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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

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Authors' Addresses [47](#)

1. Change Log

EDNOTE: Remove this section before publication

-10

Addressed WGLC comments

More consistent request format in the examples.

Explained root resource difference when there is resource discovery

Clarified when the client is supposed to do discovery

Fixed nits and minor Option length inaccuracies in the examples.

-09

WGLC comments taken into account

consensus about discovery of content-format

added additional path for content-format selection

merged DTLS sections

-08

added application/pkix-cert Content-Format TBD287.

discovery text clarified

Removed text on ct negotiation in connection to multipart-core

removed text that duplicates or contradicts [RFC7252](#) (thanks Klaus)

Stated that well-known/est is compulsory

Use of response codes clarified.

removed bugs: Max-Age and Content-Format Options in Request

Accept Option explained for est/skg and added in enroll example

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

Persistence of DTLS connection clarified.

Minor text fixes.

-07:

redone examples from scratch with openssl

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.

Fixed issues pointed out by the idnits tool.

Updated CoAP response codes section with more mappings between EST HTTP codes and EST-coaps CoAP codes.

Minor updates to the MTI EST Functions section.

Moved Change Log section higher.

-05:

repaired again

TBD8 = 62 removed from C-F registration, to be done in CT draft.

-04:

Updated Delayed response section to reflect short and long delay options.

-03:

Removed observe and simplified long waits

Repaired Content-Format specification

-02:

Added parameter discussion in [section 8](#)

Concluded Content-Format specification using multipart-ct draft

examples updated

-01:

Editorials done.

Redefinition of proxy to Registrar in [Section 6](#). Explained better the role of https-coaps Registrar, instead of "proxy"

Provide "observe" Option examples

extended block message example.

inserted new server key generation text in [Section 5.8](#) and motivated server key generation.

Broke down details for DTLS 1.3

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

provided new Content-Format tables

new media format for IANA

-00

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 fits into 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 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.

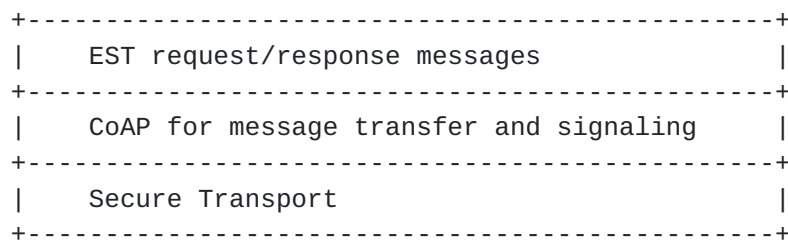


Figure 1: EST-coaps protocol layers

As per 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. Additionally, crypto agility is important, and the recommendations in [Section 4.4 of \[RFC7925\]](#) and any updates to it concerning Curve25519 and other curves also apply.

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.

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

- o 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.
- o a previously installed certificate (e.g., manufacturer IDevID [[IEEE802.1ar](#)] or a certificate issued by some other party); the server is expected to trust that certificate. 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 want to 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 \[RFC7030\]](#).

CoAP and DTLS can provide proof-of-identity for EST-coaps clients and servers with simple PKI messages as described in [Section 3.1 of \[RFC5272\]](#). Moreover, channel-binding information for linking proof-of-identity with connection-based proof-of-possession is OPTIONAL for EST-coaps. 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 EST-coaps, the same operations can be performed during the DTLS handshake. 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 as if each handshake message had been sent as a single fragment ([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. Authenticating and negotiating DTLS keys requires resources on low-end endpoints and consumes valuable bandwidth. To alleviate this situation, an EST-coaps DTLS connection MAY remain open for sequential EST transactions. For example, an EST csrattrs request that is followed by a simpleenroll request can use the same authenticated DTLS connection. However, when a cacerts 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 take place after a significant amount of time, the DTLS connections SHOULD only be kept alive for EST messages that are relatively close to each other. 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.

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:

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

5.1. Discovery and URIs

EST-coaps is targeted for low-resource networks with small packets. 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	/crt
/simpleenroll	/sen
/simplereenroll	/sren
/csrattrs	/att
/serverkeygen	/skg (PKCS#7)
/serverkeygen	/skc (application/pkix-cert)

Table 1: Short EST-coaps URI path

The /skg message is the EST /serverkeygen equivalent where the client requests for a certificate in PKCS#7 format and a private key. If the client prefers a single application/pkix-cert certificate instead of PKCS#7, he will make an /skc request.

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

In the context of CoAP, the presence and location of (path to) the management data are discovered by sending a GET request to `"/.well-known/core"` including a resource type (RT) parameter with the value `"ace.est"` [RFC6690]. Upon success, the return payload will contain the root resource of the EST resources. The example below shows the

discovery 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 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. 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 were 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 he supports non-default URIs (like /est or /est/ArbitraryLabel) or ports. The client SHOULD use resource discovery when he is unaware of the available EST-coaps resources.

It is up to the implementation to choose its resource paths; throughout this document the example root resource /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 latter ones 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
/csrattrs	OPTIONAL
/serverkeygen	OPTIONAL
/fullcmc	Not specified

Table 2: List of EST-coaps functions

While [\[RFC7030\]](#) permits a number of these functions to be used without authentication, this specification requires that the client MUST be authenticated for all 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) 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 Media-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 ([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 /crt, /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 key and certificate representations are ASN.1 encoded in binary format. An example is shown in [Appendix A.3](#).

5.4. Message Bindings

The general EST-coaps message characteristics are:

- o EST-coaps servers sometimes need to provide delayed responses which are conveyed with an 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.

- o The CoAP Options used are Uri-Host, Uri-Path, Uri-Port, Content-Format, Block, Accept and Location-Path. 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 [\[RFC7252\]](#).
- o 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. Every time the HTTP response code 200 is specified in [\[RFC7030\]](#) in response to a GET request (/cacerts, /csrattrs), the equivalent CoAP response code 2.05 or 2.03 MUST be used in EST-coaps. Similarly, 2.01, 2.02 or 2.04 MUST be used in response to EST POST requests (/simpleenroll, /simplereenroll, /serverkeygen).

HTTP response code 202 with a Retry-After header in [\[RFC7030\]](#) has no equivalent in CoAP. Retry-After is used in EST for delayed server responses. [Section 5.7](#) specifies how EST-coaps handles delayed messages.

EST makes use of HTTP 204 and 404 responses when a resource is not available for the client. The equivalent CoAP codes to use in an EST-coaps responses are 2.04 and 4.04. Additionally, EST's HTTP 401 error translates to 4.01 in EST-coaps. Other EST HTTP error messages are 400, 423 and 503. Their equivalent CoAP errors are 4.00, 4.03 and 5.03 respectively. In case a CoAP Option is unrecognized and critical, the server is expected to return a 4.02 (Bad Option).

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 should attempt 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. The EST-coaps client and server MUST support Block2. Block1 MUST be supported for EST-coaps enrollment requests that exceed 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 blocks 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, having received the first 256 bytes in the first Block2 block, the client asks for a block reduction to 128 bytes in a confirmable enrollment request and acknowledges the Block2 blocks sent up to that point.

```

POST [2001:db8::2:1]:61616/est/sen (CON)(1:0/1/256) {CSR req} -->
    <-- (ACK) (1:0/1/256) (2.31 Continue)
POST [2001:db8::2:1]:61616/est/sen (CON)(1:1/1/256) {CSR req} -->
    <-- (ACK) (1:1/1/256) (2.31 Continue)
    .
    .
    .
POST [2001:db8::2:1]:61616/est/sen (CON)(1:N1/0/256){CSR req} -->
    <-- (0.00 empty ACK)
        |
        ..... short delay before certificate is ready .....
        |
    <-- (CON) (1:N1/0/256)(2:0/1/256)(2.04 Changed) {Cert resp}
                                (ACK)                                -->
POST [2001:db8::2:1]:61616/est/sen (CON)(2:1/0/128)                -->
    <-- (ACK) (2:1/1/128) (2.04 Changed) {Cert resp}
    .
    .
    .
POST [2001:db8::2:1]:61616/est/sen (CON)(2:N2/0/128)                -->
    <-- (ACK) (2:N2/0/128) (2.04 Changed) {Cert resp}

```

Figure 2: EST-COAP enrollment with short wait

If the server is very slow (i.e. minutes) in providing the response (i.e. when a manual intervention is needed), he 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 to request the content later. After a delay of Max-Age, the client SHOULD resend the identical CSR to the server. As long as the server responds with response code 5.03 (Service Unavailable) with a Max-Age Option, the client SHOULD keep resending the enrollment request until the server responds with the certificate or the client abandons for 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 he receives the same 5.03 response and retransmits the enrollment request until he receives a certificate in a fragmented 2.01 response. Note that the server asks for a decrease in the block size when acknowledging the first Block2.

```

POST [2001:db8::2:1]:61616/est/sen (CON)(1:0/1/256) {CSR req} -->
    <-- (ACK) (1:0/1/256) (2.31 Continue)
POST [2001:db8::2:1]:61616/est/sen (CON)(1:1/1/256) {CSR req} -->
    <-- (ACK) (1:1/1/256) (2.31 Continue)
    .
    .
POST [2001:db8::2:1]:61616/est/sen (CON)(1:N1/0/256){CSR req} -->
    <-- (ACK) (1:N1/0/256) (2:0/0/128)(5.03 Service Unavailable)
                                     (Max-Age)
    |
    |
Client tries one or more times after Max-Age with identical payload
    |
    |
POST [2001:db8::2:1]:61616/est/sen (CON)(1:N1/0/256){CSR req} -->
    <-- (ACK) (1:N1/0/256) (2:0/1/128) (2.01 Created){Cert resp}
POST [2001:db8::2:1]:61616/est/sen (CON)(2:1/0/128) -->
    <-- (ACK) (2:1/1/128) (2.01 Created) {Cert resp}
    .
    .
    .
POST [2001:db8::2:1]:61616/est/sen (CON)(2:N2/0/128) -->
    <-- (ACK) (2:N2/0/128) (2.01 Created) {Cert resp}

```

Figure 3: EST-COAP enrollment with long wait

5.8. Server-side Key Generation

Constrained devices sometimes do not have the necessary hardware to generate statistically random numbers for private keys and DTLS ephemeral keys. Past experience has also shown that low-resource endpoints sometimes generate numbers which could allow someone to decrypt the communication or guess the private key and impersonate as the device [[PsQs](#)] [[RSAorig](#)]. Additionally, random number key generation is costly, thus energy draining. Even though the random numbers that constitute the identity/cert do not get generated often, an endpoint may not want to spend time and energy generating keypairs, and just ask for one from the server.

In these scenarios, server-side key generation can be used. 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 SHOULD treat 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 depicted 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 the private key is encrypted symmetrically or asymmetrically as per [[RFC7030](#)]. The symmetric key or the asymmetric keypair establishment method is out of scope of the 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. 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 is signed by the party that generated the private key, which may be the EST server or the EST CA. The SignedData is further protected by placing it inside of a CMS EnvelopedData 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 which 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 which 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 needs to be provided 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).

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.

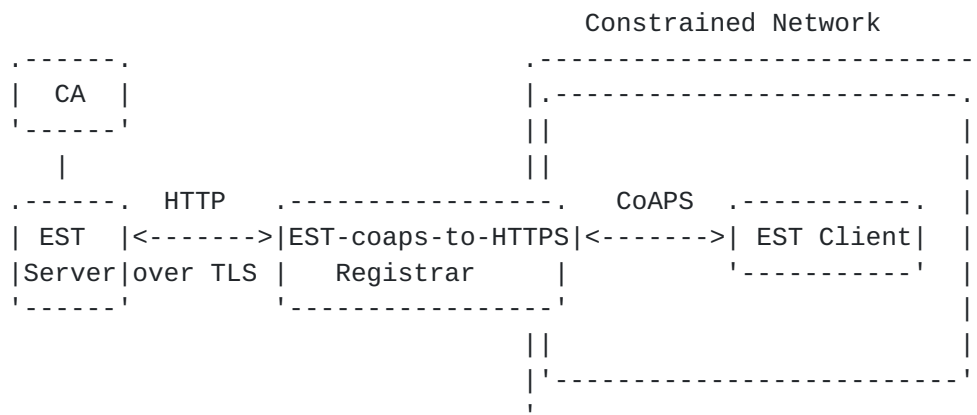


Figure 4: EST-coaps-to-HTTPS Registrar at the CoAP boundary.

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 clients and 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.

For some use cases, clients that leverage server-side key generation might prefer for the enrolled keys to be generated by the Registrar if the CA does not support server-side key generation. Such 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 support random number generation using proper entropy.

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 Media-Type is defined in [Section 9.1](#).

Additionally, a conversion from CBOR major type 2 to Base64 encoding MUST take place at the Registrar when server-side key generation is supported. If CMS end-to-end encryption is employed for the private key, the encrypted CMS EnvelopedData blob MUST be converted to binary in CBOR type 2 downstream to the client.

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.

If necessary, the EST-coaps-to-HTTP Registrar will 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 EST parameter values need to be tuned to the CoAP parameter values.

It is recommended, based on experiments, to 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. A change in a server parameter MUST ensure the adjusted value is also available to all the endpoints with which these adjusted values are to be used to communicate.

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

- o NSTART: A parameter that controls the number of simultaneous outstanding interactions that a client maintains to a given server. An EST-coaps client is not expected to interact with more than one servers at the same time, which is the default NSTART value defined in [\[RFC7252\]](#).
- o DEFAULT_LEISURE: This setting is only relevant in multicast scenarios, outside the scope of EST-coaps.
- o PROBING_RATE: A parameter which specifies the rate of re-sending non-confirmable messages. The EST messages are defined to be sent

as CoAP confirmable messages, hence this setting is not applicable.

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 3. These have been registered provisionally in the Expert Review range (0-255).

HTTP Media-Type	ID	Reference
application/pkcs7-mime; smime-type=server-generated- key	280	[RFC7030] [I-D.ietf-lamps- rfc5751-bis]
application/pkcs7-mime; smime-type=certs-only	281	[I-D.ietf-lamps-rfc5751-bi s]
application/pkcs8	284	[RFC5958] [I-D.ietf-lamps- rfc5751-bis]
application/csrattrs	285	[RFC7030] [RFC7231]
application/pkcs10	286	[RFC5967] [I-D.ietf-lamps- rfc5751-bis]
application/pkix-cert	TBD28	[RFC2585]
	7	

Table 3: 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.

- o rt="ace.est.certs". This resource depicts the support of EST get cacerts.
- o rt="ace.est.sen". This resource depicts the support of EST simple enroll.
- o rt="ace.est.sren". This resource depicts the support of EST simple reenroll.
- o rt="ace.est.att". This resource depicts the support of EST CSR attributes.
- o rt="ace.est.skg". This resource depicts the support of EST server-side key generation with the returned certificate in a PKCS#7 container.
- o rt="ace.est.skc". This resource depicts the support of EST server-side key generation with the returned certificate in application/pkix-cert format.

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.

Given that the client has only limited resources and may not be able to generate sufficiently random keys to encrypt its identity, it is possible that the client uses server generated private/public keys. The transport of these keys is inherently risky. Analysis SHOULD be done to establish whether server-side key generation enhances or decreases the probability of identity stealing.

It is also 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 successfully receiving the Distribution of CA

certificates response ([Section 4.1.3 of \[RFC7030\]](#)) limits any risk to the first DTLS exchange. Alternatively, in a case where a /sen request immediately follows a /crt, a client MAY choose to keep the connection authenticated by the Implicit TA open for efficiency reasons ([Section 4](#)). A client that pipelines EST-coaps /crt request with other requests in the same DTLS connection SHOULD revalidate the server certificate chain against the updated Explicit TA from the /crt 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 ensure that the client is to be trusted.

In accordance with [\[RFC7030\]](#), TLS cipher suites that include "_EXPORT_" and "_DES_" in their names MUST NOT be used. More information about recommendations of TLS and DTLS are included in [\[RFC7525\]](#).

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, 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. The attack was possible because of certain (D)TLS implementation imperfections. 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 \[RFC8446\]](#)). Such mechanism has not been standardized yet. Adopting a channel binding value generated from an exporter would break backwards compatibility.

Thus, in this specification we still depend in the `tls-unique` mechanism defined in [\[RFC5929\]](#), especially since the practicality of such an attack would not expose any messages exchanged with EST-coaps.

Regarding the Certificate Signing Request (CSR), a CA is expected to be able to enforce policies to recover from improper CSR requests.

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 the recommended connections are impossible. When POP linking is used the Registrar terminating the TLS connection establishes a new one 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 client has verified this information when acting as an EST server.

The introduction of an EST-coaps-to-HTTP Registrar assumes the client can trust 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, he 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 doing the right thing if 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 tunnel.

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.

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 = 0xD
  Option Value = "example.com"
Option (Uri-Port)
  Option Delta = 0x4 (option# 3+4=7)
  Option Length = 0x4
  Option Value = 9085
Option (Uri-Path)
  Option Delta = 0x4 (option# 7+4=11)
  Option Length = 0x5
  Option Value = "est"
Option (Uri-Path)
  Option Delta = 0x0 (option# 11+0=11)
  Option Length = 0x6
  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.

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 =

```
3082027b06092a864886f70d010702a082026c308202680201013100300b
06092a864886f70d010701a082024e3082024a308201f0a0030201020209
009189bcd9f9c99244b300a06082a8648ce3d0403023067310b3009060355
040613025553310b300906035504080c024341310b300906035504070c02
4c4131143012060355040a0c0b4578616d706c6520496e63311630140603
55040b0c0d63657274696669636174696f6e3110300e06035504030c0752
6f6f74204341301e170d3139303130373130343034315a170d3339303130
323130343034315a3067310b3009060355040613025553310b3009060355
04080c024341310b300906035504070c024c4131143012060355040a0c0b
4578616d706c6520496e6331163014060355040b0c0d6365727469666963
6174696f6e3110300e06035504030c07526f6f742043413059301306072a
8648ce3d020106082a8648ce3d03010703420004814994082b6e8185f3df
53f5e0bee698973335200023ddf78cd17a443ffd8ddd40908769c55652ac
2ccb75c4a50a7c7ddb7c22dae6c85cca538209fdbbf104c9a38184308181
301d0603551d0e041604142495e816ef6ffcaaf356ce4adffe33cf492abb
a8301f0603551d230418301680142495e816ef6ffcaaf356ce4adffe33cf
492abba8300f0603551d130101ff040530030101ff300e0603551d0f0101
ff040403020106301e0603551d1104173015811363657274696679406578
616d706c652e636f6d300a06082a8648ce3d0403020348003045022100da
e37c96f154c32ec0b4af52d46f3b7ecc9687ddf267bcec368f7b7f135327
2f022047a28ae5c7306163b3c3834bab3c103f743070594c089aaa0ac870
cd13b902caa1003100
```

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.]

```
3082018b30820131020100305c310b3009060355040613025553310b3009
06035504080c024341310b300906035504070c024c413114301206035504
0a0c0b6578616d706c6520496e63310c300a060355040b0c03496f54310f
300d060355040513065774313233343059301306072a8648ce3d02010608
2a8648ce3d03010703420004c8b421f11c25e47e3ac57123bf2d9fdc494f
028bc351cc80c03f150bf50cff958d75419d81a6a245dffae790be95cf75
f602f9152618f816a2b23b5638e59fd9a073303406092a864886f70d0109
0731270c2576437630292a264a4b4a3bc3a2c280c2992f3e3c2e2c3d6b6e
7634332323403d204e787e60303b06092a864886f70d01090e312e302c30
2a0603551d1104233021a01f06082b06010505070804a013301106092b06
010401b43b0a01040401020304300a06082a8648ce3d0403020348003045
02210092563a546463bd9ecff170d0fd1f2ef0d3d012160e5ee90cffedab
ec9b9a38920220179f10a3436109051abad17590a09bc87c4dce5453a6fc
1135a1e84eed754377
```

After verification of the CSR by the server, a 2.01 Content response with the issued certificate will be returned to the client.

2.01 Created
(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
0613025553310b300906035504080c02434131143012060355040a0c0b45
78616d706c6520496e6331163014060355040b0c0d636572746966696361
74696f6e3113301106035504030c0a3830322e3141522043413020170d31
39303133313131323931365a180f39393939313233313233353935395a30
5c310b3009060355040613025553310b300906035504080c024341310b30
0906035504070c024c4131143012060355040a0c0b6578616d706c652049
6e63310c300a060355040b0c03496f54310f300d06035504051306577431
3233343059301306072a8648ce3d020106082a8648ce3d03010703420004
c8b421f11c25e47e3ac57123bf2d9fdc494f028bc351cc80c03f150bf50c
ff958d75419d81a6a245dffae790be95cf75f602f9152618f816a2b23b56
38e59fd9a3818a30818730090603551d1304023000301d0603551d0e0416
041496600d8716bf7fd0e752d0ac760777ad665d02a0301f0603551d2304
183016801468d16551f951bfc82a431d0d9f08bc2d205b1160300e060355
1d0f0101ff0404030205a0302a0603551d1104233021a01f06082b060105
05070804a013301106092b06010401b43b0a01040401020304300a06082a
8648ce3d0403020349003046022100c0d81996d2507d693f3c48eaa5ee94
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.]

3081cf3078020100301631143012060355040a0c0b736b67206578616d70
6c653059301306072a8648ce3d020106082a8648ce3d030107034200041b
b8c1117896f98e4506c03d70efbe820d8e38ea97e9d65d52c8460c5852c5
1dd89a61370a2843760fc859799d78cd33f3c1846e304f1717f8123f1a28
4cc99fa000300a06082a8648ce3d04030203470030440220387cd4e9cf62
8d4af77f92ebed4890d9d141dca86cd2757dd14cbd59cdf6961802202f24
5e828c77754378b66660a4977f113cacdaa0cc7bad7d1474a7fd155d090d

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

2.01 Content

(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
6b02010104200b9a67785b65e07360b6d28cfc1d3f3925c0755799deeca7
45372b01697bd8a6a144034200041bb8c1117896f98e4506c03d70efbe82
0d8e38ea97e9d65d52c8460c5852c51dd89a61370a2843760fc859799d78
cd33f3c1846e304f1717f8123f1a284cc99f
19 0119                               # unsigned(281)
59 01D3                               # bytes(467)
308201cf06092a864886f70d010702a08201c0308201bc0201013100300b
06092a864886f70d010701a08201a23082019e30820143a0030201020208
126de8571518524b300a06082a8648ce3d04030230163114301206035504
0a0c0b736b67206578616d706c65301e170d313930313039303835373038
5a170d3339303130343038353730385a301631143012060355040a0c0b73
6b67206578616d706c653059301306072a8648ce3d020106082a8648ce3d
030107034200041bb8c1117896f98e4506c03d70efbe820d8e38ea97e9d6
5d52c8460c5852c51dd89a61370a2843760fc859799d78cd33f3c1846e30
4f1717f8123f1a284cc99fa37b307930090603551d1304023000302c0609
6086480186f842010d041f161d4f70656e53534c2047656e657261746564
204365727469666963617465301d0603551d0e04160414494be598dc8dbc
0dbc071c486b777460e5cce621301f0603551d23041830168014494be598
dc8dbc0dbc071c486b777460e5cce621300a06082a8648ce3d0403020349
003046022100a4b167d0f9add9202810e6bf6a290b8cfd9b9c9fea2cc1
c8fc3a464f79f2c202210081d31ba142751a7b4a34fd1a01fcfb08716b9e
b53bdaadc9ae60b08f52429c0fa1003100

```

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.]

```
307c06072b06010101011630220603883701311b131950617273652053455
420617320322e3939392e31206461746106092a864886f70d010907302c06
0388370231250603883703060388370413195061727365205345542061732
0322e3939392e32206461746106092b240303020801010b06096086480165
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 minimum PMTU is 1280 bytes, which is the example value assumed for the DTLS datagram size. 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. The CoAP message adds around 10 bytes, the DTLS record 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 the UDP datagram with the DTLS record that encapsulates the CoAP request 10 times. The server returns an IPv6 packet containing the 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 to avoid IP fragmentation. 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

```
GET example.com:9085/est/crts (2:0/0/64) -->
    <-- (2:0/1/64) 2.05 Content
GET example.com:9085/est/crts (2:1/0/64) -->
    <-- (2:1/1/64) 2.05 Content
        |
        |
        |
GET example.com:9085/est/crts (2:9/0/64) -->
    <-- (2:9/0/64) 2.05 Content
```

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 = 0xD
  Option Value = "example.com"
Option (Uri-Port)
  Option Delta = 0x4  (option# 3+4=7)
  Option Length = 0x4
  Option Value = 9085
Option (Uri-Path)
  Option Delta = 0x4  (option# 7+4=11)
  Option Length = 0x5
  Option Value = "est"
Option (Uri-Path)Uri-Path)
  Option Delta = 0x0  (option# 11+0=11)
  Option Length = 0x6
  Option Value = "crtts"
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 $256 = (2^{SZX} * (SZX + 4))$ 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.


```

POST [2001:db8::2:321]:61616/est/sen (CON)(1:0/1/256) {CSR req} -->
    <-- (ACK) (1:0/1/256) (2.31 Continue)
POST [2001:db8::2:321]:61616/est/sen (CON)(1:1/1/256) {CSR req} -->
    <-- (ACK) (1:1/1/256) (2.31 Continue)
    .
    .
    .
POST [2001:db8::2:321]:61616/est/sen (CON)(1:N1/0/256){CSR req} -->
    <-- (ACK) (1:N1/0/256)(2:0/1/256)(2.04 Changed){Cert resp}
POST [2001:db8::2:321]:61616/est/sen (CON)(2:1/0/256) -->
    <-- (ACK) (2:1/1/256)(2.04 Changed) {Cert resp}
    .
    .
    .
POST [2001:db8::2:321]:61616/est/sen (CON)(2:N2/0/256) -->
    <-- (ACK) (2:N2/0/256) (2.04 Changed) {Cert resp}

```

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:

91:89:bc:df:9c:99:24:4b

Signature Algorithm: ecdsa-with-SHA256

Issuer: C=US, ST=CA, L=LA, O=Example Inc,

OU=certification, CN=Root CA

Validity

Not Before: Jan 7 10:40:41 2019 GMT

Not After : Jan 2 10:40:41 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:

04:81:49:94:08:2b:6e:81:85:f3:df:53:f5:e0:be:

e6:98:97:33:35:20:00:23:dd:f7:8c:d1:7a:44:3f:

fd:8d:dd:40:90:87:69:c5:56:52:ac:2c:cb:75:c4:

a5:0a:7c:7d:db:7c:22:da:e6:c8:5c:ca:53:82:09:

fd:bb:f1:04:c9

ASN1 OID: prime256v1

NIST CURVE: P-256

X509v3 extensions:

X509v3 Subject Key Identifier:

24:95:E8:16:EF:6F:FC:AA:F3:56:CE:4A:DF:FE:33:CF:49:2A:BB:A8

X509v3 Authority Key Identifier:

keyid:

24:95:E8:16:EF:6F:FC:AA:F3:56:CE:4A:DF:FE:33:CF:49:2A:BB:A8

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

30:45:02:21:00:da:e3:7c:96:f1:54:c3:2e:c0:b4:af:52:d4:

6f:3b:7e:cc:96:87:dd:f2:67:bc:ec:36:8f:7b:7f:13:53:27:

2f:02:20:47:a2:8a:e5:c7:30:61:63:b3:c3:83:4b:ab:3c:10:

3f:74:30:70:59:4c:08:9a:aa:0a:c8:70:cd:13:b9:02:ca

[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 contained a ChallengePassword which is used for POP linking ([Section 4](#)).

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: 0=skg example

Subject Public Key Info:

Public Key Algorithm: id-ecPublicKey

Public-Key: (256 bit)

pub:

04:1b:b8:c1:11:78:96:f9:8e:45:06:c0:3d:70:ef:

be:82:0d:8e:38:ea:97:e9:d6:5d:52:c8:46:0c:58:

52:c5:1d:d8:9a:61:37:0a:28:43:76:0f:c8:59:79:

9d:78:cd:33:f3:c1:84:6e:30:4f:17:17:f8:12:3f:

1a:28:4c:c9:9f

ASN1 OID: prime256v1

NIST CURVE: P-256

Attributes:

a0:00

Signature Algorithm: ecdsa-with-SHA256

30:44:02:20:38:7c:d4:e9:cf:62:8d:4a:f7:7f:92:eb:ed:48:

90:d9:d1:41:dc:a8:6c:d2:75:7d:d1:4c:bd:59:cd:f6:96:18:

02:20:2f:24:5e:82:8c:77:75:43:78:b6:66:60:a4:97:7f:11:

3c:ac:da:a0:cc:7b:ad:7d:14:74:a7:fd:15:5d:09:0d

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

Private-Key: (256 bit)

priv:

0b:9a:67:78:5b:65:e0:73:60:b6:d2:8c:fc:1d:3f:

39:25:c0:75:57:99:de:ec:a7:45:37:2b:01:69:7b:

d8:a6

pub:

04:1b:b8:c1:11:78:96:f9:8e:45:06:c0:3d:70:ef:

be:82:0d:8e:38:ea:97:e9:d6:5d:52:c8:46:0c:58:

52:c5:1d:d8:9a:61:37:0a:28:43:76:0f:c8:59:79:

9d:78:cd:33:f3:c1:84:6e:30:4f:17:17:f8:12:3f:

1a:28:4c:c9:9f

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: 1327972925857878603 (0x126de8571518524b)

Signature Algorithm: ecdsa-with-SHA256

Issuer: O=skg example

Validity

Not Before: Jan 9 08:57:08 2019 GMT

Not After : Jan 4 08:57:08 2039 GMT

Subject: O=skg example

Subject Public Key Info:

Public Key Algorithm: id-ecPublicKey

Public-Key: (256 bit)

pub:

```
04:1b:b8:c1:11:78:96:f9:8e:45:06:c0:3d:70:ef:
be:82:0d:8e:38:ea:97:e9:d6:5d:52:c8:46:0c:58:
52:c5:1d:d8:9a:61:37:0a:28:43:76:0f:c8:59:79:
9d:78:cd:33:f3:c1:84:6e:30:4f:17:17:f8:12:3f:
1a:28:4c:c9:9f
```

ASN1 OID: prime256v1

NIST CURVE: P-256

X509v3 extensions:

X509v3 Basic Constraints:

CA:FALSE

Netscape Comment:

OpenSSL Generated Certificate

X509v3 Subject Key Identifier:

49:4B:E5:98:DC:8D:BC:0D:BC:07:1C:48:6B:77:74:60:E5:CC:E6:21

X509v3 Authority Key Identifier:

keyid:

49:4B:E5:98:DC:8D:BC:0D:BC:07:1C:48:6B:77:74:60:E5:CC:E6:21

Signature Algorithm: ecdsa-with-SHA256

```
30:46:02:21:00:a4:b1:67:d0:f9:ad:d9:20:28:10:e6:bf:6a:
29:0b:8c:fd:fc:9b:9c:9f:ea:2c:c1:c8:fc:3a:46:4f:79:f2:
c2:02:21:00:81:d3:1b:a1:42:75:1a:7b:4a:34:fd:1a:01:fc:
fb:08:71:6b:9e:b5:3b:da:ad:c9:ae:60:b0:8f:52:42:9c:0f
```

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