran Selander
Ericsson AB

Email: goran.selander@ericsson.com

John Mattsson
Ericsson AB

Email: john.mattsson@ericsson.com

Francesca Palombini
Ericsson AB

Email: francesca.palombini@ericsson.com

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M. Tiloca
RISE AB
J. Park
Universitaet Duisburg-Essen
F. Palombini
Ericsson AB

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Key Management for OSCORE Groups in ACE
draft-tiloca-ace-oscoap-joining-05

Abstract

This document describes a method to request and provision keying material in group communication scenarios where communications are based on CoAP and secured with Object Security for Constrained RESTful Environments (OSCORE). The proposed method delegates the authentication and authorization of new client nodes that join an OSCORE group through a Group Manager server. This approach builds on the ACE framework for Authentication and Authorization, and leverages protocol-specific profiles of ACE to achieve communication security, proof-of-possession and server authentication.

Status of This Memo

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

Internet-Drafts are working documents of the Internet Engineering Task Force (IETF). Note that other groups may also distribute working documents as Internet-Drafts. The list of current Internet-Drafts is at https://datatracker.ietf.org/drafts/current/.

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This Internet-Draft will expire on April 25, 2019.

Table of Contents

1. Introduction

Object Security for Constrained RESTful Environments (OSCORE) [I-D.ietf-core-object-security] is a method for application-layer protection of the Constrained Application Protocol (CoAP) [RFC7252], using CBOR Object Signing and Encryption (COSE) [RFC8152] and enabling end-to-end security of CoAP payload and options.

As described in [I-D.ietf-core-oscore-groupcomm], OSCORE may be used to protect CoAP group communication over IP multicast [RFC7390]. This relies on a Group Manager, which is responsible for managing an OSCORE group, where members exchange CoAP messages secured with OSCORE. The Group Manager can be responsible for multiple groups, coordinates the join process of new group members, and is entrusted with the distribution and renewal of group keying material.

This specification builds on the ACE framework for Authentication and Authorization [I-D.ietf-ace-oauth-authz] and defines a method to:

- Authorize a node to join an OSCORE group, and provide it with the group keying material to communicate with other group members.
- Provide updated keying material to group members upon request.
- Renew the group keying material and distribute it to the OSCORE group (rekeying) upon changes in the group membership.

A client node joins an OSCORE group through a resource server acting as Group Manager for that group. The join process relies on an Access Token, which is bound to a proof-of-possession key and authorizes the client to access a specific join resource at the Group Manager.

Messages exchanged among the participants follow the formats defined in [I-D.palombini-ace-key-groupcomm] for provisioning and renewing keying material in group communication scenarios.

In order to achieve communication security, proof-of-possession and server authentication, the client and the Group Manager leverage protocol-specific profiles of ACE. These include also possible forthcoming profiles that comply with the requirements in Appendix C of [I-D.ietf-ace-oauth-authz].

1.1. 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.

Readers are expected to be familiar with the terms and concepts described in the ACE framework for authentication and authorization [I-D.ietf-ace-oauth-authz]. The terminology for entities in the considered architecture is defined in OAuth 2.0 [RFC6749]. In particular, this includes Client (C), Resource Server (RS), and Authorization Server (AS).

Readers are expected to be familiar with the terms and concepts related to the CoAP protocol described in [RFC7252][RFC7390]. Note that, unless otherwise indicated, the term "endpoint" is used here following its OAuth definition, aimed at denoting resources such as /token and /introspect at the AS and /authz-info at the RS. This

document does not use the CoAP definition of "endpoint", which is "An entity participating in the CoAP protocol".

Readers are expected to be familiar with the terms and concepts for protection and processing of CoAP messages through OSCORE [I-D.ietf-core-object-security] also in group communication scenarios [I-D.ietf-core-oscore-groupcomm]. These include the concept of Group Manager, as the entity responsible for a set of groups where communications are secured with OSCORE. In this specification, the Group Manager acts as Resource Server.

This document refers also to the following terminology.

- Joining node: a network node intending to join an OSCORE group, where communication is based on CoAP [RFC7390] and secured with OSCORE as described in [I-D.ietf-core-oscore-groupcomm].

- Join process: the process through which a joining node becomes a member of an OSCORE group. The join process is enforced and assisted by the Group Manager responsible for that group.

- Join resource: a resource hosted by the Group Manager, associated to an OSCORE group under that Group Manager. A join resource is identifiable with the Group Identifier (Gid) of the respective group. A joining node accesses a join resource to start the join process and become a member of that group.

- Join endpoint: an endpoint at the Group Manager associated to a join resource.

- Requester: member of an OSCORE group that sends request messages to other members of the group.

- Listener: member of an OSCORE group that receives request messages from other members of the group. A listener may reply back, by sending a response message to the requester which has sent the request message.

- Pure listener: member of a group that is configured as listener and never replies back to requesters after receiving request messages. This corresponds to the term "silent server" used in [I-D.ietf-core-oscore-groupcomm].

- Group rekeying process: the process through which the Group Manager renews the security parameters and group keying material, and (re-)distributes them to the OSCORE group members.

1.2. Relation to Other Documents

Figure 1 overviews the main documents related to this specification. Arrows and asterisk-arrows denote normative references and informative refences, respectively.

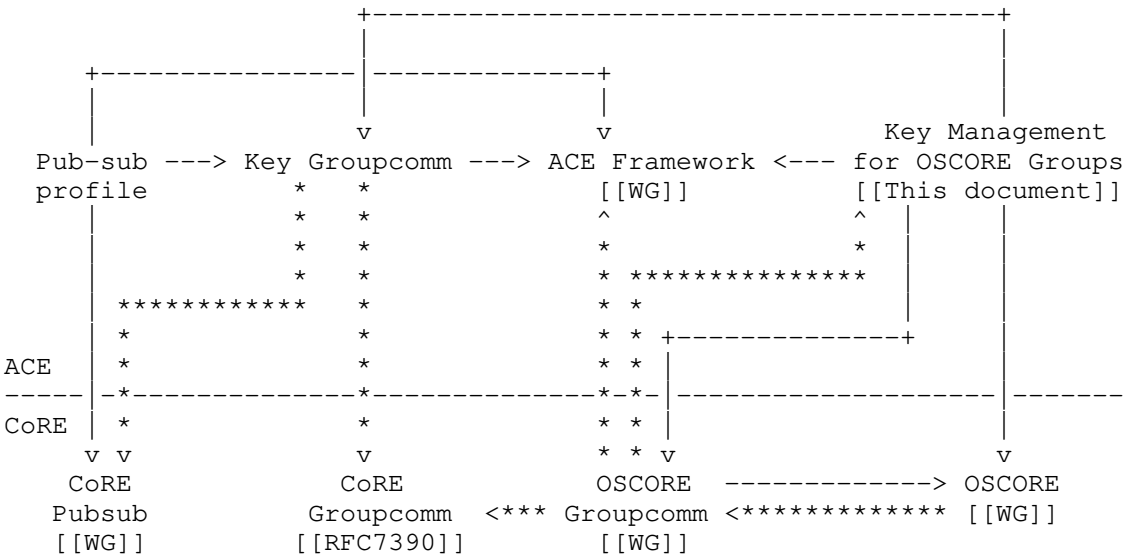

Figure 1: Related Documents

2. Protocol Overview

Group communication for CoAP over IP multicast has been enabled in [RFC7390] and can be secured with Object Security for Constrained RESTful Environments (OSCORE) [I-D.ietf-core-object-security] as described in [I-D.ietf-core-oscore-groupcomm]. A network node joins an OSCORE group by interacting with the responsible Group Manager. Once registered in the group, the new node can securely exchange messages with other group members.

This specification describes how to use the ACE framework for authentication and authorization [I-D.ietf-ace-oauth-authz] to:

- Enable a node to join an OSCORE group through the Group Manager and receive the security parameters and keying material to communicate with the other members of the gorup.

- Enable members of OSCORE groups to retrieve updated group keying material from the Group Manager.

- Enable the Group Manager to renew the security parameters and group keying material, and to (re-)distribute them to the members of the OSCORE group (rekeying).

With reference to the ACE framework and the terminology defined in OAuth 2.0 [RFC6749]:

- The Group Manager acts as Resource Server (RS), and hosts one join resource for each OSCORE group it manages. Each join resource is exported by a distinct join endpoint. During the join process, the Group Manager provides joining nodes with the parameters and keying material for taking part to secure communications in the OSCORE group. The Group Manager also maintains the group keying material and performs the group rekeying process to distribute updated keying material to the group members.

- The joining node acts as Client (C), and requests to join an OSCORE group by accessing the related join endpoint at the Group Manager.

- The Authorization Server (AS) authorizes joining nodes to join OSCORE groups under their respective Group Manager. Multiple Group Managers can be associated to the same AS. The AS MAY release Access Tokens for other purposes than joining OSCORE groups under registered Group Managers. For example, the AS may also release Access Tokens for accessing resources hosted by members of OSCORE groups.

All communications between the involved entities rely on the CoAP protocol and MUST be secured.

In particular, communications between the joining node and the Group Manager leverage protocol-specific profiles of ACE to achieve communication security, proof-of-possession and server authentication. To this end, the AS must signal the specific profile to use, consistently with requirements and assumptions defined in the ACE framework [I-D.ietf-ace-oauth-authz].

With reference to the AS, communications between the joining node and the AS (/token endpoint) as well as between the Group Manager and the AS (/introspect endpoint) can be secured by different means, for instance using DTLS [RFC6347] or OSCORE [I-D.ietf-core-object-security]. Further details on how the AS secures communications (with the joining node and the Group Manager) depend on the specifically used profile of ACE, and are out of the scope of this specification.

2.1. Overview of the Join Process

A node performs the following steps in order to join an OSCORE group. Messages exchanged among the participants follow the formats defined in [I-D.palombini-ace-key-groupcomm], and are further specified in Section 3 and Section 4 of this document. The Group Manager acts as the Key Distribution Center (KDC) defined in [I-D.palombini-ace-key-groupcomm].

1. The joining node requests an Access Token from the AS, in order to access a join resource on the Group Manager and hence join the associated OSCORE group (see Section 3). The joining node will start or continue using a secure communication channel with the Group Manager, according to the response from the AS.

2. The joining node transfers authentication and authorization information to the Group Manager by posting the obtained Access Token (see Section 4). After that, a joining node must have a secure communication channel established with the Group Manager, before starting to join an OSCORE group under that Group Manager (see Section 4). Possible ways to provide a secure communication channel are DTLS [RFC6347] and OSCORE [I-D.ietf-core-object-security].

3. The joining node starts the join process to become a member of the OSCORE group, by accessing the related join resource hosted by the Group Manager (see Section 4).

4. At the end of the join process, the joining node has received from the Group Manager the parameters and keying material to securely communicate with the other members of the OSCORE group.

5. The joining node and the Group Manager maintain the secure channel, to support possible future communications.

All further communications between the joining node and the Group Manager MUST be secured, for instance with the same secure channel mentioned in step 2.

2.2. Overview of the Group Rekeying Process

If the application requires backward and forward security, the Group Manager MUST generate new security parameters and group keying material, and distribute them to the group (rekeying) upon membership changes.

That is, the group is rekeyed when a node joins the group as a new member, or after a current member leaves the group. By doing so, a

joining node cannot access communications in the group prior its joining, while a leaving node cannot access communications in the group after its leaving.

Parameters and keying material include a new Group Identifier (Gid) for the group and a new Master Secret for the OSCORE Common Security Context of that group (see Section 2 of [I-D.ietf-core-oscore-groupcomm]).

The Group Manager MUST support the Group Rekeying Process described in Section 7. Future application profiles may define alternative message formats and distribution schemes to perform group rekeying.

3. Joining Node to Authorization Server

This section describes how the joining node interacts with the AS in order to be authorized to join an OSCORE group under a given Group Manager. In particular, it considers a joining node that intends to contact that Group Manager for the first time.

The message exchange between the joining node and the AS consists of the messages Authorization Request and Authorization Response defined in Section 3 of [I-D.palombini-ace-key-groupcomm].

In case the specific AS associated to the Group Manager is unknown to the joining node, the latter can rely on mechanisms like the Unauthorized Resource Request message described in Section 5.1.1 of [I-D.ietf-ace-oauth-authz] to discover the correct AS to contact.

3.1. Authorization Request

The joining node contacts the AS, in order to request an Access Token for accessing the join resource hosted by the Group Manager and associated to the OSCORE group. The Access Token request sent to the /token endpoint follows the format of the Authorization Request message defined in Section 3.1 of [I-D.palombini-ace-key-groupcomm]. In particular:

- The 'scope' parameter MUST be present and MUST include:
  - in the first element, either the Group Identifier (Gid) of the group to join under the Group Manager, or a value from which the Group Manager can derive the Gid of the group to join. It is up to the application to define how the Group Manager possibly performs the derivation of the full Gid. Appendix C of [I-D.ietf-core-oscore-groupcomm] provides an example of structured Gid, composed of a fixed part, namely Group Prefix, and a variable part, namely Group Epoch.

* in the second element, the role(s) that the joining node intends to have in the group it intends to join. Possible values are: "requester"; "listener"; and "pure listener". Possible combinations are: ["requester" , "listener"]; ["requester" , "pure listener"].

- The 'req_aud' parameter MUST be present and is set to the identifier of the Group Manager.

3.2. Authorization Response

The AS is responsible for authorizing the joining node to join specific OSCORE groups, according to join policies enforced on behalf of the respective Group Manager.

In case of successful authorization, the AS releases an Access Token bound to a proof-of-possession key associated to the joining node.

Then, the AS provides the joining node with the Access Token as part of an Access Token response, which follows the format of the Authorization Response message defined in Section 3.2 of [I-D.palombini-ace-key-groupcomm].

The 'exp' parameter MUST be present. Other means for the AS to specify the lifetime of Access Tokens are out of the scope of this specification.

The AS must include the 'scope' parameter in the response when the value included in the Access Token differs from the one specified by the joining node in the request. In such a case, the second element of 'scope' MUST be present and includes the role(s) that the joining node is actually authorized to take in the group, encoded as specified in Section 3.1 of this document.

Also, the 'profile' parameter indicates the specific profile of ACE to use for securing communications between the joining node and the Group Manager (see Section 5.6.4.3 of [I-D.ietf-ace-oauth-authz]).

In particular, if symmetric keys are used, the AS generates a proof-of-possession key, binds it to the Access Token, and provides it to the joining node in the 'cnf' parameter of the Access Token response. Instead, if asymmetric keys are used, the joining node provides its own public key to the AS in the 'req_cnf' parameter of the Access Token request. Then, the AS uses it as proof-of-possession key bound to the Access Token, and provides the joining node with the Group Manager's public key in the 'rs_cnf' parameter of the Access Token response.

4. Joining Node to Group Manager

First, the joining node posts the Access Token to the /authz-info endpoint at the Group Manager, in accordance with the Token post defined in Section 3.3 of [I-D.palombini-ace-key-groupcomm]. Then, the joining node establishes a secure channel with the Group Manager, according to what is specified in the Access Token response and to the signalled profile of ACE.

4.1. Join Request

Once a secure communication channel with the Group Manager has been established, the joining node requests to join the OSCORE group, by accessing the related join resource at the Group Manager.

In particular, the joining node sends to the Group Manager a confirmable CoAP request, using the method POST and targeting the join endpoint associated to that group. This join request follows the format and processing of the Key Distribution Request message defined in Section 4.1 of [I-D.palombini-ace-key-groupcomm]. In particular:

- The 'get_pub_keys' parameter is present only if the joining node wants to retrieve the public keys of the group members from the Group Manager during the join process (see Section 6). Otherwise, this parameter MUST NOT be present.

- The 'client_cred' parameter, if present, includes the public key of the joining node. This parameter MAY be omitted if: i) public keys are used as proof-of-possession keys between the joining node and the Group Manager; or ii) the joining node is asking to access the group exclusively as pure listener; or iii) the Group Manager already acquired this information during a previous join process. In any other case, this parameter MUST be present.

4.2. Join Response

The Group Manager processes the request according to [I-D.ietf-ace-oauth-authz]. If this yields a positive outcome, the Group Manager updates the group membership by registering the joining node as a new member of the OSCORE group.

The Group Manager replies to the joining node providing the updated security parameters and keying meterial necessary to participate in the group communication. This join response follows the format and processing of the Key Distribution success Response message defined in Section 4.2 of [I-D.palombini-ace-key-groupcomm]. In particular:

- The 'key' parameter includes what the joining node needs in order to set up the OSCORE Security Context as per Section 2 of [I-D.ietf-core-oscore-groupcomm]. In particular:
  - The 'kty' parameter has value "Symmetric".
  - The 'k' parameter includes the OSCORE Master Secret.
  - The 'exp' parameter specifies when the OSCORE Security Context derived from these parameters expires.
  - The 'alg' parameter, if present, has as value the AEAD algorithm used in the group.
  - The 'kid' parameter, if present, has as value the identifier of the key in the parameter 'k'.
  - The 'base IV' parameter, if present, has as value the OSCORE Common IV.
  - The 'clientID' parameter, if present, has as value the OSCORE Sender ID assigned to the joining node by the Group Manager. This parameter is not present if the node joins the group exclusively as pure listener, according to what specified in the Access Token (see Section 3.2). In any other case, this parameter MUST be present.
  - The 'serverID' parameter MUST be present and has as value the Group Identifier (Gid) associated to the group.
  - The 'kdf' parameter, if present, has as value the KDF algorithm used in the group.
  - The 'slt' parameter, if present, has as value the OSCORE Master Salt.
  - The 'cs_alg' parameter MUST be present and has as value the countersignature algorithm used in the group.
- The 'pub_keys' parameter is present only if the 'get_pub_keys' parameter was present in the join request. If present, this parameter includes the public keys of the group members that are relevant to the joining node. That is, it includes: i) the public keys of the non-pure listeners currently in the group, in case the joining node is configured (also) as requester; and ii) the public keys of the requesters currently in the group, in case the joining node is configured (also) as listener or pure listener.

- The 'group_policies' parameter SHOULD be present and includes a list of parameters indicating particular policies enforced in the group. For instance, it can indicate the method to achieve synchronization of sequence numbers among group members (see Appendix E of [I-D.ietf-core-oscore-groupcomm]).

Finally, the joining node uses the information received in the join response to set up the OSCORE Security Context, as described in Section 2 of [I-D.ietf-core-oscore-groupcomm]. From then on, the joining node can exchange group messages secured with OSCORE as described in [I-D.ietf-core-oscore-groupcomm].

If the application requires backward security, the Group Manager SHALL generate updated security parameters and group keying material, and provide it to all the current group members (see Section 7).

When the OSCORE Master Secret expires, as specified by 'exp' in the 'key' parameter of the join response, the node considers the OSCORE Security Context also invalid and to be renewed. Then, the node retrieves updated security parameters and keying material, by exchanging shortened Join Request and Join Response messages with the Group Manager, according to the approach defined in Section 6 of [I-D.palombini-ace-key-groupcomm]. Finally, the node uses the updated security parameters and keying material to set up the new OSCORE Security Context as described in Section 2 of [I-D.ietf-core-oscore-groupcomm].

5. Leaving of a Group Member

A node may be removed from the OSCORE group, due to expired or revoked authorization, or after its own request to the Group Manager.

If the application requires forward security, the Group Manager SHALL generate updated security parameters and group keying material, and provide it to the remaining group members (see Section 7). The leaving node must not be able to acquire the new security parameters and group keying material distributed after its leaving.

Same considerations in Section 5 of [I-D.palombini-ace-key-groupcomm] apply here as well, considering the Group Manager acting as KDC. In particular, a node requests to leave the OSCORE group as described in Section 5.2 of [I-D.palombini-ace-key-groupcomm].

6. Public Keys of Joining Nodes

Source authentication of OSCORE messages exchanged within the group is ensured by means of digital counter signatures (see Sections 2 and 3 of [I-D.ietf-core-oscore-groupcomm]). Therefore, group members

must be able to retrieve each other's public key from a trusted key repository, in order to verify source authenticity of incoming group messages.

As also discussed in [I-D.ietf-core-oscore-groupcomm], the Group Manager acts as trusted repository of the public keys of the group members, and provides those public keys to group members if requested to. Upon joining an OSCORE group, a joining node is thus expected to provide its own public key to the Group Manager.

In particular, four cases can occur when a new node joins a group.

- The joining node is going to join the group exclusively as pure listener. That is, it is not going to send messages to the group, and hence to produce signatures with its own private key. In this case, the joining node is not required to provide its own public key to the Group Manager upon joining the group.

- The Group Manager already acquired the public key of the joining node during a previous join process. In this case, the joining node may not provide again its own public key to the Group Manager, in order to limit the size of the join request.

- The joining node and the Group Manager use an asymmetric proof-of-possession key to establish a secure communication channel. In this case, the Group Manager stores the proof-of-possession key conveyed in the Access Token as the public key of the joining node.

- The joining node and the Group Manager use a symmetric proof-of-possession key to establish a secure communication channel. In this case, upon performing a join process with that Group Manager for the first time, the joining node specifies its own public key in the 'client_cred' parameter of the join request targeting the join endpoint (see Section 4.1).

Furthermore, as described in Section 4.1, the joining node may have explicitly requested the Group Manager to retrieve the public keys of the current group members, i.e. through the 'get_pub_keys' parameter in the join request. In this case, the Group Manager includes also such public keys in the 'pub_keys' parameter of the join response (see Section 4.2).

Later on as a group member, the node may need to retrieve the public keys of other group members. The node can do that by exchanging shortened Join Request and Join Response messages with the Group Manager, according to the approach defined in Section 7 of [I-D.palombini-ace-key-groupcomm].

7. Group Rekeying Process

In order to rekey the OSCORE group, the Group Manager distributes a new Group ID of the group and a new OSCORE Master Secret for that group. To this end, the Group Manager MUST support at least the following group rekeying scheme. Future application profiles may define alternative message formats and distribution schemes.

The Group Manager uses the same format of the Join Response message in Section 4.2. In particular:

- Only the 'key' parameter is present.
- The 'k' parameter of the 'key' parameter includes the new OSCORE Master Secret.
- The 'serverID' parameter of the 'key' parameter includes the new Group ID.

The Group Manager separately sends a group rekeying message to each group member to be rekeyed. Each rekeying message MUST be secured with the pairwise secure communication channel between the Group Manager and the group member used during the join process.

8. Security Considerations

The method described in this document leverages the following management aspects related to OSCORE groups and discussed in the sections of [I-D.ietf-core-oscore-groupcomm] referred below.

- Management of group keying material (see Section 2.1 of [I-D.ietf-core-oscore-groupcomm]). The Group Manager is responsible for the renewal and re-distribution of the keying material in the groups of its competence (rekeying). According to the specific application requirements, this can include rekeying the group upon changes in its membership. In particular, renewing the keying material is required upon a new node's joining or a current node's leaving, in case backward security and forward security have to be preserved, respectively.
- Provisioning and retrieval of public keys (see Section 2 of [I-D.ietf-core-oscore-groupcomm]). The Group Manager acts as key repository of public keys of group members, and provides them upon request.
- Synchronization of sequence numbers (see Section 5 of [I-D.ietf-core-oscore-groupcomm]). This concerns how a listener

node that has just joined an OSCORE group can synchronize with the sequence number of requesters in the same group.

Before sending the join response, the Group Manager should verify that the joining node actually owns the associated private key, for instance by performing a proof-of-possession challenge-response, whose details are out of the scope of this specification.

Further security considerations are inherited from [I-D.palombini-ace-key-groupcomm], the ACE framework for Authentication and Authorization [I-D.ietf-ace-oauth-authz], and the specific profile of ACE signalled by the AS, such as [I-D.ietf-ace-dtls-authorize] and [I-D.ietf-ace-oscore-profile].

9. IANA Considerations

This document has no actions for IANA.

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Authors' Addresses

Marco Tiloca
RISE AB
Isafjordsgatan 22
Kista SE-164 29 Stockholm
Sweden

Email: marco.tiloca@ri.se

Jiye Park
Universitaet Duisburg-Essen
Schuetzenbahn 70
Essen 45127
Germany

Email: ji-ye.park@uni-due.de

Francesca Palombini
Ericsson AB
Torshamnsgatan 23
Kista SE-16440 Stockholm
Sweden

Email: francesca.palombini@ericsson.com