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EST over secure CoAP (EST-coaps)
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Abstract

Enrollment over Secure Transport (EST) [RFC7030] is used as a certificate management protocol over HTTPS.

Low-resource devices often use the lightweight Constrained Application Protocol (CoAP) [RFC7252] for message exchanges. This document defines how to transport EST payloads over secure CoAP (EST-coaps). This allows low-resource constrained devices to re-use existing EST functionality. Example low-resource use cases for EST are: secure bootstrapping and certificate enrollment.

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1. Introduction

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). This functionality is also needed for low resource devices.

"Classical" EST uses HTTPS and this specification defines a new transport for EST using CoAP. It also profiles the use of EST to a smaller subset.

IPv6 over Low-power Wireless Personal Area Networks (6LoWPANs) [RFC4944] on IEEE 802.15.4 [ieee802.15.4] wireless networks are becoming common in many industry application domains such as lighting controls. Although IEEE 802.15.4 defines how security can be enabled between nodes within a single mesh network, it does not specify the provisioning and management of the keys. Therefore, securing a 6LoWPAN network with devices from multiple manufacturers with different provisioning techniques is often tedious and time consuming. An example use case is the application of Bootstrapping of Remote Secure Infrastructures (BRSKI) [I-D.ietf-anima-bootstrapping-keyinfra]. The low resource aspects are detailed for 6tisch in [I-D.ietf-6tisch-minimal-security] and [I-D.ietf-6tisch-dtsecurity-secure-join].

Constrained networks use DTLS [RFC6347], CoAP [RFC7252], and UDP instead of TLS [RFC5246], HTTP [RFC7230] and TCP. EST-coaps replaces the invocations of TLS and HTTP by DTLS and CoAP invocations thus enabling EST for CoAP-based low-resource devices.

Because the relatively large EST messages cannot be readily transported over constrained (6LoWPAN, LLN) wireless networks, this document specifies the use of CoAP Block-Wise Transfer ("Block") [RFC7959] to fragment EST messages at the application layer.

1.1. EST operational differences

Only the differences to EST with respect to operational scenarios are described in this section. EST-coaps server differs from EST server as follows:

o Replacement of TLS by DTLS and HTTP by CoAP, resulting in:

  * DTLS-secured CoAP sessions between EST-coaps client and EST-coaps server.

- Only certificate-based client authentication is supported, which results in:

  * The EST-coaps client does not support HTTP Basic authentication (as described in Section 3.2.3 of [RFC7030]).

  * The EST-coaps client does not support authentication at the application layer (as described in Section 3.2.3 of [RFC7030]).

1.2. 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].

Many of the concepts in this document are taken over from [RFC7030]. Consequently, much text is directly traceable to [RFC7030]. The same document structure is followed to point out the differences and commonalities between EST and EST-coaps.

2. Conformance to RFC7925 profiles

This section shows how EST-coaps fits into the profiles of low-resource devices as described in [RFC7925].

EST-coaps can transport certificates and private keys. Private keys can be transported as response to a request to a server-side key generation as described in section 4.4 of [RFC7030].

The mandatory cipher suite for DTLS is TLS_ECDHE_ECDSA_WITH_AES_128_CCM_8 defined in [RFC7251] which is the mandatory-to-implement cipher suite in CoAP. Additionally, the curve secp256r1 MUST be supported [RFC4492]; this curve is equivalent to the NIST P-256 curve. The hash algorithm is SHA-256. DTLS implementations MUST use the Supported Elliptic Curves and Supported Point Formats Extensions [RFC4492]; the uncompressed point format MUST be supported; [RFC6090] can be used as an implementation method.

The EST-coaps client MUST be configured with an explicit TA database or at least an implicit TA database from its manufacturer. The authentication of the EST-coaps server by the EST-coaps client is based on Certificate authentication in the DTLS handshake.

The authentication of the EST-coaps client is based on client certificate in the DTLS handshake. This can either be

- DTLS with 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;

- DTLS with a previously installed certificate (e.g., manufacturer-installed certificate or a certificate issued by some other party);

3. Protocol Design and Layering

EST-coaps uses CoAP to transfer EST messages, aided by Block-Wise Transfer [RFC7959] to transport CoAP messages in blocks thus avoiding (excessive) 6LoWPAN fragmentation of UDP datagrams. The use of "Block" for the transfer of larger EST messages is specified in Section 3.4. The Figure 1 below shows the layered EST-coaps architecture.

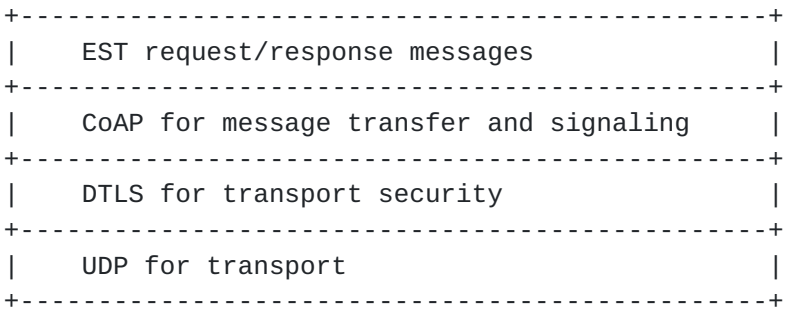


Figure 1: EST-coaps protocol layers

The EST-coaps protocol design follows closely the EST design. The parts supported by EST-coaps are identified by their message types:

- Simple enroll and reenroll, for CA to sign public client-identity key.

- CA certificate retrieval, needed to receive the complete set of CA certificates.

- CSR Attributes request messages, informs the client of the fields to include in generated CSR.

- Server-side key generation messages, to provide a private client-identity key when the client is too restricted or because of lack of an entropy source. [EDNOTE: Encrypting these keys is important. RFC7030 specifies how the private key can be encrypted with CMS using symmetric or asymmetric keys. Mention how symmetric key can be derived for EST server side key generation from the TLS KEM draft.]

3.1. Payload format

The content-format (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 (see section 3.2.2 of [RFC7030]) are in EST-coaps specified by the Content-Format Option (12) of CoAP. The combination of URI path-suffix and content-format used for CoAP MUST map to an allowed combination of path-suffix and media type as defined for EST. The required content-formats for these request and response messages are defined in Section 8. The CoAP response codes are defined in Section 3.3.

EST-coaps is designed for use between low-resource devices using CoAP and hence does not need to send base64-encoded data. Simple binary is more efficient (30% less payload compared to base64) and well supported by CoAP. Therefore, the content formats specification in Section 8 requires the use of binary for all EST-coaps Content-Formats.

3.2. Message Bindings

This section describes the general EST CoAP message characteristics.

It is RECOMMENDED to use CoAP CON messages. This recommendation does not influence the communication efficiency because all EST-coaps messages expect a response.

The Ver, TKL, Token, and Message ID values of the CoAP header are not influenced by EST.

CoAP options are used to convey Uri-Host, Uri-Path, Uri-Port, Content-Format and more in CoAP. The CoAP Options are used to communicate the HTTP fields specified in the EST REST messages.

EST URLs are HTTPS based (https://), in CoAP these will be assumed to be transformed to coaps (coaps://)

Appendix A includes some practical examples of EST messages translated to CoAP.

3.3. CoAP response codes

Section 5.9 of [RFC7252] specifies 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 (POST) request, in EST-coaps the equivalent CoAP response code 2.05 (2.01) MUST be used. Response code HTTP 202 in EST is mapped to CoAP _.__. In [I-D.hartke-core-pending] it is specified how multiple concurrently

open requests may be handled. All other HTTP 2xx response codes are not used by EST. For the following HTTP 4xx error codes that may occur: 400, 401, 403, 404, 405, 406, 412, 413, 415; the equivalent CoAP response code for EST-coaps is 4.xx. For the HTTP 5xx error codes: 500, 501, 502, 503, 504 the equivalent CoAP response code is 5.xx.

3.4. Message fragmentation

DTLS defines fragmentation only for the handshake part 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 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. Even though ECC certificates are small in size, they can vary greatly based on signature algorithms, key sizes, and OID fields used. For 256-bit curves, common ECDSA cert sizes are 500-1000 bytes which could fluctuate further based on the algorithms, OIDs, SANs and cert fields. For 384-bit curves, ECDSA certs increase in size and can sometimes reach 1.5KB. Additionally, there are times when the EST cacerts response from the server can include multiple certs 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. From [RFC0791] follows that the absolute minimum value of the IP MTU for IPv4 is as low as 68 bytes, which would leave only 40 bytes minus security overhead for a UDP payload. Thus, even with ECC certs, EST-coaps messages can still exceed sizes in MTU of 1280 for IPv6 or 60-80 bytes for 6LoWPAN [RFC4919] as explained in section 2 of [RFC7959]. EST-coaps needs to be able to fragment EST messages into multiple DTLS datagrams. Fine-grained fragmentation of EST messages is essential.

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.

The BLOCK draft defines SZX in the Block1 and Block2 option fields. These are used to convey the size of the blocks in the requests or responses.

The CoAP client MAY specify the Block1 size and MAY also specify the Block2 size. The CoAP server MAY specify the Block2 size, but not the Block1 size. As explained in Section 1 of [RFC7959]), blockwise transfers SHOULD be used in Confirmable CoAP messages to avoid the exacerbation of lost blocks.

The Size1 response MAY be parsed by the client as a size indication of the Block2 resource in the server response or by the server as a request for a size estimate by the client. Similarly, Size2 option defined in BLOCK should be parsed by the server as an indication of the size of the resource carried in Block1 options and by the client as a maximum size expected in the 4.13 (Request Entity Too Large) response to a request.

Examples of fragmented messages are shown in Appendix C.

3.5. Deployment limits

Although EST-coaps paves the way for the utilization of EST for constrained devices on constrained networks, some devices will not have enough resources to handle the large 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 UDP/CoAP. It is up to the network designer to decide which devices execute the EST protocol and which not.

4. Discovery and URI

EST-coaps is targeted to low-resource networks with small packets. Saving header space is important and an additional EST-coaps URI is specified that is shorter than the EST URI.

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. It is up to the implementation to choose its root resource; throughout this document the example root resource /est is used. The example below shows the discovery of the presence and location of management data.

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

  RES: 2.05 Content
</est>; rt="ace.est"
```

The additional EST-coaps server URIs differ from the EST URI by replacing the scheme https by coaps and by specifying a shorter resource path names:

coaps://www.example.com/est/short-name

The CoAP short URI exists next to the URI defined in [RFC7030].

coaps://www.example.com/.well-known/est/est-name
OR
coaps://www.example.com/.well-known/est/ArbitraryLabel/est-name

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
/csrattrs	/att
/serverkeygen	/skg

Table 1

When discovering the root path for the EST resources, the server MAY return the full resource paths and the used content types. This is useful when multiple content types are specified for EST-coaps server. For example, the following more complete response is possible.

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

  RES: 2.05 Content
</est>; rt="ace.est"
</est/crts>; rt="ace.est";ct=TBD1
</est/sen>; rt="ace.est";ct=TBD1 TBD4
</est/sren>; rt="ace.est";ct=TBD1 TBD4
</est/att>; rt="ace.est";ct=TBD4
</est/skg>; rt="ace.est";ct=TBD1 TBD4 TBD2
```

The return of the content-types allows the client to choose the most appropriate one from multiple content types.

5. DTLS Transport Protocol

EST-coaps depends on a secure transport mechanism over UDP that can secure (confidentiality, authenticity) the CoAP messages exchanged.

DTLS is one such secure protocol. When "TLS" is referred to in the context of EST, it is understood that in EST-coaps, security is provided using DTLS instead. No other changes are necessary (all provisional modes etc. are the same as for TLS).

CoAP was designed to avoid 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 a number of records, each of which can be transmitted separately, thus avoiding IP fragmentation" [RFC6347].

CoAP and DTLS can provide proof of identity for EST-coaps clients and server with simple PKI messages conformant to section 3.1 of [RFC5272]. EST-coaps supports the certificate types and Trust Anchors (TA) that are specified for EST in section 3 of [RFC7030].

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 translates to the contents of the first "Finished" message in the TLS handshake between server and client [RFC5929]. The client is then supposed to add this "Finished" message as a ChallengePassword in the attributes section of the PKCS#10 Request Info to prove that the client is indeed in control of the private key at the time of the TLS session when performing a /simpleenroll, for example. In the case of EST-coaps, the same operations can be performed during the DTLS handshake. In the event of handshake message fragmentation, the Hash of the handshake messages used in the MAC calculation of the Finished message

```
PRF(master_secret, finished_label, Hash(handshake_messages))
   [0..verify_data_length-1];
```

MUST be computed as if each handshake message had been sent as a single fragment [RFC6347].

In a constrained CoAP environment, endpoints can't 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. The DTLS connection

SHOULD remain open for persistent EST connections. For example, an EST cacerts request that is followed by a simpleenroll request can use the same authenticated DTLS connection. 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.

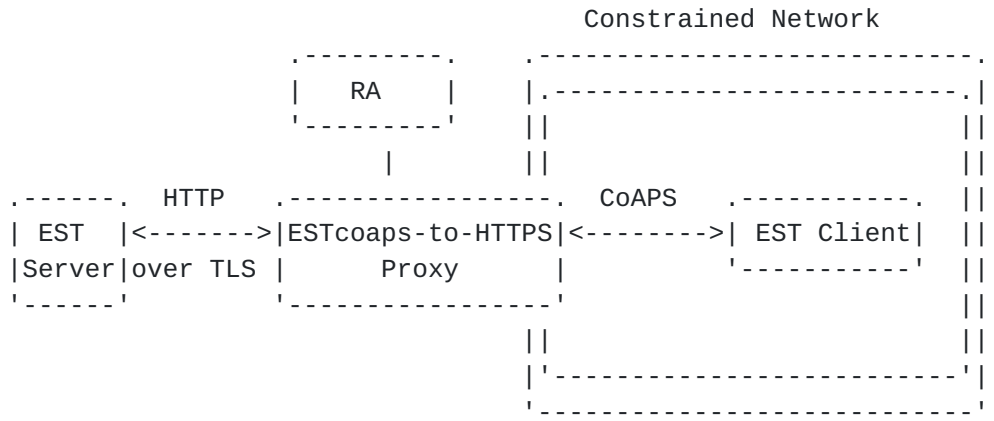
Support for Observe CoAP options [RFC7641] is out-of-scope for this document. Observe options could be used by the server to notify clients about a change in the cacerts or csr attributes (resources) and might be an area of future work.

6. Proxying

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 a non-constrained network that supports TLS/ HTTP. 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 proxy entity at the edge is required to operate between the CoAP environment and the external HTTP network. The ESTcoaps-to-HTTPS proxy SHOULD terminate EST-coaps downstream and initiate EST connections over TLS upstream.

One possible use-case, shown in one figure below, is expected to be deployed in practice:

o A proxy between any EST-client and EST-server



ESTcoaps-to-HTTPS proxy at the CoAP boundary.

Table 1 contains the URI mapping between the EST-coaps and EST the proxy SHOULD adhere to. Section 7 of [RFC8075] and Section 3.3 define the mapping between EST-coaps and HTTP response codes, that

determines how a proxy translates CoAP response codes from/to HTTP status codes. The mapping from Content-Type to media type is defined in Section 8. The conversion from binary to BSD64 needs to be done in the proxy. Conversion is possible because a TLS link exists between EST-coaps-to-HTTP proxy and EST server and a corresponding DTLS linked exists between EST-coaps-to-HTTP proxy and EST client.

Due to fragmentation of large messages into blocks, an EST-coaps-to-HTTP proxy SHOULD reassemble the BLOCKs before translating the binary content to BSD64, and consecutively relay the message upstream into the HTTP environment.

For the discovery of the EST server by the EST client in the coap environment, the EST-coaps-to-HTTP proxy MUST announce itself according to the rules of Section 4. The available functions of the proxies MUST be announced with as many resource paths. The discovery of EST server in the http environment follow the rules specified in [RFC7030].

[EDNOTE: PoP will be addressed here.]

A proxy SHOULD authenticate the client downstream and it should be authenticated by the EST server or CA upstream. The Registration Authority (RA) is necessary to (re-)create the secure connection from DTLS to TLS and vice versa. A trust relationship needs to be pre-established between the proxy and the EST servers to be able to proxy these connections on behalf of various clients.

[EDNOTE: To add more details about trust relations in this section.]

7. Parameters

[EDNOTE: This section to be populated. It will address transmission parameters described in sections 4.7 and 4.8 of the CoAP draft. EST does not impose any unique parameters that affect the CoAP parameters in Table 2 and 3 in the CoAP draft but the ones in CoAP could be affecting EST. For example, the processing delay of CAs could be less then 2s, but in this case they should send a CoAP ACK every 2s while processing.]

8. IANA Considerations

8.1. Content-Format registry

Additions to the sub-registry "CoAP Content-Formats", within the "CoRE Parameters" registry are needed for the below media types. These can be registered either in the Expert Review range (0-255) or IETF Review range (256-9999).

1.

   * application/pkcs7-mime
   * Type name: application
   * Subtype name: pkcs7-mime
   * ID: TBD1
   * Required parameters: None
   * Optional parameters: None
   * Encoding considerations: binary
   * Security considerations: As defined in this specification
   * Published specification: [RFC5751]
   * Applications that use this media type: EST

2.

   * application/pkcs8
   * Type name: application
   * Subtype name: pkcs8
   * ID: TBD2
   * Required parameters: None
   * Optional parameters: None
   * Encoding considerations: binary
   * Security considerations: As defined in this specification
   * Published specification: [RFC5958]
   * Applications that use this media type: EST

3.

   * application/csrattrs

* Type name: application

* Subtype name: csrattrs

* ID: TBD3

* Required parameters: None

* Optional parameters: None

* Encoding considerations: binary

* Security considerations: As defined in this specification

* Published specification: [RFC7030]

* Applications that use this media type: EST

4.

* application/pkcs10

* Type name: application

* Subtype name: pkcs10

* ID: TBD4

* Required parameters: None

* Optional parameters: None

* Encoding considerations: binary

* Security considerations: As defined in this specification

* Published specification: [RFC5967]

* Applications that use this media type: EST

8.2. Resource Type registry

Additions to the sub-registry "CoAP Resource Type", within the "CoRE Parameters" registry are needed for a new resource type.

o rt="ace.est" needs registration with IANA.

9. Security Considerations

9.1. proxy considerations

The proxy proposed in Section 6 must be deployed with great care, and only when the recommended connections are impossible.

[EDNOTE: To add more details about trust relations through proxies in this section.]

9.2. 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 to encrypt its certificate. The transport of these keys is inherently risky. A full probability analysis MUST be done to establish whether server side key generation enhances or decreases the probability of identity stealing.

When a client uses the Implicit TA database for certificate validation, the client cannot verify that the implicit data base can act as an RA. It is RECOMMENDED that such clients include "Linking Identity and POP Information" Section 5 in requests (to prevent such requests from being forwarded to a real EST server by a man in the middle). It is RECOMMENDED that the Implicit Trust Anchor database used for EST server authentication be carefully managed to reduce the chance of a third-party CA with poor certification practices from being trusted. Disabling the Implicit Trust Anchor database after successfully receiving the Distribution of CA certificates response (Section 4.1.3 of [RFC7030]) limits any vulnerability to the first DTLS exchange.

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 certification request links the proof-of-possession to

the TLS proof-of-identity. This implies but does not prove that the authenticated client currently has access to the private key.

Regarding the CSR attributes that the CA may list for inclusion in an enrollment request, an adversary could exclude attributes that a server may want, include attributes that a server may not want, and render meaningless other attributes that a server may want. The 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. Acknowledgements

The authors are very grateful to Klaus Hartke for his detailed explanations on the use of Block with DTLS. The authors would like to thank Esko Dijk and Michael Verschoor for the valuable discussions that helped in shaping the solution. They would also like to thank Peter Panburana from Cisco for his feedback on technical details of the solution. Constructive comments were received from Eliot Lear, Jim Schaad, Hannes Tschofenig, and Julien Vermillard.

11. Change Log

-00:

copied from vanderstok-ace-coap-est-04

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Appendix A. EST messages to EST-coaps

This section takes all examples from Appendix A of [RFC7030], changes the payload from Base64 to binary and replaces the http headers by their CoAP equivalents.

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

[EDNOTE: The payloads of the examples need to be re-generated with appropriate tools and example certificates.]

A.1. cacerts

In EST-coaps, a coaps cacerts IPv4 message can be:

GET coaps://[192.0.2.1:8085]/est/crts

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

```
  Ver = 1
  T = 0 (CON)
  Code = 0x01 (0.01 is GET)
  Options
   Option1 (Uri-Host)
     Option Delta = 0x3  (option nr = 3)
     Option Length = 0x9
     Option Value = 192.0.2.1
   Option2 (Uri-Port)
     Option Delta = 0x4  (option nr = 4+3=7)
     Option Length = 0x4
     Option Value = 8085
   Option3 (Uri-Path)
     Option Delta = 0x4   (option nr = 7+4= 11)
     Option Length = 0x9
     Option Value = /est/crts
  Payload = [Empty]
```

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

2.05 Content (Content-Format: application/pkcs7-mime)
{payload}

with CoAP fields

```
  Ver = 1
  T = 2 (ACK)
  Code = 0x45 (2.05 Content)
  Options
    Option1 (Content-Format)
      Option Delta = 0xC  (option nr = 12)
      Option Length = 0x2
      Option Value = TBD1 (defined in this document)

  Payload =
30233906092a6206734107028c2a3023260201013100300b06092a6206734107018
c0c3020bb302063c20102020900a61e75193b7acc0d06092a620673410105050030
1b3119301706035504031310657374578616d706c654341204f774f301e170d313
330353039303353333315a170d3134303530393033353333315a301b3119301706
```

```
03550403131065737445786l6d706c654341204f774f302062300d06092a6206734
10101050003204f0030204a022041003a923a2968bae4aae136ca4e2512c5200680
358482ac39d6f640e4574e654ea35f48b1e054c5da3372872f7a1e429f4edf39584
32efb2106591d3eb783c1034709f251fc86566bda2d541c792389eac4ec9e181f4b
9f596e5ef2679cc321542b11337f90a44df3c85f1516561fa968a1914f265bc0b82
76ebe3106a790d97d34c8c37c74fe1c30b396424664ac426284a9f6022e02693843
6880adfcd95c98ca1dfc2e6d75319b85d0458de28a9d13fb16d620fff7541f6a25d
7daf00435502030100013 0b040300f0603551d130101f10530030101fc1d0603551
d0e04160414084d321ca0135e77217a486b686b334b00e0603551d0f0101f104030
20106300d06092a6206734101050500032041002 3703b965746a0c2c978666d787a
94f89b495a11f0d369b28936ec2475c0f0855c8e83f823f2b871a1d92282f323c45
904ba008579216cf5223b8b1bc425a0677262047f7700240631c17f3035d1c3780b
2385241cba1f4a6e98e6be6820306b3a786de5a557795d1893822347b5f825d34a7
ad2876f8feba4d525b31066f6505796f71530003431a3e6bbfe788b4565029a7e20
a51107677552586152d051e8eebf383e92288983421d5c5652a4870c3af74b9bdbe
d6b462e2263d30f6d3020c330206bc20102020101300d06092a6206734101050500
301b311930170603550403131065737445786l6d706c654341204f774f301e170d3
133303530393033353333325a170d313430353039303353333325a301b31193017
060355040313106573744578616d706c654341204e774f302062300d06092a62067
34101010500032041f0030204a02204100ef6b677a3247c1fc03d2b9baf113e5e7e1
1f49e0421120e6b8384160f2bf02630ef544d5fd0d5623b35713c79a7229283a790
8751a634aa420a3e2a4b1f10519d046f02f5a5dd6d760c2a842356e067b7bd94338
d1faa3b3ddd4813060a207b0a097067007e45b052b60fdbae4656e11562c4f5abb7
b0cf87a79d221f1127313c53371ce1245d63db45a1203a23340ba08042c768d03b8
076a028d3a51d87d2ef107bbd6f2305ce5e67668724002fb726df9c14476c37de0f
55033f192a5ad21f9a2a71c20301000134b050300e0603551d0f0101f104030204c
1d0603551d0e04160414112966e304761732fbfe6a2c823c301f0603551d2304183
0165084d321ca0135e77217a486b686b334b00d06092a62067341010505000320 41
00b382ba3355a50e287bae15758b3beff63d34d3e357b90031495d018868e49589b
9faf46a4ad49b1d35b06ef380106677440934663c2cc111c183655f4dc41c0b3401
123d35387389db91f1e1b4131b16c291d35730b3f9b33c7475124851555fe5fc647
e8fd029605367c7e01281bf6617110021b0d10847dce0e9f0ca6c764b6334784055
172c3983d1e3a3a82301a54fcc9b0670c543a1c747164619101ff23b240b2a26394
c1f7d38d0e2f4747928ece5c34627a075a8b3122011e9d9158055c28f020c330206
bc20102020102300d06092a62067341010505003 01b311930170603550403131065
73744578616d706c654341204e774e301e170d313330353039033353333325a170
d313430353039033353333325a301b311930170603550403131065737445786d
706c654341204f774e302062300d06092a62067341010105000 3204f0030204a022
041003a923a2968bae4aae136ca4e2512c5200680358482ac39d6f640e4574e654e
a35f48b1e054c5da3372872f7a1e429f4edf3958432efb2106591d3eb783c103470
9f251fc86566bda2d541c792389eac4ec9e181f4b9f596e5ef2679cc321542b1133
7f90a44df3c85f1516561fa968a1914f265bc0b8276ebe3106a790d97d34c8c37c7
4fe1c30b396424664ac426284a9f6022e026938436880adfcd95c98ca1dfc2e6d75
319b85d0458de28a9d13fb16d620fff7541f6a25d7daf00435502030100013 4b050
300e0603551d0f0101f104030204c1d0603551d0e04160414084d321ca0135e7721
7a486b686b334b01f0603551d230418301653112966e304761732fbfe6a2c823c30
0d06092a62067341010505000320 41002e106933a443070acf5594a3a584d08af7e
06c295059370a06639eff9bd418d13bc25a298223164a6cf1856b11a81617282e4a
```

```
410d82ef086839c6e23569032276306545535 1e4c596acc7c016b225dec094706c2
a10608f403b10821984c7c152343b18a768c2ad30238dc45dd653ee6092b0d5cd4c
2f7d236043269357f76d13f95fb5f00d0e19263c6833948e1ba612ce8197af650e2
5d882c12f4b6b9b67252c608ef064aca3f9bc867d71172349d510bb7651cd438837
73d927deb41c4673020bb302063c201020209009b9dda3324700d06092a62067341
01050500301b311930170603550403131065737445786 16d706c654341204e774e3
01e170d313330353039303353333325a170d313430353039303353333325a301b
311930170603550403131065737445786 16d706c654341204e774e302062300d060
92a62067341010105000 3204f0030204a02204100ef6b677a3247c1fc03d2b9baf1
13e5e7e11f49e0421120e6b8384160f2bf02630ef544d5fd0d5623b35713c79a722
9283a7908751a634aa420a3e2a4b1f10519d046f02f5a5dd6d760c2a842356e067b
7bd94338d1faa3b3ddd4813060a207b0a097067007e45b052b60fdbae4656e11562
c4f5abb7b0cf87a79d221f1127313c53371ce1245d63db45a1203a23340ba08042c
768d03b8076a028d3a51d87d2ef107bbd6f2305ce5e67668724002fb726df9c1447
6c37de0f55033f192a5ad21f9a2a71c20301000130b040300f0603551d130101f10
530030101fc1d0603551d0e04160414112966e304761732fbfe6a2c823c300e0603
551d0f0101f10403020106300d06092a62067341010505000 3204100423f06d4b76
0f4b42744a279035571696f272a0060f1325a40898509601ad14004f652db6312a1
475c4d7cd50f4b269035585d7856c5337765a66b38462d5bdaa7778aab24bbe2815
e37722cd10e7166c50e75ab75a1271324460211991e7445a2960f47351a1a629253
34119794b90e320bc730d6c1bee496e7ac125ce9a1eca595a3a4c54a865e6b623c9
247bfd0a7c19b56077392555c955e233642bec643ae37c166c5e221d797aea3748f
0391c8d692a5cf9bb71f6d0e37984d6fa673a30d0c006343116f58403100
```

A.2. csrattrs

In the following valid /csrattrs exchange, the EST-coaps client authenticates itself with a certificate issued by the connected CA.

The initial DTLS handshake is identical to the enrollment example. The IPv6 CoAP GET request looks like:

```
REQ:
GET coaps://[2001:db8::2:1]:61616/est/att
```

A 2.05 Content response contains attributes which are relevant for the authenticated client. In this example, the EST-coaps server two attributes that the client can ignore when they are unknown to him.:

A.3. enroll / reenroll

[EDNOTE: We might need a new Option for the Retry-After response message. We might need a new Option for the WWW-Authenticate response.]

During the Enroll/Reenroll exchange, the EST-coaps client uses a CSR (PKCS#10) request in the POST request payload.

After verification of the certificate by the server, a 2.05 Content response with the issued certificate will be returned.

POST [2001:db8::2:1]:61616/est/sen
(Content-Format: application/pkcs10)
30208530206d020100301f311d301b06035504031314646 56d6f7374657034203
133363831343133353230206230 0d06092a620673410101050003204f0030204a
022041005d9f4dffd3c5949f646a9584367778560950b355c35b8e34726dd3764
54231734795b4c09b9c6d75d408311307a81f7adef7f5d241f7d5be85620c5d44
38bbb4242cf215c167f2ccf36c364ea2618a62f0536576369d6304e6a96877224
7d86824f079faac7a6f694cfda5b84c42087dc062d462190c525813f210a036a7
37b4f30d8891f4b75559fb72752453146332d51c937557716ccec624f5125c3a4
447ad3115020048113fef54ad554ee88af09a2583aac9024075113db4990b1786
b871691e0f02030100018701f06092a6206734109073112131 02b72724369722f
372b455975353054343 00d06092a62067341010505000320 4100441b40177a3a6
5501487735a8ad5d3827a4eaa867013920e2afcda87aa81733c7c0353be47e1bf
a7cda5176e7ccc6be22ae03498588d5f2de3b143f2b1a6175ec544e8e7625af6b
836fd4416894c2e55ea99c6606f69075d6d53475d410729aa6d806afbb9986caf
7b844b5b3e4545f19071865ada007060cad6db26a592d4a7bda7d586b68110962
17071103407553155cddc75481e272b5ed553a8593fb7e25100a6f7605085dab4
fc7e0731f0e7fe305703791362d5157e92e6b5c2e3edbcadb40

RET:
2.05 Content (Content-Format: application/pkcs7-mime)
3020f806092a62067341070283293020e50201013100300b06092a62067341070
1830b3020c730206fc20102020115300d06092a6206734101050050030 1b311930
17060355040313106573744578616d706c654341204e774e301e170d313330353
0393233313535335a170d3134303530393233313535335a301f311d301b060355
0403131464656d6f737465703420313336383134313335323020623 00d06092a6
2067341010105000320 4f0030204a022041005d9f4dffd3c5949f646a95843677
78560950b355c35b8e34726dd376454231734795b4c09b9c6d75d408311307a81
f7adef7f5d241f7d5be85620c5d4438bbb4242cf215c167f2ccf36c364ea2618a
62f0536576369d6304e6a968772247d86824f079faac7a6f694cfda5b84c42087
dc062d462190c525813f210a036a737b4f30d8891f4b75559fb72752453146332
d51c937557716ccec624f5125c3a4447ad3115020048113fef54ad554ee88af09
a2583aac9024075113db4990b1786b871691e0f020301000134b050300e060355
1d0f0101f104030204c1d0603551d0e04160414e81d0788aa2710304c5ecd4d1e
065701f0603551d230418301653112966e304761732fbfe6a2c823c300d06092a
62067341010505000320 41002910d86f2ffeeb914c046816871de601567d291b4
3fabee0f0e8ff81cea27302a7133e20e9d04029866a8963c7d14e26fbe8a0ab1b
77fbb1214bbcdc906fbc381137ec1de685f79406c3e416b8d82f97174bc691637
5a4e1c4bf744c7572b4b2c6bade9fb35da786392ee0d95e3970542565f3886ad6
7746d1b12484bb02616e63302dc371dc6006e431fb7c457598dd204b367b0b3d3
258760a303f1102db26327f929b7c5a60173e1799491b69150248756026b80553
171e4733ad3d13c0103100

[EDNOTE: If POP is used, make sure tls-unique in the CSR is a valid HMAC output.]

A.4. serverkeygen

During this valid /serverkeygen exchange, the EST-coaps client authenticates itself using the certificate provided by the connected CA.

[EDNOTE: the client incudes a CSR with a public key that the server should ignore, so we need a content-format here.]

[EDNote: If POP is used, make sure tls-unique in the CSR is a valid HMAC output.]

The initial DTLS handshake is identical to the enrollment example. The CoAP GET request looks like:

```
POST coaps://[192.0.2.1:8085]/est/skg
302081302069020100305b313e303c06035504031335736572766572 4b657947656e207265712062792063 6c69656e7420696e2064656d6f207374657020313220313336383134313935353119301706035504051310504944 3a576964676574205 34e3a3130302062300d06092a620673410101050003204f0030204a02204100f4 dfa6c03f7f2766b23776c333d2c0f9d1a7a6ee36d01499bbe6f075d1e38a57e98 ecc197f51b75228454b7f19652332de5e52e4a974c6ae34e1df80b33f15f47d3b cbf76116bb0e4d3e04a9651218a476a13fc186c2a255e4065ff7c271cff104e47 31fad53c22b21a1e5138bf9ad0187314ac39445949a48805392390e78c7659621 6d3e61327a534f5ea7721d2b1343c7362b37da502717cfc2475653c7a3860c5f4 0612a5db6d33794d755264b6327e3a3263b149628585b85e57e42f6b3277591b0 2030100018701f06092a620673410907311213106446734158 6d4a6e6a6f6b427 4447672300d06092a6206734101050500032041004 72d11007e5a2b2c2023d47a 6d71d046c307701d8ebc9e47272713378390b4ee321462a3dbe54579f5a514f6f 4050af497f428189b63655d03a194ef729f101743e5d03fbc6ae1e84486d1300a f9288724381909188c851fa9a5059802eb64449f2a3c9e441353d136768da27ff 4f277651d676a6a7e51931b08f56135a2230891fd184960e1313e7a1a9139ed19 28196867079a456cd2266cb754a45151b7b1b939e381be333fea61580fe5d25bf 4823dbd2d6a98445b46305c10637e202856611

RET:
2.05 Content (Content-Format: application/pkcs8)
30213e020100300d06092a620673410101050004212830212402010002204100 3c0bc2748f2003e3e8ea15f746f2a71e83f585412b92cf6f8e64de02e056153274 dd01c95dd9cff3112aa141774ab655c3d56359c3b3df055294692ed848e7e30a1 1bf14e47e0693d93017022b4cdb3e6d40325356152b213c8b535851e681a7074c 0c6d2b60e7c32fc0336b28e743eba4e5921074d47195d3c05e43c527526e692d5 45e562578d2d4b5f2191bff89d3eef0222764a2674637a1f99257216647df6704 efec5adbf54dab24231844eb595875795000e673dd6862310a146ad7e31083010 001022041004e6b3f78b7791d6377f33117c17844531c81111fb8000282816264 915565bc7c3f3f643b537a2c69140a31c22550fa97e5132c61b74166b68626704 260620333050f510096b6570f5880e7e1c15dc0ca6ce2b5f187e2325da14ab705 ad004717f3b2f779127b5c535e0cee6a343b502722f2397a26126e0af606b5aa7
```

```
f96313511c0b7eb26354f91b82269de62757e3def807a6afdf83ddcbb0614bb7c
542e6975d6456554e7bd9988fbd1930cd44d0e01ee9182ca54539418653150254
1ad1a2a11e5021040bfce554b642c29131e7d65455e83c5406d76771912f758f5
ee3ee36af386f38ffa313c0f661880c5a2b0970485d36f528e7f77a2e55b4ad76
1242d1c2f75939c8061217d31491d305d3e07d6161c43e26f7de4477b1811de92
33dc75b426302104015bf48ac376f52887813461fc54635517bcb67293837053e
8ce1a33da7a35565a75a370dc14555b5316cb55742380350774d769d151ff0456
0214389a232a2258326163167504cfce44cd316f63bb8a52da53a4cb74fd87194
c0844881f791f23b0813ea0921325edd14459d41c8a1593f04316388e40b35fef
7d2a195a5930fa54774427ac821eee2c62790d2c17bd192af794c611011506557
83d4efe22185cbd83368786f2b1e68a5a27067e321066f0217b4b6d7971a3c21a
241366b7907187583b511102103369047e5cce0b65012200df5ec697b5827575c
db6821ff299d6a69574b31ddf0fbe9245ea2f74396c24b3a7565067e41366423b
5bdd2b2a78194094dbe333f493d159b8e07722f2280d48388db7f1c9f0633bb0e
173de2c3aa1f200af535411c7090210401421e2ea217e37312dcc606f453a6634
f3df4dc31a9e910614406412e70eec9247f10672a500947a64356c015a845a7d1
50e2e3911a2b3b61070a73247166da10bb45474cc97d1ec2bc392524307f35118
f917438f607f18181684376e13a39e07
--estServerExampleBoundary
3020c506092a620673410702833630 20f20201013100300b06092a62067341070
183183020d430207cc20102020116300d06092a620673410105050030 1b311930
17060355040313106573744578616d706c654341204e774e301e170d313330353
0393233323535365a170d313430353039323332353536 5a302c312a3028060355
040313217365727665727369646520 6b65792067656e6572617465642072657 37
06f6e7365302062300d06092a620673410101050003204f0030204a022041003c
0bc2748f2003e3e8ea15f746f2a71e83f585412b92cf6f8e64de02e056153274d
d01c95dd9cff3112aa141774ab655c3d56359c3b3df055294692ed848e7e30a11
bf14e47e0693d93017022b4cdb3e6d40325356152b213c8b535851e681a7074c0
c6d2b60e7c32fc0336b28e743eba4e5921074d47195d3c05e43c527526e692d54
5e562578d2d4b5f2191bff89d3eef0222764a2674637a1f99257216647df6704e
fec5adbf54dab24231844eb595875795000e673dd6862310a146ad7e310830100
0134b050300e0603551d0f0101f104030204c1d0603551d0e04160414764b1bd5
e69935626e476b195a1a8c1f0603551d230418301653112966e304761732fbfe6
a2c823c300d06092a620673410105050003204100474e5100a9cdaaa813b30f48
40340fb17e7d6d6063064a5a7f2162301c464b5a8176623dfb1a4a484e618de1c
3c3c5927cf590f4541233ff3c251e772a9a3f2c5fc6e5ef2fe155e5e385deb846
b36eb4c3c7ef713f2d137ae8be4c022715fd033a818d55250f4e6077718180755
a4fa677130da60818175ca4ab2af1d15563624c51e13dfdcf381881b72327e2f4
9b7467e631a27b5b5c7d542bd2edaf78c0ac294f3972278996bdf673a334ff74c
84aa7d65726310252f6a4f41281ec10ca2243864e3c5743103100
```

Without the DecryptKeyIdentifier attribute, the response has no additional encryption beyond DTLS. [EDNOTE: Add comment about deriving symmetric keys by using the TLS KEM draft.]

The response contains first a preamble that can be ignored. The EST-coaps server can use the preamble to include additional explanations, like ownership or support information

Appendix B. Encoding for server side key generation

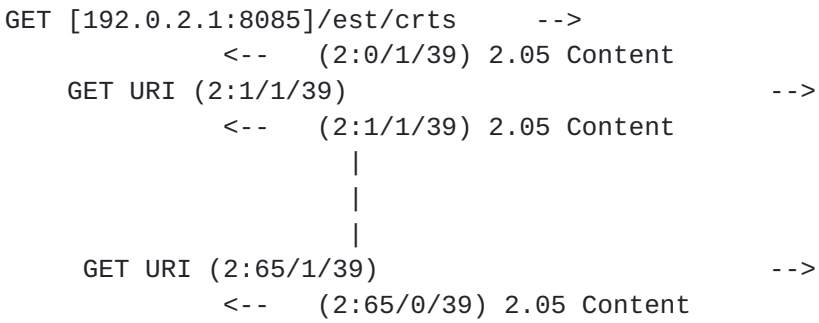
Sever side key generation for CoAP can be implemented efficiently using multipart encoding

[EDNOTE: text to be written.]

Appendix C. EST-coaps Block message examples

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 valid /cacerts exchange over DTLS. The content length of the cacerts response in appendix A.1 of [RFC7030] is 4246 bytes using base64. This leads to a length of 2509 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 39 packets with a payload of 64 bytes each, followed by a packet of 13 bytes. The client sends an IPv6 packet containing the UDP datagram with the DTLS record that encapsulates the CoAP Request 40 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 indicating the kind of Block option (2 in this case because used in the response) followed by a colon, and then the block number (NUM), the more bit (M = 0 means last block), and block size exponent (2**(SZX+4)) separated by slashes. The Length 64 is used with SZX= 2 to avoid IP fragmentation. The CoAP Request is sent with confirmable (CON) option and the content format of the Response is /application/ cacerts.



For further detailing the CoAP headers of the first two blocks are written out.

The header of the first GET looks like:

```
  Ver = 1
  T = 0 (CON)
  Code = 0x01 (0.1 GET)
  Options
   Option1 (Uri-Host)
     Option Delta = 0x3  (option nr = 3)
     Option Length = 0x9
     Option Value = 192.0.2.1
   Option2 (Uri-Port)
     Option Delta = 0x4   (option nr = 3+4=7)
     Option Length = 0x4
     Option Value = 8085
   Option3 (Uri-Path)
     Option Delta = 0x4    (option nr = 7+4=11)
     Option Length = 0x9
     Option Value = /est/crts
  Payload = [Empty]
```

The header of the first response looks like:

```
  Ver = 1
  T = 2 (ACK)
  Code = 0x45 (2.05 Content.)
  Options
    Option1 (Content-Format)
      Option Delta = 0xC  (option 12)
      Option Length = 0x2
      Option Value = TBD1
    Option2 (Block2)
      Option Delta = 0xB  (option 23 = 12 + 11)
      Option Length = 0x1
      Option Value = 0x0A (block number = 0, M=1, SZX=2)
  Payload =
30233906092a6206734107028c2a3023260201013100300b06092a6206734107018
c0c3020bb302063c20102020900a61e75193b7acc0d06092a6206734101
```

The second Block2:

```
     Ver = 1
     T = 2 (means ACK)
     Code = 0x45 (2.05 Content.)
     Options
       Option1 (Content-Format)
         Option Delta = 0xC   (option 12)
         Option Length = 0x2
         Option Value = TBD1
       Option2 (Block2)
         Option Delta = 0xB  (option 23 = 12 + 11)
         Option Length = 0x1
         Option Value = 0x1A (block number = 1, M=1, SZX=2)
     Payload =
   05050030
   1b311930170603550403131065737445786l6d706c654341204f774f301e170d313
   330353039303353333315a170d313430353039303353333315a
```

The 40th and final Block2:

```
     Ver = 1
     T = 2 (means ACK)
     Code = 0x21
     Options
       Option1 (Content-Format)
         Option Delta = 0xC   (option 12)
         Option Length = 0x2
         Option Value = TBD1
       Option2 (Block2)
         Option Delta = 0xB  (option 23 = 12 + 11)
         Option Length = 0x2
         Option Value = 0x272 (block number = 39, M=0, SZX=2)
     Payload = 73a30d0c006343116f58403100
```

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