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A Bootstrapping Procedure to Discover and Authenticate DNS-over-(D)TLS and DNS-over-HTTPS Servers
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Abstract

This document specifies mechanisms to automatically bootstrap endpoints (e.g., hosts, Customer Equipment) to discover and authenticate DNS-over-(D)TLS and DNS-over-HTTPS servers provided by a local network.

Status of This Memo

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

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1. Introduction

Traditionally a caching DNS server has been provided by local networks. This provides benefits such as low latency to reach that DNS server (owing to its network proximity to the endpoint). However, if an endpoint is configured to use Internet-hosted or public DNS-over-(D)TLS [RFC7858] [RFC8094] or DNS-over-HTTPS [RFC8484] servers, any available local DNS server cannot serve DNS requests from local endpoints. If public DNS servers are used instead of using local DNS servers, some operational problems can occur such as those listed below:

- "Split DNS" [RFC2775] to use the special internal-only domain names (e.g., "internal.example.com") in enterprise networks will

not work, and ".local" and "home.arpa" names cannot be locally resolved in home networks.

- Content Delivery Networks (CDNs) that map traffic based on DNS may lose the ability to direct end-user traffic to a nearby service-specific cluster in cases where a DNS service is being used that is not affiliated with the local network and which does not send "EDNS Client Subnet" (ECS) information [RFC7871] to the CDN's DNS authorities [CDN].

If public DNS servers are used instead of using local DNS servers, the following discusses the impact on network-based security:

- Various network security services are provided by Enterprise networks to protect endpoints (e.g,. Hosts, IoT devices). [I-D.camwinget-tls-use-cases] discusses some of the network-based security service use cases. These network security services act on DNS requests originating from endpoints.

- However, if an endpoint is configured to use public DNS-over-(D)TLS or DNS-over-HTTPS servers, network security services cannot act efficiently on DNS requests from these endpoints.

- In order to act on DNS requests from endpoints, network security services can block DNS-over-(D)TLS traffic by dropping outgoing packets to destination port 853. Identifying DNS-over-HTTPS traffic is far more challenging than DNS-over-(D)TLS traffic. Network security services may try to identify the domains offering DNS-over-HTTPS servers, and DNS-over-HTTPS traffic can be blocked by dropping outgoing packets to these domains. If an endpoint has enabled strict privacy profile (Section 5 of [RFC8310]), and the network security service blocks the traffic to the public DNS server, the DNS service won't be available to the endpoint and ultimately the endpoint cannot access Internet-reachable services.

- If an endpoint has enabled opportunistic privacy profile (Section 5 of [RFC8310]), and the network security service blocks traffic to the public DNS server, the endpoint will either fallback to an encrypted connection without authenticating the DNS server provided by the local network or fallback to clear text DNS, and cannot exchange encrypted DNS messages.

If the network security service fails to block DNS-over-(D)TLS or DNS-over-HTTPS traffic, this can compromise the endpoint security; some of the potential security threats are listed below:

- The network security service cannot prevent an endpoint from accessing malicious domains.

- If the endpoint is an IoT device which is configured to use public DNS-over-(D)TLS or DNS-over-HTTPS servers, and if a policy enforcement point in the local network is programmed using, for example, a Manufacturer Usage Description (MUD) file [RFC8520] by a MUD manager to only allow intented communications to and from the IoT device, the policy enforcement point cannot enforce the network Access Control List (ACL) rules based on domain names (Section 8 of [RFC8520]).

If the network security service sucessfully blocks DNS-over-(D)TLS and DNS-over-HTTPS traffic, this can still compromise the endpoint security and privacy; some of the potential security threats are listed below:

- Pervasive monitoring of DNS traffic.

- An internal attacker can modify the DNS responses to re-direct the client to malicious servers.

To overcome the above threats, this document specifies a mechanism to automatically bootstrap endpoints to discover and authenticate the DNS-over-(D)TLS and DNS-over-HTTPS servers provided by their local network. The overall procedure can be structured into the following steps:

- Bootstrapping (Section 4) is necessary only when connecting to a new network or when the network's DNS certificate has changed. Bootstrapping authenticates the Enrollment over Secure Transport (EST) [RFC7030] server to the endpoint. After authenticating the EST server, DNS server certificate used by the local network is downloaded to the endpoint. This DNS server certificate enables subsequent authenticated encrypted communication with the local DNS server (e.g., DNS-over-HTTPS) during in the connection phase.

- Discovery (Section 6) is performed by a previously bootstrapped endpoint whenever connecting to a network. During discovery, the endpoint is instructed which privacy-enabling DNS protocol(s), port number(s), and IP addresses are supported on a local network. This effectively takes the place of DNS server IP address traditionally provided by IPv4 or IPv6 DHCP or by IPv6 Router Advertisement [RFC8106].

- Connection handshake and service invocation (Section 7): The DNS client initiates a (D)TLS handshake with the DNS server learned in the discovery phase, and validates the DNS server's identity using the credentials obtained in the bootstrapping phase.

Note: The strict and opportunistic privacy profiles as defined in [RFC8310] only applies to DNS-over-(D)TLS protocols, there has been no such distinction made for DNS-over-HTTPS protocol.

2. Scope

The problems discussed in Section 1 will be encountered in Enterprise networks. Typically Enterprise networks do not assume that all devices in their network are managed by the IT team or Mobile Device Management (MDM) devices, especially in the quite common BYOD ("Bring Your Own Device") scenario. The mechanisms specified in this document can be used by BYOD devices to discover and authenticate DNS-over-(D)TLS and DNS-over-HTTPS servers provided by the Enterprise network. This mechanism can also be used by IoT devices (managed by IT team) after onboarding to discover and authenticate DNS-over-(D)TLS and DNS-over-HTTPS servers provided by the Enterprise network.

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.

(D)TLS is used for statements that apply to both Transport Layer Security [RFC8446] and Datagram Transport Layer Security [RFC6347]. Specific terms are used for any statement that applies to either protocol alone.

This document uses the terms defined in [RFC8499].

4. Bootstrapping Endpoint Devices

The following steps detail the mechanism to automatically bootstrap an endpoint with the local network's DNS server certificate:

1. The endpoint authenticates to the local network and discovers the Enrollment over Secure Transport (EST) [RFC7030] server using the procedure discussed in Section 8.

2. The endpoint establishes provisional TLS connection with that EST server, i.e., the endpoint provisionally accepts the unverified TLS server certificate. However, the endpoint MUST authenticate the EST server before it accepts the DNS server certificate. The endpoint either uses password-based authenticated key exchange (PAKE) with TLS 1.3 [I-D.barnes-tls-pake] as an authentication

method or uses the mutual authentication protocol for HTTP [RFC8120] to authenticate the discovered EST server.

As a reminder, PAKE is an authentication method that allows the use of usernames and passwords over unencrypted channels without revealing the passwords to an eavesdropper. Similarty, the mutual authentication for HTTP is based on PAKE and provides mutual authentication between an HTTP client and an HTTP server using username and password as credentials. The cryptographic algorithms to use with the mutual authentication protocol for HTTP are defined in [RFC8121].

3. The endpoint needs to use PAKE scheme to perform authentication the first time it connects to an EST server. If the EST server authentication is successful, the server's identity can be used to authenticate subsequent TLS connections to that EST server. The endpoint configures the reference identifier for the EST server using the DNS-ID identifier type in the EST server certificate. On subsequent connections to the EST server, the endpoint MUST validate the EST server certificate using the Implict Trust Anchor database (i.e, the EST server certificate must pass PKIX certification path validation) and matches the reference identifier against the EST server's identity according to the rules specified in Section 6.4 of [RFC6125].

4. The endpoint learns the End-Entity certificates [RFC8295] from the EST server. The certificate provisioned to the DNS server in the local network will be treated as a End-Entity certificate. As a reminder, the End-Entity certificates must be validated by the endpoint using an authorized trust anchor (Section 3.2 of [RFC8295]). The endpoint needs to identify the certificate provisioned to the DNS server. The SRV-ID identifier type [RFC6125] within subjectAltName entry MUST be used to identify the DNS server certificate.

   For example, DNS server certificate will include SRV-ID "_domain-s.example.net" along with DNS-ID "example.net". The SRV service label "domain-s" is defined in Section 6 of [RFC7858]. As a reminder, the protocol component is not included in the SRV-ID [RFC4985].

5. The endpoint configures the authentication domain name (ADN) (defined in [RFC8310]) for the DNS server from the DNS-ID identifier type within subjectAltName entry in the DNS server certificate. The DNS server certificate is associated with the ADN to be matched with the certificate given by the DNS server in (D)TLS. To some extent, this approach is similar to certificate usage PKIX-EE(1) defined in [RFC7671].

Figure 1 illustrates a sequence diagram for bootstrapping an endpoint with the local network's DNS server certificate.

Figure 1: Bootstrapping Endpoint Devices

5. Bootstrapping IoT Devices

The following steps explain the mechanism to automatically bootstrap IoT devices with local network's CA certificates and DNS server certificate:

- Bootstrapping Remote Secure Key Infrastructures (BRSKI) discussed in [I-D.ietf-anima-bootstrapping-keyinfra] provides a solution for secure automated bootstrap of devices. BRSKI specifies means to provision credentials on devices to be used to operationally access networks. In addition, BRSKI provides an automated mechanism for the bootstrap distribution of CA certificates from

the EST server. The IoT device can use BRSKI to automatically bootstrap the IoT device using the IoT manufacturer provisioned X.509 certificate, in combination with a registrar provided by the local network and IoT device manufacturer's authorizing service (MASA):

1. The IoT device authenticates to the local network using the IoT manufacturer provisioned X.509 certificate. The IoT device can request and get a voucher from the MASA service via the registrar. The voucher is signed by the MASA service and includes the local network's CA public key.

2. The IoT device validates the signed voucher using the manufacturer installed trust anchor associated with the MASA, stores the CA's public key and validates the provisional TLS connection to the registrar.

3. The IoT device requests the full EST distribution of current CA certificates (Section 5.9.1 in [I-D.ietf-anima-bootstrapping-keyinfra]) from the registrar operating as a BRSKI-EST server. The IoT devices stores the CA certificates as Explicit Trust Anchor database entries. The IoT device uses the Explicit Trust Anchor database to validate the DNS server certificate.

4. The IoT device learns the End-Entity certificates from the BRSKI-EST server. The certificate provisioned to the DNS server in the local network will be treated as an End-Entity certificate. The IoT device needs to identify the certificate provisioned to the DNS server. The SRV-ID identifier type within subjectAltName entry MUST be used to identify the DNS server certificate.

5. The endpoint configures the ADN for the DNS server from the DNS-ID identifier type within subjectAltName entry in the DNS server certificate. The DNS server certificate is associated with the ADN to be matched with the certificate given by the DNS server in (D)TLS.

6. DNS-over-(D)TLS and DNS-over-HTTPS Server Discovery Procedure

This specification defines "DPRIVE" as the application service tag (Section 12.1.1) and "dns.tls" (Section 12.1.2), "dns.dtls" (Section 12.1.3), and "dns.https" (Section 12.1.4) as application protocol tags. A DNS client discovers the DNS server in the local network supporting DNS-over-TLS, DNS-over-DTLS and DNS-over-HTTPS protocols by using the following discovery mechanism:

- The DNS client makes an S-NAPTR [RFC3958] lookup with the authentication domain name and the 'DPRIVE' application service tag to learn the protocols DNS-over-TLS, DNS-over-DTLS, and DNS-over-HTTPS supported by the DNS server and the DNS privacy protocol preferred by the DNS server administrators. The S-NAPTR lookup is performed using an recursive DNS resolver discovered from an untrusted source (such as DHCP).

- In the example depicted in Figure 2, for authentication domain name 'example.net', the resolution algorithm will result in the privacy-enabling protocols supported by the DNS server and usable DNS server IP addresses and port numbers.

```
example.net.
IN NAPTR 100 10 "" DPRIVE:dns.tls  "" dns1.example.net.
IN NAPTR 200 10 "" DPRIVE:dns.dtls "" dns2.example.net.

dns1.example.net.
IN NAPTR 100 10 S DPRIVE:dns.tls "" _domain-s._tcp.example.net.

dns2.example.net.
IN NAPTR 100 10 S DPRIVE:dns.dtls "" _domain-s._udp.example.net.

_domain-s._tcp.example.net.
IN SRV   0 0 853 a.example.net.

_domain-s._udp.example.net.
IN SRV   0 0 853 a.example.net.

a.example.net.
IN A        192.0.2.1
IN AAAA     2001:db8:8:4::2
```

Figure 2

- If DNS-over-HTTPS protocol is supported by the DNS server, the DNS client finds the URI template of the DNS-over-HTTPS server using one of the mechanisms discussed in [I-D.ietf-doh-resolver-associated-doh] to use the https URI scheme (Section 3 of [RFC8484]).

- If no DNS-specific S-NAPTR records can be retrieved, the discovery procedure fails for this authentication domain name. However, before retrying a lookup that has failed, a DNS client MUST wait a time period that is appropriate for the encountered error (e.g., NXDOMAIN, timeout, etc.).

7. Connection Handshake and Service Invocation

The DNS client initiates (D)TLS handshake with the DNS server, the DNS server presents its certificate in ServerHello message, and the DNS client MUST match the DNS server certificate downloaded in Step 4 in Section 4 or Section 5 with the certificate provided by the DNS server in (D)TLS handshake. If the match is successful, the DNS client MUST validate the server certificate using the Implicit Trust Anchor database (i.e., the DNS server certificate must pass PKIX certification path validation).

If the match is successful and server certificate is successfully validated, the client continues with the connection as normal. Otherwise, the client MUST treat the server certificate validation failure as a non-recoverable error. If the DNS client cannot reach or establish an authenticated and encrypted connection with the privacy-enabling DNS server provided by the local network, the DNS client can fallback to the privacy-enabling public DNS server.

8. EST Service Discovery Procedure

DNS-based Service Discovery (DNS-SD) [RFC6763] and Multicast DNS (mDNS) [RFC6762] provide generic solutions for discovering services available in a local network. DNS-SD/mDNS define a set of naming rules for certain DNS record types that they use for advertising and discovering services.

Section 4.1 of [RFC6763] specifies that a service instance name in DNS-SD has the following structure:

<Instance> . <Service> . <Domain>

The <Domain> portion specifies the DNS sub-domain where the service instance is registered. It may be "local.", indicating the mDNS local domain, or it may be a conventional domain name such as "example.com.". The <Service> portion of the EST service instance name MUST be "_est._tcp".

8.1. mDNS

A EST client application can proactively discover EST server being advertised in the site by multicasting a PTR query to the following:

o "_est._tcp.local"

A EST server can send out gratuitous multicast DNS answer packets whenever it starts up, wakes from sleep, or detects a change in EST

server configuration. EST client application receive these gratuitous packets and cache information contained in it.

9. Network Reattachment

On subsequent attachments to the network, the endpoint discovers the privacy-enabling DNS server using the authentication domain name (configured in Step 5 of Section 4 or Section 5), initiates (D)TLS handshake with the DNS server and follows the mechanism discussed in Section 7 to validate the DNS server certificate.

If the DNS server certificate invalid (e.g., revoked or expired) or the procedure to discover the privacy-enabling DNS server fails (e.g. the domain name of the privacy-enabling DNS server has changed because the Enterprise network has switched to a public privacy-enabling DNS server capable of blocking access to malicious domains), the endpoint discovers and initiates TLS handshake with the EST server, and uses the validation techniques described in [RFC6125] to compare the reference identifier (created in Step 2 of Section 4 in this document) to the EST server certificate and verifies the entire certification path as per [RFC5280]. The endpoint then gets the DNS server certificate from the EST server. If the DNS-ID identifier type within subjectAltName entry in the DNS server certificate does not match the configured ADN, the ADN is replaced with the DNS-ID identifier type. The DNS server certificate associated with the ADN is replaced with the one provided by the EST server. If the ADN has changed, the endpoint discovers the privacy-enabling DNS server, initiates (D)TLS handshake with the DNS server and follows the mechanism discussed in Section 7 to validate the DNS server certificate.

Figure 3 illustrates a sequence diagram for re-configuring an endpoint with ADN and local network's DNS server certificate on subsequent attachments to the network.

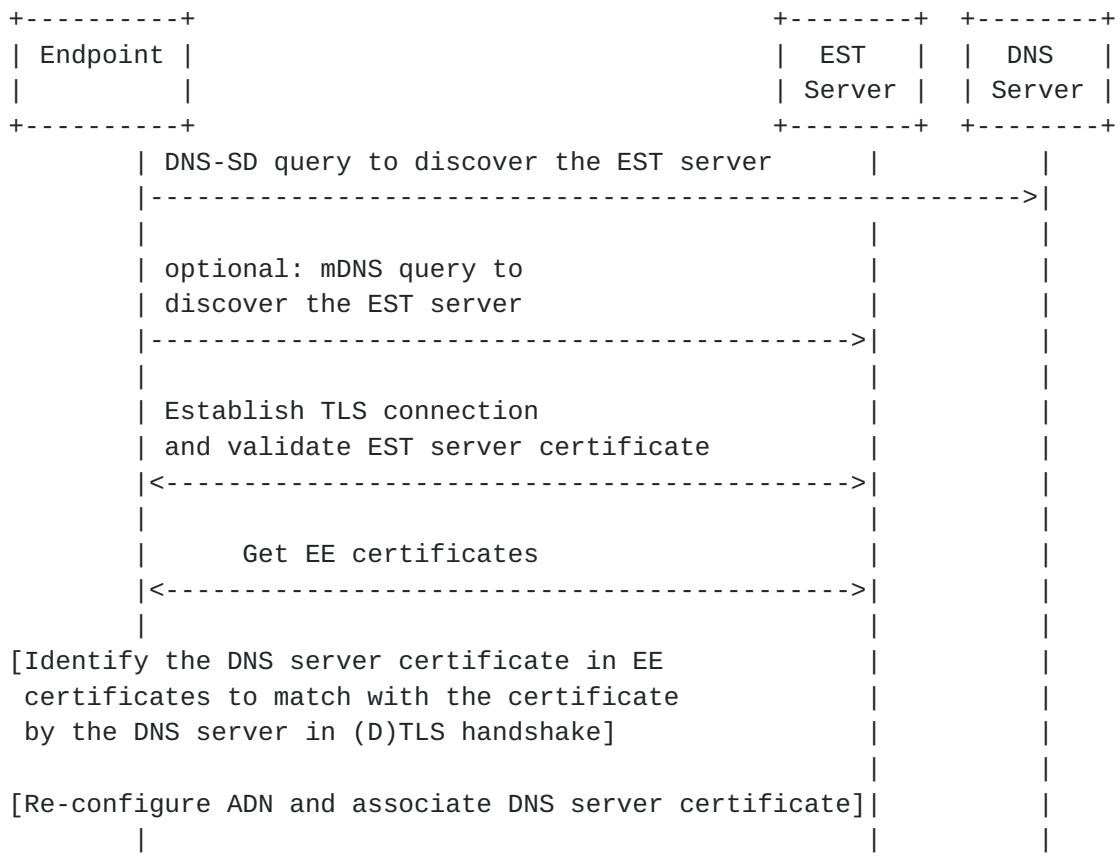

Figure 3: Bootstrapping Endpoint Devices on subsequent attachments to the network

10. Privacy Considerations

[RFC7626] discusses DNS privacy considerations in both "on the wire" (Section 2.4 of [RFC7626]) and "in the server" (Section 2.5 of [RFC7626] contexts. The endpoint may not know if the DNS-over-(D)TLS or DNS-over-HTTPS server in the local network has a privacy preserving data policy. A new privacy certificate extension is defined that identifies the privacy preserving data policy of the DNS server.

10.1. Privacy Extension Format

Like all X.509 certificate extensions, the privacy certificate extension is defined using ASN.1 [ASN1-88]. The non-critical privacy extension is identified by id-pe-privacy.

```
   PKIX Object Identifier Registry

   id-pkix OBJECT IDENTIFIER ::= { iso(1) identified-organization(3)
             dod(6) internet(1) security(5) mechanisms(5) pkix(7) }

   PKIX Arcs
   id-mod  OBJECT IDENTIFIER ::= { id-pkix 0 }    -- modules
   id-pe   OBJECT IDENTIFIER ::= { id-pkix 1 }    -- private
   certificate extensions

   PKIX modules
   id-mod-privacy-extn         OBJECT IDENTIFIER ::= { id-mod TBD2 }
   id-pe-privacy OBJECT IDENTIFIER  ::=  { id-pe TBD1 }
```

A non-null privacy always includes a base privacy. The privacy extension includes the following information:

- If the client IP address is Personally Identifiable Information (PII) data or non PII-data.
- If the client IP address is logged or not, and if client IP address is indeed logged, it is stored in temporary or permanant logs.
- If the server clears the stored transaction data (e.g., DNS messages) or not, and if the server clears the stored transaction data, the period for which the transaction data is stored.
- If the transaction data is shared with partners or not, and if the transaction data is shared with partners, the names of the partners. If anonymized data or client identifiable data is shared with partners.
- If the transaction data is shared or sold to third parties.
- If the DNS server will block DNS resolution of certain domains (e.g., malicious domains).
- A URL that points to the privacy preserving data policy, and a URL that points to the security assessment report of the DNS server by a third party auditor.

10.2. Privacy Extension Syntax

The syntax for the privacy extension is as follows:

```
   Privacy ::=  CHOICE  {
     none                 NULL,
                          -- No privacy policy provided
     pPolicy              PrivacyPolicy
                          -- Privacy preserving data policy  }


   PrivacyPolicy ::=  SEQUENCE  {
     base              PrivacyInfo,
     pURL         [0]  PrivacyURL OPTIONAL,
     aURL         [1]  AuditURL OPTIONAL  }

  PrivacyInfo  ::=  SEQUENCE  {
     ipaddresspii      BOOLEAN,
                       -- TRUE means client IP address is PII
     log          [0]  Logging,
     retention    [1]  DataRetention,
     sdata        [2]  ShareData,
     transferdata [3]  BOOLEAN,
                       -- TRUE means share or sell data to third parties
     blockdomains [4]  BOOLEAN
                       -- TRUE means domains will be blocked  }

   Logging ::=  SEQUENCE  {
     logip               BOOLEAN,
                         -- TRUE means client IP address logging
     temporary           BOOLEAN  OPTIONAL
                         -- TRUE means temporary logs  }

   DataRetention ::=  SEQUENCE  {
     cleardata           BOOLEAN,
                         -- TRUE means the server clears
                         -- the stored transaction data
     period              INTEGER OPTIONAL
                         -- Number of Hours the
                         -- transaction data is stored  }

   ShareData ::=  SEQUENCE  {
     sharepartners       BOOLEAN,
                         -- TRUE means data is shared with partners
     partners       [1]  SEQUENCE SIZE (1..MAX) OF UTF8String OPTIONAL,
                         -- Names of the partners
     anonymizeddata  [0]  BOOLEAN OPTIONAL
                         -- TRUE means anonymized data
                         -- is shared with partners  }

   PrivacyURL  ::=  IA5String  -- MUST use https scheme
   AuditURL    ::=  IA5String  -- MUST use https scheme
```

11. Security Considerations

The bootstrapping procedure to obtain the certificate of the local networks DNS server uses a client identity and password to authenticate the EST server using PAKE schemes. Security considerations such as those discussed in [I-D.barnes-tls-pake] or [RFC8120] and [RFC8121] need to be taken into consideration.

Users cannot be expected to enable or disable the bootstrapping or the discovery procedure as they switch networks. Thus, it is RECOMMENDED that users indicate to their system in some way that they desire bootstrapping to be performed when connecting to a specific network, similar to the way users disable VPN connection in specific network (e.g., Enterprise network) and enable VPN connection by default in other networks.

If an endpoint has enabled strict privacy profile, and the network security service blocks the traffic to the privacy-enabling public DNS server, a hard failure occurs and the user is notified. The user has a choice to switch to another network or if the user trusts the network, the user can enable strict privacy profile with the DNS-over-(D)TLS or DNS-over-HTTPS server discovered in the network instead of downgrading to opportunistic privacy profile.

The primary attacks against the methods described in Section 6 are the ones that would lead to impersonation of a DNS server and spoofing the DNS response to indicate that the DNS server does not support any privacy-enabling protocols. To protect against DNS-vectored attacks, secured DNS (DNSSEC) can be used to ensure the validity of the DNS records received. Impersonation of the DNS server is prevented by validating the certificate presented by the DNS server. If the EST server conveys the DNS server certificate, but the S-NAPTR lookup indicates that the DNS server does not support any privacy-enabling protocols, the client can detect the DNS response is spoofed.

Security considerations in [I-D.ietf-anima-bootstrapping-keyinfra] need to be taken into consideration for IoT devices.

12. IANA Considerations

IANA is requested to allocate the SRV service name of "est".

IANA is requested to add the following entry in the "SMI Security for PKIX Certificate Extension" (1.3.6.1.5.5.7.1) registry:

Decimal	Description	References
TBD1	id-pe-privacy	this document

IANA is requested to add the following entry in the "SMI Security for PKIX Module Identifier" (1.3.6.1.5.5.7.0) registry:

Decimal	Description	References
TBD2	id-mod-privacy-extn	this document

12.1. Application Service & Application Protocol Tags

This document requests IANA to make the following allocations from the registry available at: https://www.iana.org/assignments/s-naptr-parameters/s-naptr-parameters.xhtml.

12.1.1. DNS Application Service Tag Registration

- Application Protocol Tag: DPRIVE
- Intended Usage: See Section 6
- Security Considerations: See Section 11
- Contact Information: <one of the authors>

12.1.2. dns.tls Application Protocol Tag Registration

- Application Protocol Tag: dns.tls
- Intended Usage: See Section 6
- Security Considerations: See Section 11
- Contact Information: <one of the authors>

12.1.3. dns.dtls Application Protocol Tag Registration

- Application Protocol Tag: dns.dtls
- Intended Usage: See Section 6
- Security Considerations: See Section 11
- Contact Information: <one of the authors>

12.1.4. dns.https Application Protocol Tag Registration

- Application Protocol Tag: dnshttps
- Intended Usage: See Section 6
- Security Considerations: See Section 11
- Contact Information: <one of the authors>

13. Acknowledgments

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14. References

14.1. Normative References

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