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Zero Touch Provisioning for NETCONF or RESTCONF based Management
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Abstract

This draft presents a secure technique for establishing a NETCONF or RESTCONF connection between a newly deployed device, configured with just its factory default settings, and its deployment specific network management system (NMS).

Editorial Note (To be removed by RFC Editor)

This draft contains many placeholder values that need to be replaced with finalized values at the time of publication. This note summarizes all of the substitutions that are needed. Please note that no other RFC Editor instructions are specified anywhere else in this document.

Artwork in the IANA Considerations section contains placeholder values for DHCP options pending IANA assignment. Please apply the following replacements:

- "OPTION_V4_ZEROTOUCH_REDIRECT" --> the option code assigned for the "DHCPv4 Zero Touch Option" option

- "OPTION_V6_ZEROTOUCH_REDIRECT" --> the option code assigned for the "DHCPv6 Zero Touch Option" option

Artwork in this document contains shorthand references to drafts in progress. Please apply the following replacements:

- "XXXX" --> the assigned RFC value for this draft

Artwork in this document contains placeholder values for the date of publication of this draft. Please apply the following replacement:

- "2017-06-19" --> the publication date of this draft

Please update the following references to reflect their final RFC assignments:

- I-D.ieft-netconf-netconf-client-server
- I-D.ietf-anima-bootstrapping-keyinfra

The following one Appendix section is to be removed prior to publication:

- Appendix A. Change Log

Status of This Memo

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

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This Internet-Draft will expire on December 21, 2017.

Copyright Notice

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1. Introduction

A fundamental business requirement for any network operator is to reduce costs where possible. For network operators, deploying devices to many locations can be a significant cost, as sending trained specialists to each site for installations is both cost prohibitive and does not scale.

This document defines a bootstrapping strategy enabling devices to securely obtain bootstrapping data with no installer action beyond physical placement and connecting network and power cables. The ultimate goal of this document is to enable a secure NETCONF [RFC6241] or RESTCONF [RFC8040] connection to a deployment specific network management system (NMS).

1.1. Use Cases

- Device connecting to a remotely administered network

  This use-case involves scenarios, such as a remote branch office or convenience store, whereby a device connects as an access gateway to an ISP's network. Assuming it is not possible to customize the ISP's network to provide any bootstrapping support, and with no other nearby device to leverage, the device has no recourse but to reach out to an Internet-based bootstrap server to bootstrap off of.

- Device connecting to a locally administered network

  This use-case covers all other scenarios and differs only in that the device may additionally leverage nearby devices, which may direct it to use a local service to bootstrap off of. If no such information is available, or the device is unable to use the information provided, it can then reach out to network just as it would for the remotely administered network use-case.

1.2. Terminology

This document uses the following terms (sorted by name):

Artifact: The term "artifact" is used throughout to represent any of the three artifacts defined in Section 3 (Zero Touch Information, Ownership Voucher, and Owner Certificate). These artifacts collectively provide all the bootstrapping data a device may use.

Bootstrapping Data: The term "bootstrapping data" is used throughout this document to refer to the collection of data that a device may obtain from any source of bootstrapping data. Specifically, it refers to the artifacts defined in Section 3.

Bootstrap Server: The term "bootstrap server" is used within this document to mean any RESTCONF server implementing the YANG module defined in Section 9.3.

Device: The term "device" is used throughout this document to refer to the network element that needs to be bootstrapped. See Section 7 for more information about devices.

Initial Secure Device Identifier (IDevID): The term "IDevID" is defined in [Std-802.1AR-2009] as the secure device identifier (DevID) installed on the device by the manufacturer. This

identifier is used in this document to enable a Bootstrap Server to securely identify and authenticate a device.

Manufacturer: The term "manufacturer" is used herein to refer to the manufacturer of a device or a delegate of the manufacturer.

Network Management System (NMS): The acronym "NMS" is used throughout this document to refer to the deployment specific management system that the bootstrapping process is responsible for introducing devices to. From a device's perspective, when the bootstrapping process has completed, the NMS is a NETCONF or RESTCONF client.

Onboarding Information: The term "onboarding information" is used herein to refer to one of the two types of 'zero touch information' defined in this document, the other being 'redirect information'. Specifically, onboarding information guides a device to, for instance, install a specific boot-image and commit a specific configuration.

Owner: The term "owner" is used throughout this document to refer to the person or organization that purchased or otherwise owns a device.

Owner Certificate: The term "owner certificate" is used in this document to represent an X.509 certificate that binds an owner identity to a public key, which a device can use to validate a signature over the zero touch information artifacts. The owner certificate is one of the three bootstrapping artifacts described in Section 3.

Ownership Voucher: The term "ownership voucher" is used in this document to represent the voucher artifact defined in [I-D.ietf-anima-voucher]. The ownership voucher is used to assign a device to an owner. The ownership voucher is one of the three bootstrapping artifacts described in Section 3.

Redirect Information: The term "redirect information" is used herein to refer to one of the two types of 'zero touch information' defined in this document, the other being 'onboarding information'. Specifically, redirect information directs a device to connect to a specified bootstrap server.

Redirect Server: The term "redirect server" is used to refer to a bootstrap server that only returns redirect information. A redirect server is particularly useful when hosted by a manufacturer, as an Internet-based resource to redirect devices to deployment-specific bootstrap servers.

Signed Data: The term "signed data" is used throughout to mean either redirect information or onboarding information that has been signed, specifically by a private key possessed by a device's owner.

Unsigned Data: The term "unsigned data" is used throughout to mean either redirect information or onboarding information that has not been signed.

Zero Touch Information: The term "zero touch information" is used generally herein to refer either redirect information or onboarding information. Zero touch information is one of the three bootstrapping artifacts described in Section 3.

1.3. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

1.4. Tree Diagram Notation

A simplified graphical representation of the data models is used in this document. The meaning of the symbols in these diagrams is as follows:

- Brackets "[" and "]" enclose list keys.
- Braces "{" and "}" enclose feature names, and indicate that the named feature must be present for the subtree to be present.
- Abbreviations before data node names: "rw" (read-write) represents configuration data and "ro" (read-only) represents state data.
- Symbols after data node names: "?" means an optional node, "!" means a presence container, and "*" denotes a list and leaf-list.
- Parentheses enclose choice and case nodes, and case nodes are also marked with a colon (":").
- Ellipsis ("...") stands for contents of subtrees that are not shown.

2. Types of Bootstrapping Information

This document defines two types of information that devices access during the bootstrapping process. These information types are described in this section. Examples are provided in Section 8.2

2.1. Redirect Information

Redirect information redirects a device to another bootstrap server. Redirect information encodes a list of bootstrap servers, each defined by its hostname or IP address, an optional port, and an optional trust anchor certificate.

Redirect information is YANG modeled data formally defined by the "redirect-information" container in the YANG module presented in Section 8.3. This container has the tree diagram shown below. Please see Section 1.4 for tree diagram notation.

```
  +--:(redirect-information)
     +--ro redirect-information
        +--ro bootstrap-server* [address]
           +--ro address         inet:host
           +--ro port?           inet:port-number
           +--ro trust-anchor?   binary
```

Redirect information MAY be trusted or untrusted. The redirect information is trusted whenever it is obtained via a secure connection to a trusted bootstrap server, or whenever it is signed by the device's owner. In all other cases, the redirect information is untrusted.

Trusted redirect information is useful for enabling a device to establish a secure connection to a bootstrap server, which is possible when the redirect information includes the bootstrap server's trust anchor certificate. When a device is able to establish a secure connection to a bootstrap server, the data is implicitly trusted, and does not need to be signed.

Untrusted redirect information is useful for directing a device to a bootstrap server where signed data has been staged for it to obtain. When the redirect information is untrusted, the device MUST discard any potentially included trust anchor certificates and SHOULD establish a provisional connection (by blindly accepting the TLS certificate) to any of the specified bootstrap servers. In this case, the device MUST NOT trust the bootstrap server, and data provided by the bootstrap server MUST be signed for it to be of any use to the device.

How devices process redirect information is described more formally in Section 7.5.

2.2. Onboarding Information

Bootstrap information provides all the data necessary for a device to bootstrap itself, in order to be considered ready to be managed (e.g., by an NMS). As defined in this document, this data includes information about a boot image the device MUST be running, an initial configuration the device MUST commit, and optional scripts that, if specified, the device MUST successfully execute.

Bootstrap information is YANG modeled data formally defined by the "onboarding-information" container in the YANG module presented in Section 8.3. This container has the tree diagram shown below. Please see Section 1.4 for tree diagram notation.

```
  +--:(onboarding-information)
     +--ro onboarding-information
        +--ro boot-image
        |  +--ro name       string
        |  +--ro (hash-algorithm)
        |  |  +--:(sha256)
        |  |     +--ro sha256?    string
        |  +--ro uri*       inet:uri
        +--ro configuration-handling       enumeration
        +--ro pre-configuration-script?    script
        +--ro configuration?
        +--ro post-configuration-script?   script
```

Bootstrap information MUST be trusted for it to be of any use to a device. There is no option for a device to process untrusted onboarding information.

Bootstrap information is trusted whenever it is obtained via a secure connection to a trusted bootstrap server, or whenever it is signed by the device's owner. In all other cases, the onboarding information is untrusted.

How devices process onboarding information is described more formally in Section 7.6.

3. Artifacts

This document defines the following three artifacts that can be made available to devices while they are bootstrapping. As will be seen in Section 5, each source of bootstrapping information specifies a means for providing each of the artifacts defined in this section.

3.1. Zero Touch Information

The zero touch information artifact encodes the essential bootstrapping data for the device. This artifact is used to encode the redirect information and onboarding information types discussed in Section 2.

The zero touch information artifact is a PKCS#7 SignedData structure, as specified by Section 9.1 of [RFC2315], encoded using ASN.1 distinguished encoding rules (DER), as specified in ITU-T X.690. The PKCS#7 structure MUST contain JSON-encoded content conforming to the YANG module specified in Section 8.3.

In order for the zero touch information artifact to be trusted when conveyed over an untrusted transport, the PKCS#7 structure MUST also contain a 'signerInfo' structure, as described in Section 9.1 of [RFC2315], containing a signature generated over the content using the private key associated with the owner certificate (Section 3.2).

3.2. Owner Certificate

The owner certificate artifact is a certificate that is used to identify an 'owner' (e.g., an organization), as known to a trusted certificate authority. The owner certificate is signed by a trusted certificate authority (CA), whose certificate is placed into the ownership voucher (Section 3.3).

The owner certificate is used by a device to verify the signature attached to the zero touch information artifact (Section 3.1) that the device SHOULD have also received, as described in Section 4. In particular, the device verifies signature using the public key in the owner certificate over the content contained within the zero touch information artifact.

In order to validate the owner certificate, a device MUST verify that the owner certificate's certificate-chain includes the certificate specified by the ownership voucher (Section 3.3) that the device SHOULD have also received, as described in Section 4, and the device MUST verify that owner certificate contains an identifier matching the one specified in the voucher and, for devices that verify certificate revocation status, the device MUST also verify that the certificate has neither expired nor been revoked.

The owner certificate artifact is formally an unsigned PKCS #7 SignedData structure as specified by Section 9.1 in [RFC2315], encoded using ASN.1 distinguished encoding rules (DER), as specified in ITU-T X.690.

The owner certificate PKCS#7 structure MUST contain the owner certificate itself, as well as all intermediate certificates leading up to the trust anchor certificate specified in the ownership voucher. The owner certificate artifact MAY optionally include the trust anchor certificate.

Additionally, in order to support devices deployed on private networks, the owner certificate PKCS#7 structure MAY also contain suitably fresh CRLs [RFC5280] and/or OCSP Responses [RFC6960]. Having these revocation objects stapled to the owner certificate precludes the need for the device to have to download them dynamically using the CRL distribution point or an OCSP responder specified in the associated certificates.

3.3. Ownership Voucher

The ownership voucher artifact is used to securely identify a device's owner, as it is known to the manufacturer. The ownership voucher is signed by the device's manufacturer or delegate.

More specifically, the ownership voucher is used to verify the owner certificate (Section 3.2) that the device SHOULD have also received, as described in Section 4. In particular, the device verifies that the owner certificate has a chain of trust leading to the trusted certificate included in the ownership voucher, even if it is itself (e.g., self-signed certificate).

In order to validate the ownership voucher, a device MUST perform a number of checks. The device MUST verify that the voucher specifies the device's serial number. The device MUST verify that the ownership voucher has a chain of trust to a trusted certificate known to the device (Section 7.1). If the ownership voucher contains an expiration date, the device MUST also verify that the ownership voucher has not expired.

The ownership voucher artifact, including its encoding, is formally defined in [I-D.ietf-anima-voucher].

4. Artifact Groupings

Section 3 lists all the possible bootstrapping artifacts, but only certain groupings of these artifacts make sense to return in the various bootstrapping situations described in this document. The remainder of this section identifies these groupings to further clarify how the artifacts are used.

4.1. Unsigned Information

The first grouping of artifacts is for unsigned information. That is, when the zero touch information artifact (Section 3.1) has not been signed.

Unsigned information is useful for cases when transport level security can be used to convey trust (e.g., HTTPS), or when the information can be processed in a provisional manner (i.e. unsigned redirect information).

Conveying unsigned information entails communicating just one of the three artifacts listed in Section 3 as follows:

List of artifacts included in this grouping:
- zero touch information (with no embedded signature)

4.2. Signed Information (without Revocations)

The second grouping of artifacts is for when the zero touch information artifact (Section 3.1) has been signed, but without any revocation information, because the device is expected to download the revocation information dynamically (e.g., using the CRL distribution point or OCSP Responder listed in the owner certificate and and the pinned domain certificate specified in the ownership voucher).

Signed information is needed when the information is obtained from an untrusted source of bootstrapping data (Section 5), in order for the device to be able to trust the information.

Revocation information may not need to be provided because, for instance, the device only uses revocation information obtained dynamically from Internet based resources. Another possible reason may be because the device does not have a reliable clock, and therefore the manufacturer decides to never revoke information (e.g., ownership assignments are forever).

Conveying signed information without revocation information entails communicating all three of the artifacts listed in Section 3 as follows:

List of artifacts included in this grouping:
- zero touch information (with an embedded signature)
- owner certificate (with no stapled revocation objects)
- ownership voucher (with no stapled revocation objects)

4.3. Signed Information (with Revocations)

The third grouping of artifacts is for when the zero touch information artifact (Section 3.1) has been signed and also includes revocation information.

Signed information, as described above, is needed when the information is obtained from an untrusted source of bootstrapping data (Section 5), in order for the device be able to trust the information.

Revocation information may need to be provided because, for instance, the device is deployed on a private network and therefore unable to obtain the revocation information from Internet based resources.

Conveying signed information with revocation information entails communicating all three of the artifacts listed in Section 3 as follows:

List of artifacts included in this grouping:
- zero touch information (with an embedded signature)
- owner certificate (with stapled revocation objects)
- ownership voucher (with stapled revocation objects)

5. Sources of Bootstrapping Data

This section defines some sources for zero touch bootstrapping data that a device can access. The list of sources defined here is not meant to be exhaustive. It is left to future documents to define additional sources for obtaining zero touch bootstrapping data.

For each source defined in this section, details are given for how each of the three artifacts listed in Section 3 is provided.

5.1. Removable Storage

A directly attached removable storage device (e.g., a USB flash drive) MAY be used as a source of zero touch bootstrapping data.

To use a removable storage device as a source of bootstrapping data, a device need only detect if the removable storage device is plugged in and mount its filesystem.

Use of a removable storage device is compelling, as it doesn't require any external infrastructure to work. It is notable that the raw boot image file can be located on the removable storage device, enabling a removable storage device to be a fully self-standing bootstrapping solution.

A removable storage device is an untrusted source of bootstrapping data. This means that the information stored on the removable storage device either MUST be signed, or it MUST be information that can be processed provisionally (e.g., unsigned redirect information).

From an artifact perspective, since a removable storage device presents itself as a filesystem, the bootstrapping artifacts need to be presented as files. The three artifacts defined in Section 3 are mapped to files below.

Artifact to File Mapping:

Zero Touch Information: Mapped to a file containing the binary artifact described in Section 3.1 (e.g., zerotouch-information.pkcs7).

Owner Certificate: Mapped to a file containing the binary artifact described in Section 3.2 (e.g., owner-certificate.pkcs7).

Ownership Voucher: Mapped to a file containing the binary artifact described in Section 3.3 (e.g., ownership-voucher.pkcs7).

The format of the removable storage device's filesystem and the naming of the files are outside the scope of this document. However, in order to facilitate interoperability, it is RECOMMENDED devices support open and/or standards based filesystems. It is also RECOMMENDED that devices assume a file naming convention that enables more than one instance of bootstrapping data to exist on a removable storage device. The file naming convention SHOULD be unique to the manufacturer, in order to enable bootstrapping data from multiple manufacturers to exist on a removable storage device.

5.2. DNS Server

A DNS server MAY be used as a source of zero touch bootstrapping data.

Using a DNS server may be a compelling option for deployments having existing DNS infrastructure, as it enables a touchless bootstrapping option that does not entail utilizing an Internet based resource hosted by a 3rd-party.

To use a DNS server as a source of bootstrapping data, a device MAY perform a multicast DNS [RFC6762] query searching for the service "_zerotouch._tcp.local.". Alternatively the device MAY perform DNS-SD [RFC6763] via normal DNS operation, using the domain returned to

it from the DHCP server; for example, searching for the service "_zerotouch._tcp.example.com".

Unsigned DNS records (e.g., not using DNSSEC as described in [RFC6698]) are an untrusted source of bootstrapping data. This means that the information stored in the DNS records either MUST be signed, or it MUST be information that can be processed provisionally (e.g., unsigned redirect information).

From an artifact perspective, since a DNS server presents resource records (Section 3.2.1 of [RFC1035]), the bootstrapping artifacts need to be presented as resource records. The three artifacts defined in Section 3 are mapped to resource records below.

Artifact to Resource Record Mapping:

Zero Touch Information: Mapped to a TXT record called "zt-info" containing the base64-encoding of the binary artifact described in Section 3.1.

Owner Certificate: Mapped to a TXT record called "zt-cert" containing the base64-encoding of the binary artifact described in Section 3.2.

Ownership Voucher: Mapped to a TXT record called "zt-voucher" containing the base64-encoding of the binary artifact described in Section 3.3.

TXT records have an upper size limit of 65535 bytes (Section 3.2.1 in RFC1035), since 'RDLENGTH' is a 16-bit field. Please see Section 3.1.3 in RFC4408 for how a TXT record can achieve this size. Due to this size limitation, some zero touch information artifacts may not fit. In particular, onboarding information could hit this upper bound, depending on the size of the included configuration and scripts.

When onboarding information (not redirect information) is provided, it is notable that the URL for the boot-image the device can download would have to point to another server (e.g., http://, ftp://, etc.), as DNS servers do not themselves distribute files.

5.3. DHCP Server

A DHCP server MAY be used as a source of zero touch bootstrapping data.

Using a DHCP server may be a compelling option for deployments having existing DHCP infrastructure, as it enables a touchless bootstrapping

option that does not entail utilizing an Internet based resource hosted by a 3rd-party.

A DHCP server is an untrusted source of bootstrapping data. Thus the information stored on the DHCP server either MUST be signed, or it MUST be information that can be processed provisionally (e.g., unsigned redirect information).

However, unlike other sources of bootstrapping data described in this document, the DHCP protocol (especially DHCP for IPv4) is limited in the amount of data that can be conveyed, to the extent that signed data cannot be communicated. This means only unsigned redirect information can be conveyed. Since the redirect information is unsigned, it SHOULD NOT include the optional trust anchor certificate, as the device would have to discard it anyway.

From an artifact perspective, the three artifacts defined in Section 3 are mapped to the DHCP fields specified in Section 10 as follows:

Zero Touch Information: This artifact is not supported directly. Instead, the essence of redirect information (not onboarding information) is mapped to the DHCP fields described in Section 10.

Owner Certificate: Not supported. There is not enough space in the DHCP packet to hold an owner certificate artifact.

Ownership Voucher: Not supported. There is not enough space in the DHCP packet to hold an ownership voucher artifact.

5.4. Bootstrap Server

A bootstrap server MAY be used as a source of zero touch bootstrapping data. A bootstrap server is defined as a RESTCONF [RFC8040] server implementing the YANG module provided in Section 9.

Unlike any other source of bootstrap data described in this document, a bootstrap server is not only a source of data, but it can also receive data from devices using the YANG-defined "notification" action statement defined in the YANG module (Section 9.3). The data sent from devices both enables visibility into the bootstrapping process (e.g., warnings and errors) as well as provides potentially useful completion status information (e.g., the device's SSH host-keys).

To use a bootstrap server as a source of bootstrapping data, a device MUST use the RESTCONF protocol to access the YANG container node

/device, passing its own serial number in the URL as the key to the 'device' list.

Using a bootstrap server as a source of bootstrapping data is a compelling option as it MAY use transport-level security, in lieu of signed data, which may be easier to deploy in some situations. Additionally, the bootstrap server is able to receive notifications from devices, which may be critical to some deployments (e.g., the passing of the device's SSH host keys).

A bootstrap server may be trusted or an untrusted source of bootstrapping data, depending on how the device learned about the bootstrap server's trust anchor from a trusted source. When a bootstrap server is trusted, the information returned from it MAY be signed. However, when the server is untrusted, in order for its information to be of any use to the device, the bootstrap information MUST either be signed or be information that can be processed provisionally (e.g., unsigned redirect information).

When a device is able to trust a bootstrap server, it MUST send its IDevID certificate in the form of a TLS client certificate, and it MUST send notifications to the bootstrap server. When a device is not able to trust a bootstrap server, it MUST NOT send its IDevID certificate in the form of a TLS client certificate, and it MUST NOT send any notifications to the bootstrap server.

From an artifact perspective, since a bootstrap server presents data as a YANG-modeled data, the bootstrapping artifacts need to be mapped to nodes in the YANG module. The three artifacts defined in Section 3 are mapped to bootstrap server nodes defined in Section 9.3 below.

Artifact to Bootstrap Server Node Mapping:

Zero Touch Information: Mapped to the leaf node /device/zerotouch-information.

Owner Certificate: Mapped to the leaf node /device/owner-certificate.

Ownership Voucher: Mapped to the leaf node /device/ownership-voucher.

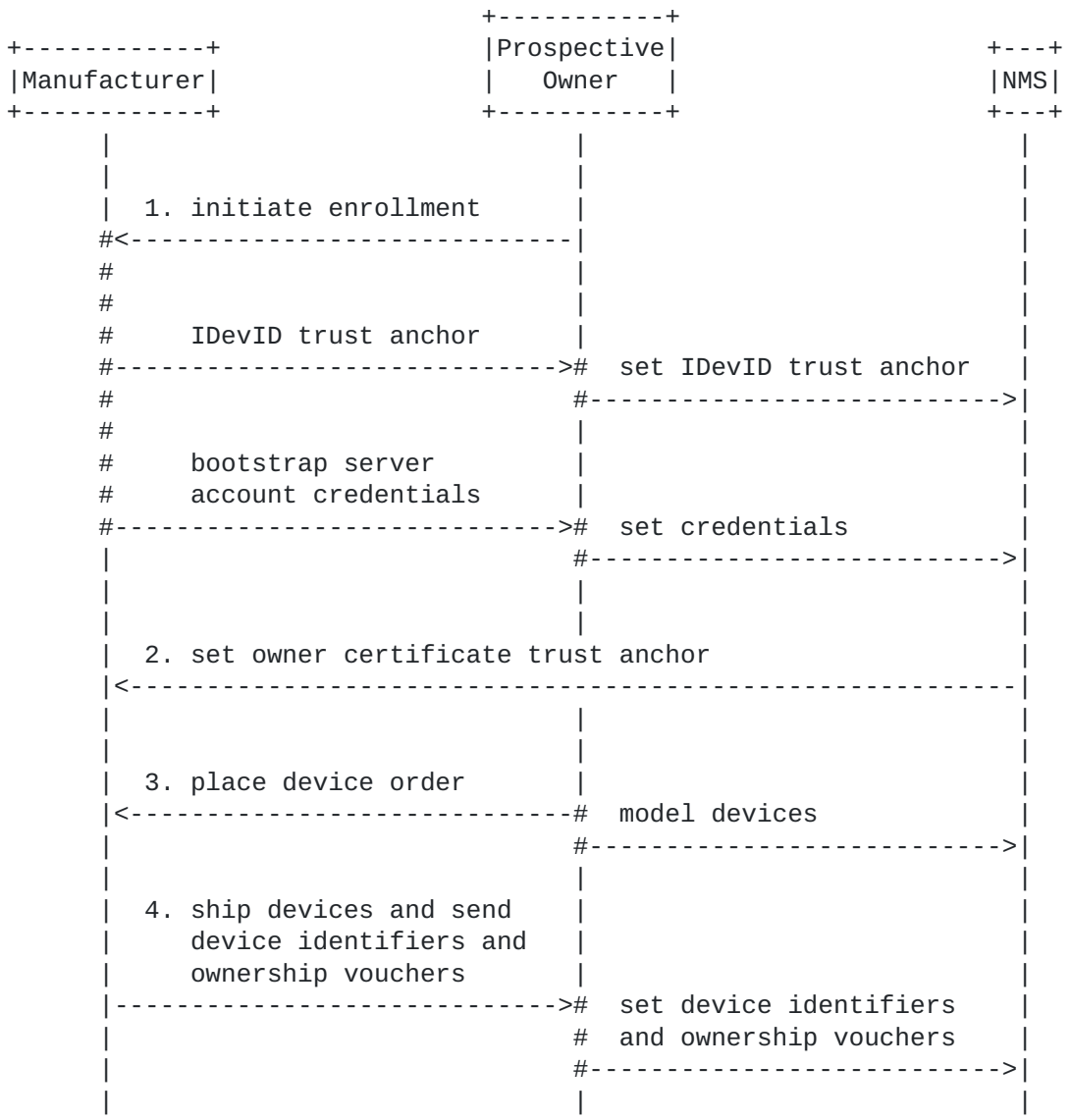
While RESTCONF servers typically support a nested hierarchy of resources, zero touch bootstrap servers only need to support the paths /device and /device/notification. The device processing instructions provided in Section 7.3 only uses these two URLs.

6. Workflow Overview

The zero touch solution presented in this document is conceptualized to be composed of the workflows described in this section. Implementations MAY vary in details. Each diagram is followed by a detailed description of the steps presented in the diagram, with further explanation on how implementations may vary.

6.1. Enrollment and Ordering Devices

The following diagram illustrates key interactions that may occur from when a prospective owner enrolls in a manufacturer's zero touch program to when the manufacturer ships devices for an order placed by the prospective owner.



Each numbered item below corresponds to a numbered item in the diagram above.

1. A prospective owner of a manufacturer's devices, or an existing owner that wishes to start using zero touch for future device orders, initiates an enrollment process with the manufacturer or delegate. This process includes the following:

   * Regardless how the prospective owner intends to bootstrap their devices, they will always obtain from the manufacturer or delegate the trust anchor certificate for its device's IDevID certificates. This certificate will need to be

installed on the prospective owner's NMS so that the NMS can subsequently authenticate the devices' IDevID certificates.

* If the manufacturer hosts an Internet based bootstrap server (e.g., a redirect server) such as described in Section 5.4, then credentials necessary to configure the bootstrap server would be provided to the prospective owner. If the bootstrap server is configurable through an API (outside the scope of this document), then the credentials might be installed on the prospective owner's NMS so that the NMS can subsequently configure the manufacturer-hosted bootstrap server directly.

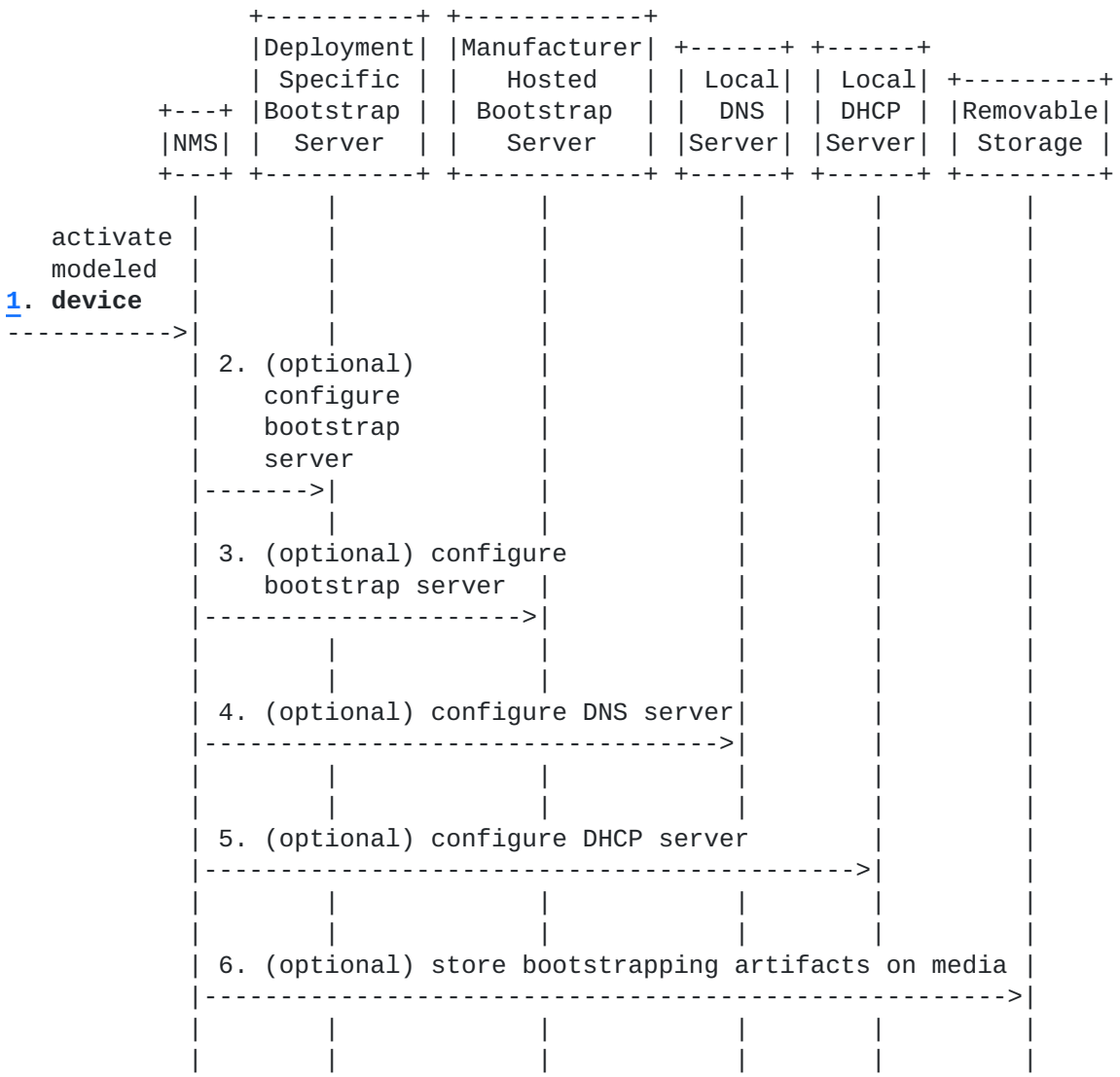
2. If the manufacturer's devices are able to validate signed data (Section 7.4), and assuming that the prospective owner's NMS is able to prepare and sign the bootstrapping data itself, the prospective owner's NMS might set a trust anchor certificate onto the manufacturer's bootstrap server, using the credentials provided in the previous step. This certificate is the trust anchor certificate that the prospective owner would like the manufacturer to place into the ownership vouchers it generates, thereby enabling devices to trust the owner's owner certificate. How this trust anchor certifiate is used to enable devices to validate signed bootstrapping data is described in Section 7.4.

3. Some time later, the prospective owner places an order with the manufacturer or delegate, perhaps with a special flag checked for zero touch handling. At this time, or perhaps before placing the order, the owner may model the devices in their NMS, creating virtual objects for the devices with no real-world device associations. For instance the model can be used to simulate the device's location in the network and the configuration it should have when fully operational.

4. When the manufacturer or delegate fulfills the order, shipping the devices to their intended locations, they may notify the owner of the devices's serial numbers and shipping destinations, which the owner may use to stage the network for when the devices power on. Additionally, the manufacturer may send one or more ownership vouchers, cryptographically assigning ownership of those devices to the owner. The owner may set this information on their NMS, perhaps binding specific modeled devices to the serial numbers and ownership vouchers.

6.2. Owner Stages the Network for Bootstrap

The following diagram illustrates how an owner might stage the network for bootstrapping devices.



Each numbered item below corresponds to a numbered item in the diagram above.

1. Having previously modeled the devices, including setting their fully operational configurations and associating both device serial numbers and ownership vouchers, the owner might "activate" one or more modeled devices. That is, the owner tells the NMS to perform the steps necessary to prepare for when the real-world devices power up and initiate the bootstrapping process. Note that, in some deployments, this step might be combined with the last step from the previous workflow. Here it is depicted that an NMS performs the steps, but they may be performed manually or through some other mechanism.

2. If it is desired to use a deployment specific bootstrap server, it MUST be configured to provide the bootstrapping information for the specific devices. Configuring the bootstrap server MAY occur via a programmatic API not defined by this document. Illustrated here as an external component, the bootstrap server MAY be implemented as an internal component of the NMS itself.

3. If it is desired to use a manufacturer (or delegate) hosted bootstrap server, it MUST be configured to provide the bootstrapping information for the specific devices. The configuration MUST be either redirect or onboarding information. That is, either the manufacturer hosted bootstrap server will redirect the device to another bootstrap server, or provide the device with its bootstrapping information itself. The types of bootstrapping information the manufacturer hosted bootstrap server supports MAY vary by implementation; some implementations may only support redirect information, or only support onboarding information, or support both redirect and onboarding information. Configuring the bootstrap server MAY occur via a programmatic API not defined by this document.

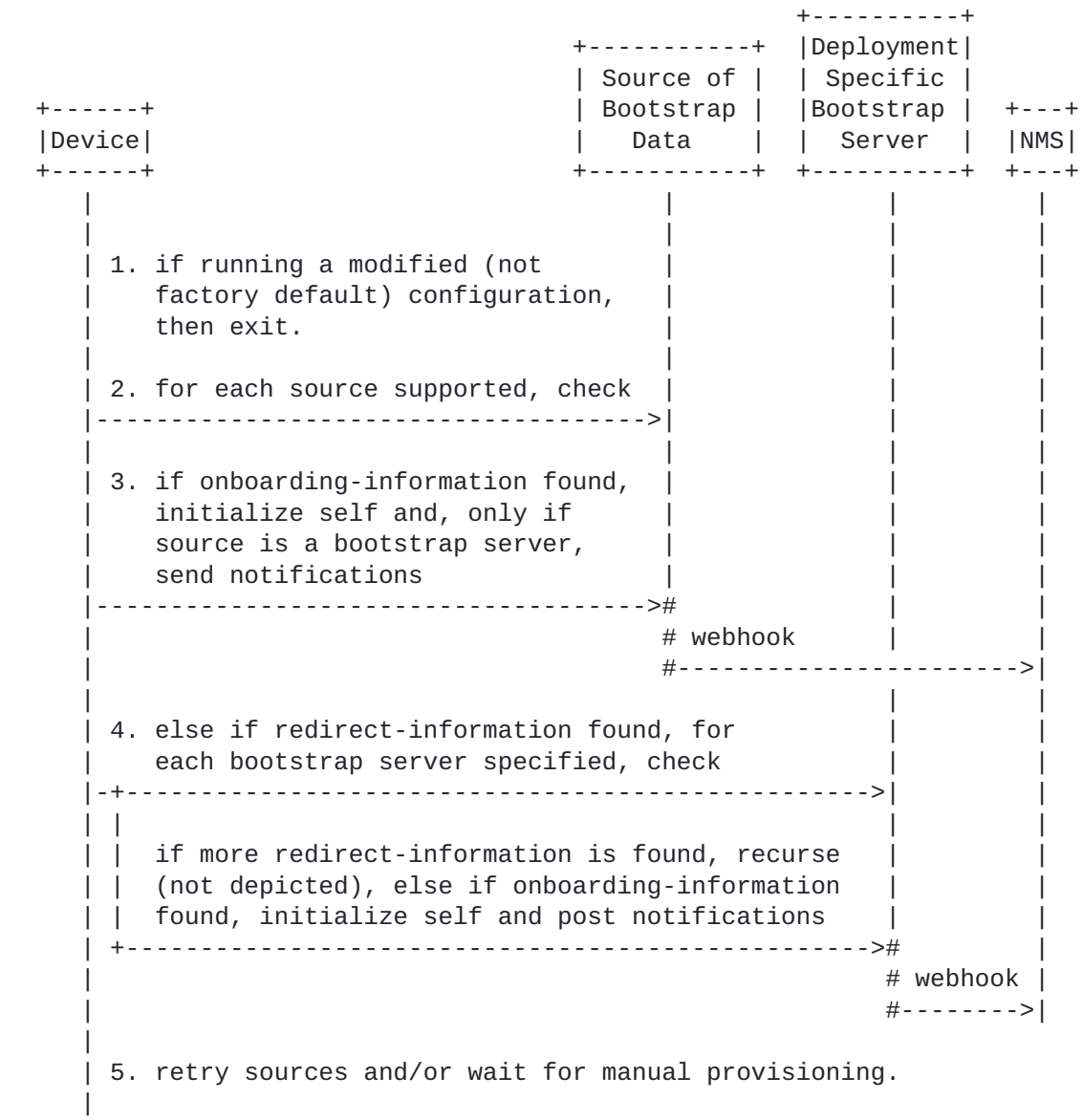
4. If it is desired to use a DNS server to supply bootstrapping information, a DNS server needs to be configured. If multicast DNS-SD is desired, then the server MUST reside on the local network, otherwise the DNS server MAY reside on a remote network. Please see Section 5.2 for more information about how to configure DNS servers. Configuring the DNS server MAY occur via a programmatic API not defined by this document.

5. If it is desired to use a DHCP server to supply bootstrapping data, a DHCP server needs to be configured. The DHCP server may be accessed directly or via a DHCP relay. Please see Section 5.3 for more information about how to configure DHCP servers. Configuring the DHCP server MAY occur via a programmatic API not defined by this document.

6. If it is desired to use a removable storage device (e.g., USB flash drive) to supply bootstrapping information, the information would need to be placed onto it. Please see Section 5.1 for more information about how to configure a removable storage device.

6.3. Device Powers On

The following diagram illustrates the sequence of activities that occur when a device powers on.



The interactions in the above diagram are described below.

1. Upon power being applied, the device's bootstrapping logic first checks to see if it is running in its factory default state. If it is in a modified state, then the bootstrapping logic exits and none of the following interactions occur.

2. For each source of bootstrapping data the device supports, preferably in order of closeness to the device (e.g., removable storage before Internet based servers), the device checks to see if there is any bootstrapping data for it there.

3. If onboarding information is found, the device initializes itself accordingly (e.g., installing a boot-image and committing an initial configuration). If the source is a bootstrap server, and the bootstrap server can be trusted (i.e., TLS-level authentication), the device also sends progress notifications to the bootstrap server.

   * The contents of the initial configuration SHOULD configure an administrator account on the device (e.g., username, ssh-rsa key, etc.) and SHOULD configure the device either to listen for NETCONF or RESTCONF connections or to initiate call home connections [RFC8071].

   * If the bootstrap server supports forwarding device notifications to external systems (e.g., via a webhook), the "bootstrap-complete" notification (Section 9.3) informs the external system to know when it can, for instance, initiate a connection to the device (assuming it knows the device's address and the device was configured to listen for connections). To support this further, the bootstrap-complete notification MAY also relay the device's SSH host keys and/or TLS certificates, with which the external system can use to authenticate subsequent connections to the device.

   If the device is ever able to complete the bootstrapping process successfully (i.e., no longer running its factory default configuration), it exits the bootstrapping logic without considering any additional sources of bootstrapping data.

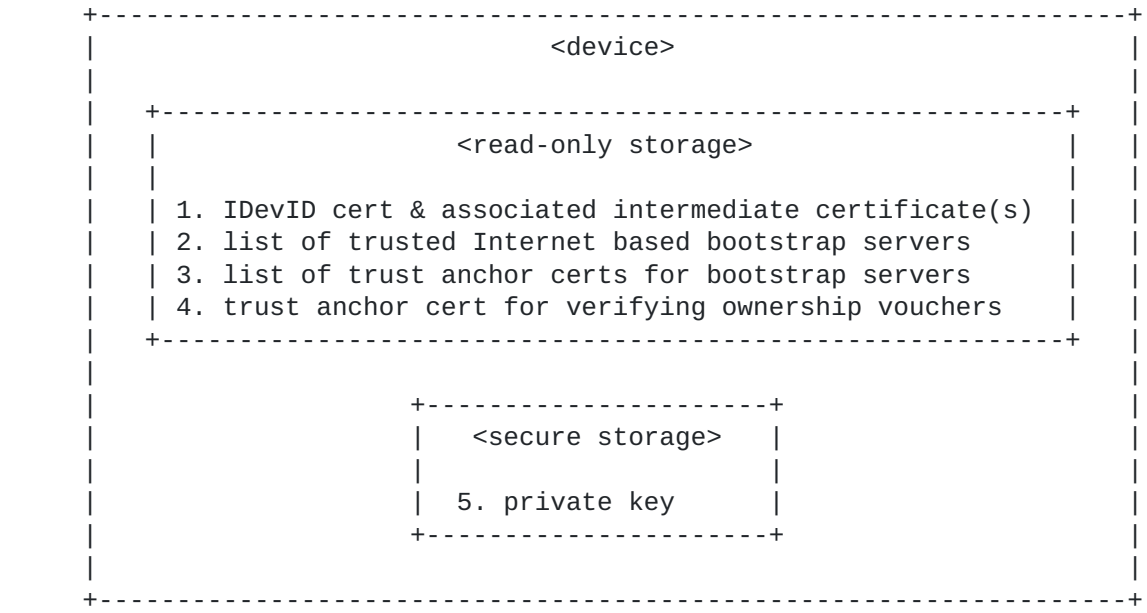
4. Otherwise, if redirect information is found, the device iterates through the list of specified bootstrap servers, checking to see if there is any bootstrapping data for it on them. If the bootstrap server returns more redirect information, then the device processes it recursively. Otherwise, if the bootstrap server returns onboarding information, the device processes it following the description provided in (3) above.

5. After having tried all supported sources of bootstrapping data, the device MAY retry again all the sources and/or provide manageability interfaces for manual configuration (e.g., CLI, HTTP, NETCONF, etc.). If manual configuration is allowed, and such configuration is provided, the device MUST immediately cease trying to obtain bootstrapping data, as it would then no longer be in running its factory default configuration.

7. Device Details

Devices supporting the bootstrapping strategy described in this document MUST have the preconfigured factory default state and bootstrapping logic described in the following sections.

7.1. Factory Default State



Each numbered item below corresponds to a numbered item in the diagram above.

1. Devices MUST be manufactured with an initial device identifier (IDevID), as defined in [Std-802.1AR-2009]. The IDevID is an X.509 certificate, encoding the device's serial number. The device MUST also possess any intermediate certificates between the IDevID certificate and the manufacturer's IDevID trust anchor certificate, which is provided to prospective owners separately (e.g., Section 6.1).

2. Devices that support loading bootstrapping data from an Internet-based bootstrap server (see Section 5.4) MUST be manufactured with a configured list of trusted bootstrap servers. Consistent with redirect information (Section 2.1, each bootstrap server MAY be identified by its hostname or IP address, and an optional port.

3. Devices that support loading bootstrapping data from an Internet-based bootstrap server (see Section 5.4) MUST also be

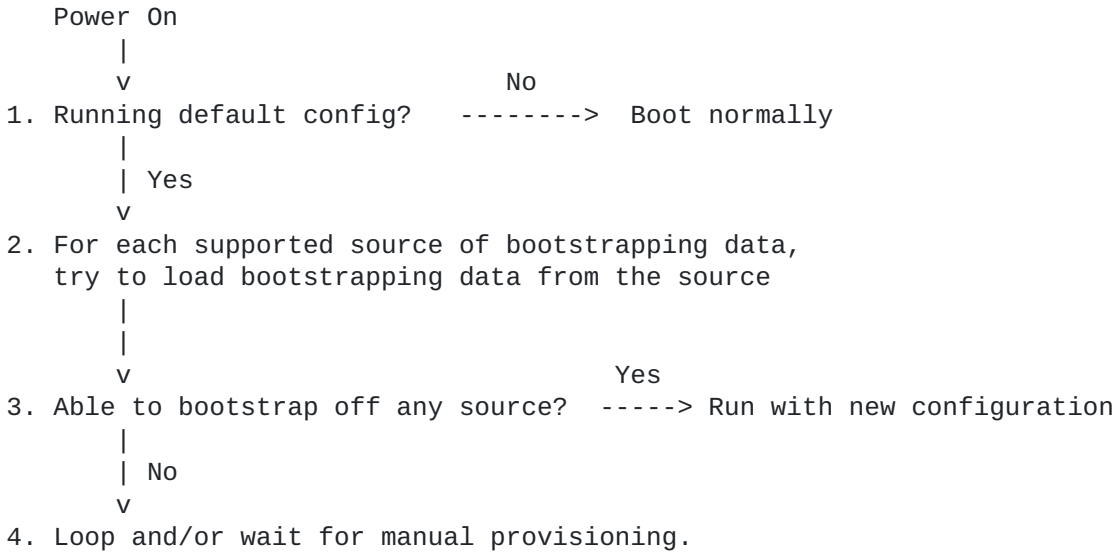
manufactured with a list of trust anchor certificates that can be used for X.509 certificate path validation ([RFC6125], Section 6) on the bootstrap server's TLS server certificate.

4. Devices that support loading owner signed data (see Section 1.2) MUST also be manufactured with the manufacturer's trust anchor certificate for the ownership vouchers.

5. Devices MUST be manufactured with a private key that corresponds to the public key encoded in the device's IDevID certificate. This private key SHOULD be securely stored, ideally by a cryptographic processor (e.g., a TPM).

7.2. Boot Sequence

A device claiming to support the bootstrapping strategy defined in this document MUST support the boot sequence described in this section.



Each numbered item below corresponds to a numbered item in the diagram above.

1. When the device powers on, it first checks to see if it is running the factory default configuration. If it is running a modified configuration, then it boots normally.

2. The device iterates over its list of sources for bootstrapping data (Section 5). Details for how to processes a source of bootstrapping data are provided in Section 7.3.

3. If the device is able to bootstrap itself off any of the sources of bootstrapping data, it runs with the new bootstrapped configuration.

4. Otherwise the device MAY loop back through the list of bootstrapping sources again and/or wait for manual provisioning.

7.3. Processing a Source of Bootstrapping Data

This section describes a recursive algorithm that devices can use to, ultimately, obtain onboarding information. The algorithm is recursive only because sources of bootstrapping data MAY return redirect information, which causes the algorithm to run again, for the newly discovered sources of information. To be clear, an expression that captures all possible combinations is "(redirect information)* onboarding information". That is, zero or more redirect information responses, followed by one bootstrap information response.

An important aspect of the algorithm is knowing when data needs to be signed or not. The following figure provides a summary of options:

Kind of Bootstrapping Data	Untrusted Source Can Provide?	Trusted Source Can Provide?
Unsigned Redirect Info	Yes+	Yes
Signed Redirect Info	Yes	Yes*
Unsigned Bootstrap Info	No	Yes
Signed Bootstrap Info	Yes	Yes*

The '+' above denotes that the source redirected to MUST return signed data, or more unsigned redirect information.

The '*' above denotes that, while possible, it is generally unnecessary for a trusted source to return signed data. In fact, it's only needed when the '+' case occurs.

As an example, imagine a device initially obtains unsigned redirect information, which redirects it to an [untrusted] bootstrap server where it obtains more unsigned redirect information, which redirects it to another [untrusted] bootstrap server where it obtains signed redirect information, which redirects it to a [trusted] bootstrap server where it obtains redirect information (signed or unsigned doesn't matter, its trusted either way), but without an included trust anchor certificate, which is unexpected but possible, so the device can't trust the server it's redirected to, and so on, until finally the device obtains some onboarding information.

To support this behavior, this recursive algorithm uses a conceptually global-scoped variable algorithm variable called "trust-state". The trust-state variable is initialized to FALSE. The ultimate goal of this algorithm is for the device to process onboarding information (Section 2.2) while the trust-state variable is TRUE.

If the data source is a bootstrap server, the only source of bootstrapping data defined in this document that can be trusted via transport level security, and the device is able to authenticate the server using X.509 certificate path validation ([RFC6125], Section 6) to one of the device's preconfigured trust anchors, or to a trust anchor that it learned from a previous step, then the device MUST set trust-state to TRUE.

If trust-state is TRUE, when connecting to the bootstrap server, the device MUST use its IDevID certificate for client certificate based authentication and MUST POST progress notifications using the bootstrap server's "notification" action. Otherwise, if trust-state is FALSE, when connecting to the bootstrap server, the device MUST NOT use its IDevID certificate for a client certificate based authentication and MUST NOT POST progress notifications using the bootstrap server's "notification" action.

When accessing a bootstrap server, the device SHOULD only access its top-level resource, to obtain all the data staged for it in a single GET request.

For any source of bootstrapping data (e.g., Section 5), if the data is signed and the device is able to validate the signed data using the algorithm described in Section 7.4, then the device MUST set trust-state to TRUE, else the device MUST set trust-state to FALSE. Note, this is worded to cover the special case when signed data is returned even from a trusted bootstrap server.

If the data is onboarding information (not redirect information), and trust-state is FALSE, the device MUST exit the recursive algorithm (as this is not allowed, per the figure above), returning to the state machine described in Section 7.2. Otherwise, the device MUST attempt to process the onboarding information as described in Section 7.6. In either case, success or failure, the device MUST exit the recursive algorithm, returning to the state machine described in Section 7.2, the only difference being in how it responds to the "Able to bootstrap off any source?" conditional described in the figure in the section.

If the data is redirect information, the device MUST process the redirect information as described in Section 7.5. This is the

recursion step, it will cause to device to reenter this algorithm, but this time the data source will most definitely be a bootstrap server, as that is all redirect information is able to redirect a device to.

7.4. Validating Signed Data

Whenever a device is presented signed data from an untrusted source, it MUST validate the signed data as described in this section. If the signed data is provided by a trusted source, a redundant trust case, the device MAY skip verifying the signature.

Whenever there is signed data, the device MUST also be provided an ownership voucher and an owner certificate. Depending on circumstances, the device MAY also be provided certificate revocations. How all the needed artifacts are provided for each source of bootstrapping data is defined in Section 5.

The device MUST first authenticate the ownership voucher by validating the signature on it to one of its preconfigured trust anchors (see Section 7.1) and verify that the ownership voucher contains the device's serial number. If the ownership voucher contains an expiration timestamp, the device MUST also verify that the ownership voucher has not expired. If the authentication of the ownership voucher is successful, the device extracts from it information that can be used to verify the owner certificate in the next step.

Next the device MUST authenticate the owner certificate by performing X.509 certificate path verification to the trusted certificate provided in the voucher. If the device insists on verifying revocation status, it MUST also verify that none of the certificates in the chain of certificates have been revoked or expired. If the authentication of the owner certificate is successful, the device extracts the owner's public key from the owner certificate for use in the next step.

Finally the device MUST verify the signature over information artifact was generated by the private key matching the public key extracted from the owner certificate in the previous step.

If any of these steps fail, then the device MUST mark the data as invalid and not perform any of the subsequent steps.

7.5. Processing Redirect Information

In order to process redirect information (Section 2.1), the device MUST follow the steps presented in this section.

Processing redirect information is straightforward. The device sequentially steps through the list of provided bootstrap servers until it can find one it can bootstrap off of.

If a hostname is provided, and the hostname's DNS resolution is to more than one IP address, the device MUST attempt to connect to all of the DNS resolved addresses at least once, before moving on to the next bootstrap server. If the device is able to obtain bootstrapping data from any of the DNS resolved addresses, it MUST immediately process that data, without attempting to connect to any of the other DNS resolved addresses.

If the redirect information is trusted (e.g., trust-state is TRUE), and the bootstrap server entry contains a trust anchor certificate, then the device MUST authenticate the bootstrap server using X.509 certificate path validation ([RFC6125], Section 6) to the specified trust anchor. If the device is unable to authenticate the bootstrap server to the specified trust anchor, the device MUST NOT attempt a provisional connection to the bootstrap server (i.e., by blindly accepting its server certificate).

If the redirect information is untrusted (e.g., trust-state is FALSE), the device MUST discard any trust anchors provided by the redirect information and establish a provisional connection to the bootstrap server (i.e., by blindly accepting its TLS server certificate).

7.6. Processing Onboarding Information

In order to process onboarding information (Section 2.2), the device MUST follow the steps presented in this section.

When processing onboarding information, the device MUST first process the boot image information, then execute the pre-configuration script (if any), then commit the initial configuration, and then execute the script (if any), in that order. If the device encounters an error at any step, it MUST NOT proceed to the next step.

First the device MUST determine if the image it is running satisfies the specified boot image criteria (e.g., name or fingerprint match). If it does not, the device MUST download (using the supplied URI), verify, and install the specified boot image, and then reboot. To verify the boot image, the device MUST check that the boot image file

matches the fingerprint (e.g., sha256) supplied by the bootstrapping information. Upon rebooting, the device MUST still be in its factory default state, causing the bootstrapping process to run again, which will eventually come to this very point, but this time the device's running image will satisfy the specified criteria, and thus the device will move to processing the next step.

Next, for devices that support executing scripts, if a pre-configuration script has been specified, the device MUST execute the script and check its exit status code to determine if had any warnings or errors. In the case of errors, the device MUST reset itself in such a way that force the reinstallation of its boot image, thereby wiping out any bad state the script might have left behind.

Next the device commits the provided initial configuration. Assuming no errors, the device moves to processing the next step.

Again, for devices that support executing scripts, if a post-configuration script has been specified, the device MUST execute the script and check its exit status code to determine if it had any warnings or errors. In the case of errors, the device MUST reset itself in such a way that force the reinstallation of its boot image, thereby wiping out any bad state the script might have left behind.

At this point, the device has completely processed the bootstrapping data and is ready to be managed. If the device obtained the bootstrap information from a trusted bootstrap server, the device MUST send the 'bootstrap-complete' notification now.

At this point the device is configured and no longer running its factory default configuration. Notably, if the onboarding information configured the device it initiate a call home connection, the device would proceed to do so now.

8. The Zero Touch Information Artifact

This section defines a YANG [RFC6020] module that is used to define the data model for the zero touch information artifact described in Section 3.1. Examples illustrating this artifact in use are provided in Section 8.2.

8.1. Tree Diagram

The following tree diagram provides an overview of the data model for the zero touch information artifact. The syntax used for this tree diagram is described in Section 1.4.

```
module: ietf-zerotouch-information
  +---- (information-type)
     +--:(redirect-information)
     |  +---- redirect-information
     |     +---- bootstrap-server* [address]
     |        +---- address         inet:host
     |        +---- port?           inet:port-number
     |        +---- trust-anchor?   binary
     +--:(onboarding-information)
        +---- onboarding-information
           +---- boot-image
           |  +---- name      string
           |  +---- (hash-algorithm)
           |  |  +--:(sha256)
           |  |     +---- sha256?   string
           |  +---- uri*      inet:uri
           +---- configuration-handling?      enumeration
           +---- pre-configuration-script?    script
           +---- configuration?               <anydata>
           +---- post-configuration-script?   script
```

8.2. Example Usage

This section presents examples for how the zero touch information artifact (Section 3.1) can be encoded into a document that can be distributed outside the bootstrap server's RESTCONF API.

The following example illustrates how redirect information can be encoded into an artifact.

```
   <redirect-information
     xmlns="urn:ietf:params:xml:ns:yang:ietf-zerotouch-information">
     <bootstrap-server>
       <address>phs1.example.com</address>
       <port>8443</port>
       <trust-anchor>Base64-encoded X.50 </trust-anchor>
     </bootstrap-server>
     <bootstrap-server>
       <address>phs2.example.com</address>
       <port>8443</port>
       <trust-anchor>Base64-encoded X.50 </trust-anchor>
     </bootstrap-server>
     <bootstrap-server>
       <address>phs3.example.com</address>
       <port>8443</port>
       <trust-anchor>Base64-encoded X.50 </trust-anchor>
     </bootstrap-server>
   </redirect-information>
```

The following example illustrates how onboarding information can be encoded into an artifact. This example uses data models from [RFC7317] and [I-D.ietf-netconf-netconf-client-server].

```
<-- '\' line wrapping added for formatting purposes only -->

<onboarding-information
  xmlns="urn:ietf:params:xml:ns:yang:ietf-zerotouch-information">
  <boot-image>
    <name>boot-image-v3.2R1.6.img</name>
    <sha256>Hex-encoded SHA256 hash</sha256>
    <uri>file:///some/path/to/raw/file </uri>
  </boot-image>
  <configuration-handling>merge</configuration-handling>
  <configuration>
    <!-- from ietf-system.yang -->
    <system xmlns="urn:ietf:params:xml:ns:yang:ietf-system">
      <authentication>
        <user>
          <name>admin</name>
          <authorized-key>
            <name>admin's rsa ssh host-key</name>
            <algorithm>ssh-rsa</algorithm>
            <key-data>AAAAB3NzaC1yc2EAAAADAQABAAABAQDeJMV8zrtsi8CgEsRC\
            jCzfve2m6zD3awSBPrh7ICggLQvHVbPL89eHLuecStKL3HrEgXaI/O2Mwj\
            E1lG9YxLzeS5p2ngzK61vikUSqfMukeBohFTrDZ8bUtrF+HMLlTRnoCVcC\
            WAw1lOr9IDGDAuww6G45gLcHalHMmBtQxKnZdzU9kx/fL3ZS5G76Fy6sA5\
            vg7SLqQFPjXXft2CAhin8xwYRZy6r/2N9PMJ2Dnepvq4H2DKqBIe340jWq\
```

```
            EIuA7LvEJYql4unq4Iog+/+CiumTkmQIWRgIoj4FCzYkO9NvRE6fOSLLf6\
            gakWVOZZgQ8929uWjCWlGlqn2mPibp2Go1</key-data>
          </authorized-key>
        </user>
      </authentication>
    </system>
    <!-- from ietf-netconf-server.yang -->
    <netconf-server
      xmlns="urn:ietf:params:xml:ns:yang:ietf-netconf-server">
      <call-home>
        <netconf-client>
          <name>config-mgr</name>
          <ssh>
            <endpoints>
              <endpoint>
                <name>east-data-center</name>
                <address>11.22.33.44</address>
              </endpoint>
              <endpoint>
                <name>west-data-center</name>
                <address>55.66.77.88</address>
              </endpoint>
            </endpoints>
            <host-keys>
              <host-key>
                <name>certificate</name>
                <certificate>builtin-idevid-cert</certificate>
              </host-key>
            </host-keys>
            <client-cert-auth>
              <trusted-ca-certs>deployment-specific-ca-certs</trusted-ca-certs>
              <trusted-client-certs>explicitly-trusted-client-certs</trusted-
client-certs>
            </client-cert-auth>
          </ssh>
          <connection-type>
            <periodic>
              <idle-timeout>300</idle-timeout>
              <reconnect-timeout>60</reconnect-timeout>
            </periodic>
          </connection-type>
          <reconnect-strategy>
            <start-with>last-connected</start-with>
            <max-attempts>3</max-attempts>
          </reconnect-strategy>
        </netconf-client>
      </call-home>
    </netconf-server>
  </configuration>
```

```
</onboarding-information>
```

8.3. YANG Module

The zero touch information artifact is normatively defined by the YANG module defined in this section.

Note: the module defined herein uses data types defined in [RFC5280], [RFC6234], and [RFC6991].

```
<CODE BEGINS> file "ietf-zerotouch-information@2017-06-19.yang"

module ietf-zerotouch-information {
  yang-version "1.1";

  namespace "urn:ietf:params:xml:ns:yang:ietf-zerotouch-information";
  prefix    "zti";

  import ietf-inet-types {
    prefix inet;
    reference "RFC 6991: Common YANG Data Types";
  }

  import ietf-restconf {
    prefix rc;
    description
      "This import statement is only present to access
       the yang-data extension defined in RFC 8040.";
    reference "RFC 8040: RESTCONF Protocol";
  }

  organization
   "IETF NETCONF (Network Configuration) Working Group";

  contact
   "WG Web:   http://tools.ietf.org/wg/netconf
    WG List:  <mailto:netconf@ietf.org>
    Author:   Kent Watsen <mailto:kwatsen@juniper.net>";

  description
   "This module defines the data model for the Zero Touch Information
    artifact defined by RFC XXXX: Zero Touch Provisioning for NETCONF
    or RESTCONF based Management.

    Copyright (c) 2014 IETF Trust and the persons identified as
    authors of the code. All rights reserved.

    Redistribution and use in source and binary forms, with or without
```

```
    modification, is permitted pursuant to, and subject to the license
    terms contained in, the Simplified BSD License set forth in Section
    4.c of the IETF Trust's Legal Provisions Relating to IETF Documents
    (http://trustee.ietf.org/license-info).

    This version of this YANG module is part of RFC XXXX; see the RFC
    itself for full legal notices.";

  revision "2017-06-19" {
    description
     "Initial version";
    reference
     "RFC XXXX: Zero Touch Provisioning for NETCONF or RESTCONF based
      Management";
  }

  rc:yang-data zerotouch-information {

    choice information-type {
      mandatory true;
      description
        "This choice statement ensures the response only contains
         redirect-information or onboarding-information.  Note that
         this is the only mandatory true node, as the other nodes
         are not needed when the device trusts the bootstrap server,
         in which case the data does not need to be signed.";

      container redirect-information {
        description
          "This is redirect information, as described in Section 2.1
           in RFC XXXX.  Its purpose is to redirect a device to another
           bootstrap server.";
        reference
          "RFC XXXX: Zero Touch Provisioning for NETCONF or RESTCONF
           based Management";

        list bootstrap-server {
          key address;
          description
            "A bootstrap server entry.";

          leaf address {
            type inet:host;
            mandatory true;
            description
             "The IP address or hostname of the bootstrap server the
              device should redirect to.";
          }
```

```
        leaf port {
          type inet:port-number;
          default 443;
          description
           "The port number the bootstrap server listens on.";
        }
        leaf trust-anchor { //should there be two fields like voucher?
          type binary;
          description
            "An X.509 v3 certificate structure as specified by RFC
             5280, Section 4, encoded using ASN.1 distinguished
             encoding rules (DER), as specified in ITU-T X.690.  A
             certificate that a device can use as a trust anchor
             to authenticate the bootstrap server it is being
             redirected to.";
          reference
            "RFC 5280:
               Internet X.509 Public Key Infrastructure Certificate
               and Certificate Revocation List (CRL) Profile.
             ITU-T X.690:
                Information technology - ASN.1 encoding rules:
                Specification of Basic Encoding Rules (BER),
                Canonical Encoding Rules (CER) and Distinguished
                Encoding Rules (DER).";
        }
      }
    }

    container onboarding-information {

      description
        "This is bootstrap information, as described in Section 2.2 in
         RFC XXXX.  Its purpose is to provide the device everything it
         needs to bootstrap itself.";
      reference
        "RFC XXXX: Zero Touch Provisioning for NETCONF or RESTCONF
         based Management";

      container boot-image {
        description
          "Specifies criteria for the boot image the device MUST
           be running.";

        leaf name {  // maybe this should be a regex?
          type string;
          mandatory true;
          description
            "The name of a software image that the device MUST
```

```
            be running in order to process the remaining nodes.";
        }
        choice hash-algorithm {
           mandatory true;
           description
             "Identifies the hash algorithm used.";
           leaf sha256 {
              type string;
              description
                "The hex-encoded SHA-256 hash over the boot
                 image file.  This is used by the device to
                 verify a downloaded boot image file.";
              reference
                "RFC 6234: US Secure Hash Algorithms.";
           }
        }
        leaf-list uri {
          type inet:uri;
          min-elements 1;
          description
            "An ordered list of URIs to where the boot-image file MAY
             be obtained.  Deployments MUST know in which URI schemes
             (http, ftp, etc.) a device supports.  If a secure scheme
             (e.g., https) is provided, a device MAY establish a
             provisional connection to the server, by blindly
             accepting the server's credentials (e.g., its TLS
             certificate)";
        }
      }

      leaf configuration-handling {
        type enumeration {
          enum merge {
            description
             "Merge configuration into existing running configuration.";
          }
          enum replace {
            description
              "Replace existing running configuration with the passed
               configuration.";
          }
        }
        description
          "This enumeration indicates how the server should process
           the provided configuration.  When not specified, the device
           MAY determine how to process the configuration using other
           means (e.g., vendor-specific metadata).";
      }
```

```
        leaf pre-configuration-script {
          type script;
          description
            "A script that, when present, is executed before the
             configuration has been processed.";
        }

        anydata configuration {
          must "../configuration-handling";
          description
            "Any configuration data model known to the device.  It may
             contain manufacturer-specific and/or standards-based data
             models.";
        }

        leaf post-configuration-script {
          type script;
          description
            "A script that, when present, is executed after the
             configuration has been processed.";
        }
      }
    }
  }

  typedef script {
    type binary;
    description
      "A device specific script that enables the execution of commands
       to perform actions not possible thru configuration alone.

       No attempt is made to standardize the contents, running context,
       or programming language of the script.  The contents of the
       script are considered specific to the vendor, product line,
       and/or model of the device.

       If a script is erroneously provided to a device that does not
       support the execution of scripts, the device SHOULD send a
       'script-warning' notification message, but otherwise continue
       processing the bootstrapping data as if the script had not
       been present.

       The script returns exit status code '0' on success and non-zero
       on error, with accompanying stderr/stdout for logging purposes.
       In the case of an error, the exit status code will specify what
       the device should do.

       If the exit status code is greater than zero, then the device
```

```
        should assume that the script had a soft error, which the
        script believes does not affect manageability.  If the device
        obtained the bootstrap information from a bootstrap server,
        it SHOULD send a 'script-warning' notification message.

        If the exit status code is less than zero, the device should
        assume the script had a hard error, which the script believes
        will affect manageability.  In this case, the device SHOULD
        send a 'script-error' notification message followed by a
        reset that will force a new boot-image install (wiping out
        anything the script may have done) and restart the entire
        bootstrapping process again.";
    }

}

<CODE ENDS>
```

9. The Zero Touch Bootstrap Server API

This section defines a YANG [RFC6020] module that is used to define the RESTCONF [RFC8040] API used by the bootstrap server defined in Section 5.4. Examples illustrating this API in use are provided in Section 9.2.

9.1. Tree Diagram

The following tree diagram provides an overview for the bootstrap server RESTCONF API. The syntax used for this tree diagram is described in Section 1.4.

```
module: ietf-zerotouch-bootstrap-server
    +--ro device* [unique-id]
       +--ro unique-id                string
       +--ro zerotouch-information    pkcs7
       +--ro owner-certificate?       pkcs7
       +--ro ownership-voucher?       pkcs7
       +---x notification
          +---w input
             +---w notification-type    enumeration
             +---w message?             string
             +---w ssh-host-keys
             |  +---w ssh-host-key*
             |     +---w format      enumeration
             |     +---w key-data    string
             +---w trust-anchors
                +---w trust-anchor*
                   +---w protocol*      enumeration
                   +---w certificate    pkcs7
```

In the above diagram, notice that all of the protocol accessible nodes are read-only, to assert that devices can only pull data from the bootstrap server.

Also notice that the module defines an action statement, which devices use to provide progress notifications to the bootstrap server.

9.2. Example Usage

This section presents some examples illustrating the bootstrap server's API. Two examples are provided, one illustrating a device fetching bootstrapping data from the server, and the other illustrating a data posting a progress notification to the server.

The following example illustrates a device using the API to fetch its bootstrapping data from the bootstrap server. In this example, the device receives a signed response; an unsigned response would look similar except the last two fields (owner-certificate and ownership-voucher) would be absent in the response.

```
REQUEST
-------
['\' line wrapping added for formatting only]

GET https://example.com/restconf/data/ietf-zerotouch-bootstrap-server:\
device=123456 HTTP/1.1
HOST: example.com
Accept: application/yang.data+xml


RESPONSE
--------

HTTP/1.1 200 OK
Date: Sat, 31 Oct 2015 17:02:40 GMT
Server: example-server
Content-Type: application/yang.data+xml

<!-- '\' line wrapping added for formatting purposes only -->

<device
  xmlns="urn:ietf:params:xml:ns:yang:ietf-zerotouch-bootstrap-server">
  <unique-id>123456789</unique-id>
  <zerotouch-information>Base64-encoded PKCS#7<zerotouch-information>
  <owner-certificate>Base64-encoded PKCS#7</owner-certificate>
  <ownership-voucher>Base64-encoded PKCS#7</ownership-voucher>
</device>
```

The following example illustrates a device using the API to post a notification to a bootstrap server. Illustrated below is the 'bootstrap-complete' message, but the device may send other notifications to the server while bootstrapping (e.g., to provide status updates). In this message, the device is sending both its SSH host keys and TLS server certificate, which the bootstrap server may, for example, pass to an NMS, as discussed in Section 6.3.

Note that devices that are able to present an IDevID certificate [Std-802.1AR-2009] when establishing SSH or TLS connections do not need to include its DevID certificate in the bootstrap-complete message. It is unnecessary to send the DevID certificate in this case because the IDevID certificate does not need to be pinned by an NMS in order to be trusted.

Note that the bootstrap server MUST NOT process a notification from a device without first authenticating the device. This is in contrast to when a device is fetching data from the server, a read-only operation, in which case device authentication is not strictly required (e.g., when sending signed information).

```
REQUEST
-------
['\' line wrapping added for formatting only]

POST https://example.com/restconf/data/ietf-zerotouch:\
device=123456/notification HTTP/1.1
HOST: example.com
Content-Type: application/yang.data+xml

<!-- '\' line wrapping added for formatting purposes only -->

<input
  xmlns="urn:ietf:params:xml:ns:yang:ietf-zerotouch-bootstrap-server">
  <notification-type>bootstrap-complete</notification-type>
  <message>example message</message>
  <ssh-host-keys>
    <ssh-host-key>
      <format>ssh-rsa</format>
      <key-data>Base64-encoded SSH RSA Public Key</key-data>
    </ssh-host-key>
    <ssh-host-key>
      <format>ssh-dsa</format>
      <key-data>Base64-encoded SSH DSA Public Key</key-data>
    </ssh-host-key>
  </ssh-host-keys>
  <trust-anchors>
    <trust-anchor>
      <protocol>netconf-ssh</protocol>
      <protocol>netconf-tls</protocol>
      <protocol>restconf-tls</protocol>
      <protocol>netconf-ch-ssh</protocol>
      <protocol>netconf-ch-tls</protocol>
      <protocol>restconf-ch-tls</protocol>
      <certificate>Base64-encoded X.509</certificate>
    </trust-anchor>
  </trust-anchors>
</input>


RESPONSE
--------

HTTP/1.1 204 No Content
Date: Sat, 31 Oct 2015 17:02:40 GMT
Server: example-server
```

9.3. YANG Module

The bootstrap server's device-facing API is normatively defined by the YANG module defined in this section.

Note: the module defined herein uses data types defined in [RFC2315], [RFC5280], and [I-D.ietf-anima-voucher].

```
<CODE BEGINS> file "ietf-zerotouch-bootstrap-server@2017-06-19.yang"

module ietf-zerotouch-bootstrap-server {
  yang-version "1.1";

  namespace
    "urn:ietf:params:xml:ns:yang:ietf-zerotouch-bootstrap-server";
  prefix    "ztbs";

  organization
   "IETF NETCONF (Network Configuration) Working Group";

  contact
   "WG Web:   <http://tools.ietf.org/wg/netconf/>
    WG List:  <mailto:netconf@ietf.org>
    Author:   Kent Watsen
              <mailto:kwatsen@juniper.net>";

  description
   "This module defines an interface for bootstrap servers, as defined
    by RFC XXXX: Zero Touch Provisioning for NETCONF or RESTCONF based
    Management.

    Copyright (c) 2014 IETF Trust and the persons identified as
    authors of the code. All rights reserved.

    Redistribution and use in source and binary forms, with or without
    modification, is permitted pursuant to, and subject to the license
    terms contained in, the Simplified BSD License set forth in Section
    4.c of the IETF Trust's Legal Provisions Relating to IETF Documents
    (http://trustee.ietf.org/license-info).

    This version of this YANG module is part of RFC XXXX; see the RFC
    itself for full legal notices.";

  revision "2017-06-19" {
    description
     "Initial version";
    reference
     "RFC XXXX: Zero Touch Provisioning for NETCONF or RESTCONF based
```

```
      Management";
  }

  // typedefs

  typedef pkcs7 {
    type binary;
    description
      "A PKCS #7 SignedData structure, as specified by Section 9.1
       in RFC 2315, encoded using ASN.1 distinguished encoding rules
       (DER), as specified in ITU-T X.690.";
     reference
       "RFC 2315:
          PKCS #7: Cryptographic Message Syntax Version 1.5.
        ITU-T X.690:
          Information technology - ASN.1 encoding rules:
          Specification of Basic Encoding Rules (BER),
          Canonical Encoding Rules (CER) and Distinguished
          Encoding Rules (DER).";
  }

  // protocol accessible node

  list device {
    key unique-id;
    config false;

    description
      "A device's record entry.  This is the only RESTCONF resource
       that a device will GET, as described in Section 8.2 in RFC XXXX.
       Getting just this top-level node provides a device with all the
       data it needs in a single request.";
    reference
      "RFC XXXX: Zero Touch Provisioning for NETCONF or
       RESTCONF based Management";

    leaf unique-id {
      type string;
      description
        "A unique identifier for the device (e.g., serial number).
         Each device accesses its bootstrapping record by its unique
         identifier.";
    }

    leaf zerotouch-information {
      type pkcs7;
      mandatory true;
      description
```

```
        "A 'zerotouch-information' artifact, as described in Section
         4.1 of RFC XXXX.  When conveyed over an untrusted transport, in
         order to be processed by a device, this PKCS#7 SignedData
         structure  MUST contain a 'signerInfo' structure, described
         in Section 9.1 of RFC 2315, containing a signature generated
         using the owner's private key.";
      reference
        "RFC XXXX: Zero Touch Provisioning for NETCONF or
           RESTCONF based Management.
         RFC 2315:
           PKCS #7: Cryptographic Message Syntax Version 1.5";
    }

    leaf owner-certificate {
      type pkcs7;
      description
        "An unsigned PKCS #7 SignedData structure, as specified by
         Section 9.1 in RFC 2315, encoded using ASN.1 distinguished
         encoding rules (DER), as specified in ITU-T X.690.

         This structure MUST contain the owner certificate and all
         intermediate certificates leading up to at least the trust
         anchor certificate specified in the ownership voucher.
         Additionally, if needed by the device, this structure MAY
         also contain suitably fresh CRL and or OCSP Responses.

         X.509 certificates and CRLs are described in RFC 5280.
         OCSP Responses are described in RFC 6960.";
      reference
       "RFC 2315:
          PKCS #7: Cryptographic Message Syntax Version 1.5.
        RFC 5280:
          Internet X.509 Public Key Infrastructure Certificate
          and Certificate Revocation List (CRL) Profile.
        RFC 6960:
          X.509 Internet Public Key Infrastructure Online
          Certificate Status Protocol - OCSP.
        ITU-T X.690:
          Information technology - ASN.1 encoding rules:
          Specification of Basic Encoding Rules (BER),
          Canonical Encoding Rules (CER) and Distinguished
          Encoding Rules (DER).";
    }

    leaf ownership-voucher {
      type pkcs7;
      must "../owner-certificate" {
        description
```

```
          "An owner certificate must be present whenever an ownership
           voucher is presented.";
      }
      description
        "A 'voucher' artifact, as described in Section 5 of
         I-D.ietf-anima-voucher.  The voucher informs the device
         who it's 'owner' is.  The voucher encodes the device's
         serial number, so that the device can be ensured that
         the voucher applies to it.  The voucher is signed by
         the device's manufacturer or delagate.";
      reference
        "I-D.etf-anima-voucher:
           Voucher and Voucher Revocation Profiles for Bootstrapping
           Protocols";
    }

    action notification {
      input {
        leaf notification-type {
          type enumeration {
            enum bootstrap-initiated {
              description
                "Indicates that the device has just accessed the
                 bootstrap server.  The 'message' field below MAY
                 contain any additional information that the
                 manufacturer thinks might be useful.";
            }
            enum parsing-warning {
              description
                "Indicates that the device had a non-fatal error when
                 parsing the response from the bootstrap server.  The
                 'message' field below SHOULD indicate the specific
                 warning that occurred.";
            }
            enum parsing-error {
              description
                "Indicates that the device encountered a fatal error
                 when parsing the response from the bootstrap server.
                 For instance, this could be due to malformed encoding,
                 the device expecting signed data when only unsigned
                 data is provided, because the ownership voucher didn't
                 include the device's unique identifier, or because the
                 signature didn't match.  The 'message' field below
                 SHOULD indicate the specific error.  This notification
                 also indicates that the device has abandoned trying to
                 bootstrap off this bootstrap server.";
            }
            enum boot-image-warning {
```

```
        description
          "Indicates that the device encountered a non-fatal
           error condition when trying to install a boot-image.
           A possible reason might include a need to reformat a
           partition causing loss of data.  The 'message' field
           below SHOULD indicate any warning messages that were
           generated.";
      }
      enum boot-image-error {
        description
          "Indicates that the device encountered an error when
           trying to install a boot-image, which could be for
           reasons such as a file server being unreachable,
           file not found, signature mismatch, etc.  The
           'message' field SHOULD indicate the specific error
           that occurred.  This notification also indicates
           that the device has abandoned trying to bootstrap
           off this bootstrap server.";
      }
      enum pre-script-warning {
        description
          "Indicates that the device obtained a greater than
           zero exit status code from the script when it was
           executed.  The 'message' field below SHOULD indicate
           both the resulting exit status code, as well as
           capture any stdout/stderr messages the script may
           have produced.";
      }
      enum pre-script-error {
        description
          "Indicates that the device obtained a less than zero
           exit status code from the script when it was executed.
           The 'message' field below SHOULD indicate both the
           resulting exit status code, as well as capture any
           stdout/stderr messages the script may have produced.
           This notification also indicates that the device has
           abandoned trying to bootstrap off this bootstrap
           server.";
      }
      enum config-warning {
        description
          "Indicates that the device obtained warning messages
           when it committed the initial configuration.  The
           'message' field below SHOULD indicate any warning
           messages that were generated.";
      }
      enum config-error {
        description
```

```
            "Indicates that the device obtained error messages
             when it committed the initial configuration.  The
             'message' field below SHOULD indicate the error
             messages that were generated.  This notification
             also indicates that the device has abandoned trying
             to bootstrap off this bootstrap server.";
          }
          enum post-script-warning {
            description
              "Indicates that the device obtained a greater than
               zero exit status code from the script when it was
               executed.  The 'message' field below SHOULD indicate
               both the resulting exit status code, as well as
               capture any stdout/stderr messages the script may
               have produced.";
          }
          enum post-script-error {
            description
              "Indicates that the device obtained a less than zero
               exit status code from the script when it was executed.
               The 'message' field below SHOULD indicate both the
               resulting exit status code, as well as capture any
               stdout/stderr messages the script may have produced.
               This notification also indicates that the device has
               abandoned trying to bootstrap off this bootstrap
               server.";
          }
          enum bootstrap-complete {
            description
              "Indicates that the device successfully processed the
               all the bootstrapping data and that it is ready to be
               managed.  The 'message' field below MAY contain any
               additional information that the manufacturer thinks
               might be useful.  After sending this notification,
               the device is not expected to access the bootstrap
               server again.";
          }
          enum informational {
            description
              "Indicates any additional information not captured by
               any of the other notification-type. For instance, a
               message indicating that the device is about to reboot
               after having installed a boot-image could be provided.
               The 'message' field below SHOULD contain information
               that the manufacturer thinks might be useful.";
          }
        }
        mandatory true;
```

```
          description
            "The type of notification provided.";
        }
        leaf message {
          type string;
          description
            "An optional human-readable value.";
        }
        container ssh-host-keys {
          when "../notification-type = 'bootstrap-complete'" {
            description
              "SSH host keys are only sent when the notification
               type is 'bootstrap-complete'.";
          }
          description
            "A list of SSH host keys an NMS may use to authenticate
             a NETCONF connection to the device with.";
          list ssh-host-key {
            description
              "An SSH host-key";
            leaf format {
              type enumeration {
                enum ssh-dss { description "ssh-dss"; }
                enum ssh-rsa { description "ssh-rsa"; }
              }
              mandatory true;
              description
                "The format of the SSH host key.";
            }
            leaf key-data {
              type string;
              mandatory true;
              description
                "The key data for the SSH host key";
            }
          }
        }
        container trust-anchors {
          when "../notification-type = 'bootstrap-complete'" {
            description
              "Trust anchors are only sent when the notification
               type is 'bootstrap-complete'.";
          }
          description
            "A list of trust anchor certificates an NMS may use to
             authenticate a NETCONF or RESTCONF connection to the
             device with.";
          list trust-anchor {
```

```
            description
              "A list of trust anchor certificates an NMS may use to
               authenticate a NETCONF or RESTCONF connection to the
               device with.";
            leaf-list protocol {
              type enumeration {
                enum netconf-ssh     { description "netconf-ssh"; }
                enum netconf-tls     { description "netconf-tls"; }
                enum restconf-tls    { description "restconf-tls"; }
                enum netconf-ch-ssh  { description "netconf-ch-ssh"; }
                enum netconf-ch-tls  { description "netconf-ch-tls"; }
                enum restconf-ch-tls { description "restconf-ch-tls"; }
              }
              min-elements 1;
              description
                "The protocols that this trust anchor secures.";
            }
            leaf certificate {
              type pkcs7;
              mandatory true;
              description
                "An X.509 v3 certificate structure, as specified by
                 Section 4 in RFC5280, encoded using ASN.1 distinguished
                 encoding rules (DER), as specified in ITU-T X.690.";
              reference
                "RFC 5280:
                   Internet X.509 Public Key Infrastructure Certificate
                   and Certificate Revocation List (CRL) Profile.
                 ITU-T X.690:
                    Information technology - ASN.1 encoding rules:
                    Specification of Basic Encoding Rules (BER),
                    Canonical Encoding Rules (CER) and Distinguished
                    Encoding Rules (DER).";
            }
          }
        }
      }
    } // end action

  } // end device

}

<CODE ENDS>
```

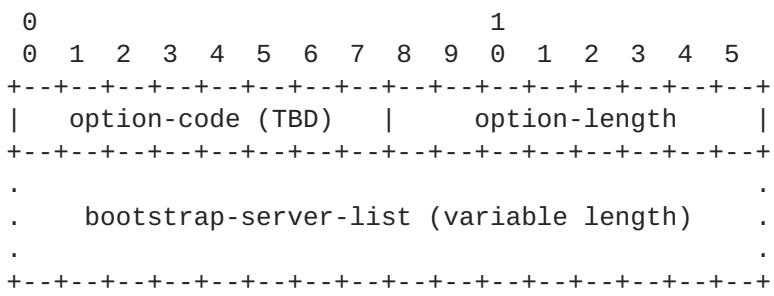
10. DHCP Zero Touch Options

This section defines two DHCP options, one for DHCPv4 and one for DHCPv6. These two options are semantically the same, though syntactically different.

10.1. DHCPv4 Zero Touch Option

The DHCPv4 Zero Touch Option is used to provision the client with one or more URIs for bootstrap servers that can be contacted to attempt further configuration.

DHCPv4 Zero Touch Redirect Option



- option-code: OPTION_V4_ZEROTOUCH_REDIRECT (TBD)
- option-length: The option length in octets
- bootstrap-server-list: A list of servers for the client to attempt contacting, in order to obtain further bootstrapping data, in the format shown in [common-field-encoding].

DHCPv4 Client Behavior

Clients MAY request the OPTION_V4_ZEROTOUCH_REDIRECT by including its option code in the Parameter Request List (55) in DHCP request messages.

On receipt of a DHCPv4 Reply message which contains the OPTION_V4_ZEROTOUCH_REDIRECT, the client performs the following steps:

1. Check the contents of the DHCPv4 message for at least one valid URI. If there is more than one valid URI in the list, a candidate list of possible URIs is created.

2. Attempt to connect to the one of the URIs in the candidate list. The order in which these are processed by the client is implementation specific and not defined here.

3. If a successful connection to the Zero Touch bootstrap server, then the client stops processing entries in the list and proceeds according to Section 6.3, step(3).

4. If the Zero Touch bootstrap server does not respond, provides an invalid response, or the transaction otherwise fails, the client SHOULD attempt to contact another server from the candidate list.

Any invalid URI entries received in the uri-data field are ignored by the client. If OPTION_V4_ZEROTOUCH_REDIRECT does not contain at least one valid URI entry in the uri-data field, then the client MUST discard the option.

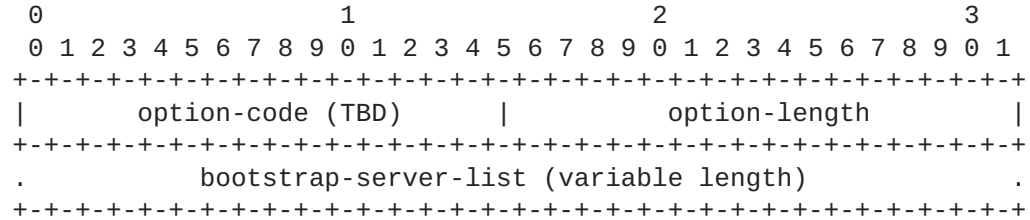
DHCPv4 Server Behavior

The DHCPv4 server MAY include a single instance of Option OPTION_V4_ZEROTOUCH_REDIRECT in DHCP messages it sends. Servers MUST NOT send more than one instance of the OPTION_V4_ZEROTOUCH_REDIRECT option.

10.2. DHCPv6 Zero Touch Option

The DHCPv6 Zero Touch Option is used to provision the client with one or more URIs for bootstrap servers that can be contacted to attempt further configuration.

DHCPv6 Zero Touch Redirect Option



o option-code: OPTION_V6_ZEROTOUCH_REDIRECT (TBD)
o option-length: The option length in octets
o bootstrap-server-list: A list of servers for the client to attempt contacting, in order to obtain further bootstrapping data, in the format shown in [common-field-encoding].

DHCPv6 Client Behavior

Clients MAY request the OPTION_V6_ZEROTOUCH_REDIRECT option, as defined in [RFC3315], Sections 17.1.1, 18.1.1, 18.1.3, 18.1.4, 18.1.5, and 22.7. As a convenience to the reader, we mention here

that the client includes requested option codes in the Option Request Option.

On receipt of a DHCPv6 reply message which contains the OPTION_V6_ZEROTOUCH_REDIRECT, the client performs the following steps:

1. Check the contents of the DHCPv6 message for at least one valid URI. If there is more than one valid URI in the list, a candidate list of possible URIs is created.

2. Attempt to connect to the one of the URIs in the candidate list. The order in which these are processed by the client is implementation specific and not defined here.

3. If a successful connection to the Netconf Zero Touch Bootstrap server, then the client stops processing entries in the list and proceeds according to Section 6.3, step(3).

4. If the Zero Touch bootstrap server does not respond, provides and invalid response or the transaction otherwise fails, the client SHOULD attempt to contact another server from the candidate list.

Any invalid URI entries received in the uri-data field are ignored by the client. If OPTION_V6_ZEROTOUCH_REDIRECT does not contain at least one valid URI entry in the uri-data field, then the client MUST discard the option.

DHCPv6 Server Behavior

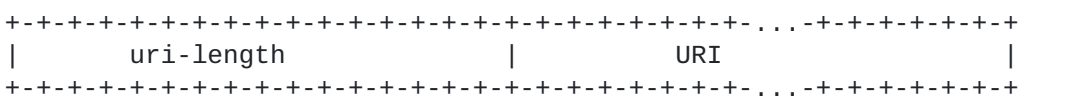
Sections 17.2.2 and 18.2 of [RFC3315] govern server operation in regard to option assignment. As a convenience to the reader, we mention here that the server will send a particular option code only if configured with specific values for that option code and if the client requested it.

Option OPTION_V6_ZEROTOUCH_REDIRECT is a singleton. Servers MUST NOT send more than one instance of the OPTION_V6_ZEROTOUCH_REDIRECT option.

10.3. Common Field Encoding

Both of the DHCPv4 and DHCPv6 options defined in this section encode a list of bootstrap server URIs. The 'URI' structure is an option that can contain multiple URIs (see [RFC7227], Section 5.7).

bootstrap-server-list:



o uri-length: variable, in octets.

o URI: URI of Netconf zerotouch bootstrap server, using the HTTPS URI scheme defined in Section 2.7.2 of RFC7230.

11. Security Considerations

11.1. Immutable storage for trust anchors

Devices MUST ensure that all their trust anchor certificates, including those for connecting to bootstrap servers and verifying ownership vouchers, are protected from external modification.

It may be necessary to update these certificates over time (e.g., the manufacturer wants to delegate trust to a new CA). It is therefore expected that devices MAY update these trust anchors when needed through a verifiable process, such as a software upgrade using signed software images.

11.2. Clock Sensitivity

The solution in this document relies on TLS certificates, owner certificates, and ownership vouchers, all of which require an accurate clock in order to be processed correctly (e.g., to test validity dates and revocation status). Implementations MUST ensure devices have an accurate clock when shipped from manufacturing facilities, and take steps to prevent clock tampering.

If it is not possible to ensure clock accuracy, it is RECOMMENDED that implementations disable the aspects of the solution having clock sensitivity. In particular, such implementations should assume that TLS certificates and owner certificates are not revokable. In real-world terms, this means that manufacturers SHOULD only issue a single ownership voucher for the lifetime of some devices.

It is important to note that implementations SHOULD NOT rely on NTP for time, as it is not a secure protocol.

11.3. Blindly authenticating a bootstrap server

This document allows a device to blindly authenticate a bootstrap server's TLS certificate. It does so to allow for cases where the redirect information may be obtained in an unsecured manner, which is desirable to support in some cases.

To compensate for this, this document requires that devices, when connected to an untrusted bootstrap server, do not send their IDevID certificate for client authentication, and they do not POST any progress notifications, and they assert that data downloaded from the server is signed.

11.4. Entropy loss over time

Section 7.2.7.2 of the IEEE Std 802.1AR-2009 standard says that IDevID certificate should never expire (i.e. having the notAfter value 99991231235959Z). Given the long-lived nature of these certificates, it is paramount to use a strong key length (e.g., 512-bit ECC).

11.5. Serial Numbers

This draft uses the device's serial number both in the IDevID certificate as well as in the bootstrap server API. Serial numbers are are ubiquitous and prominently contained in invoices and on labels affixed to devices and their packaging. That said, serial numbers many times encode revealing information, such as the device's model number, manufacture date, and/or sequence number. Knowledge of this information may provide an adversary with details needed to launch an attack.

11.6. Sequencing Sources of Bootstrapping Data

For devices supporting more than one source for bootstrapping data, no particular sequencing order has to be observed for security reasons, as the solution for each source is considered equally secure. However, from a privacy perspective, it is RECOMMENDED that devices access local sources before accessing remote sources.

12. IANA Considerations

12.1. The BOOTP Manufacturer Extensions and DHCP Options Registry

IANA is kindly requested to allocate a new option code from the "BOOTP Manufacturer Extensions and DHCP Options" registry maintained at http://www.iana.org/assignments/bootp-dhcp-parameters:

TBD for OPTION_V4_ZEROTOUCH_REDIRECT

And a new option code from the "Dynamic Host Configuration Protocol for IPv6 (DHCPv6)" registry maintained at http://www.iana.org/assignments/dhcpv6-parameters:

TBD for OPTION_V6_ZEROTOUCH_REDIRECT

12.2. The IETF XML Registry

This document registers two URIs in the IETF XML registry [RFC3688]. Following the format in [RFC3688], the following registrations are requested:

URI: urn:ietf:params:xml:ns:yang:ietf-zerotouch-information
Registrant Contact: The NETCONF WG of the IETF.
XML: N/A, the requested URI is an XML namespace.

URI: urn:ietf:params:xml:ns:yang:ietf-zerotouch-bootstrap-server
Registrant Contact: The NETCONF WG of the IETF.
XML: N/A, the requested URI is an XML namespace.

12.3. The YANG Module Names Registry

This document registers two YANG modules in the YANG Module Names registry [RFC6020]. Following the format defined in [RFC6020], the the following registrations are requested:

```
name:         ietf-zerotouch-information
namespace:    urn:ietf:params:xml:ns:yang:ietf-zerotouch-information
prefix:       zt
reference:    RFC XXXX

name:         ietf-zerotouch-bootstrap-server
namespace:    urn:ietf:params:xml:ns:yang:ietf-zerotouch-bootstrap-server
prefix:       zt
reference:    RFC XXXX
```

13. Other Considerations

Both this document and [I-D.ietf-anima-bootstrapping-keyinfra] define bootstrapping mechanisms. The authors have collaborated on both solutions and believe that each solution has merit and, in fact, can work together. That is, it is possible for a device to support both solutions simultaneously.

14. Acknowledgements

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Appendix A. Change Log

A.1. ID to 00

- Major structural update; the essence is the same. Most every section was rewritten to some degree.
- Added a Use Cases section
- Added diagrams for "Actors and Roles" and "NMS Precondition" sections, and greatly improved the "Device Boot Sequence" diagram
- Removed support for physical presence or any ability for configlets to not be signed.
- Defined the Zero Touch Information DHCP option
- Added an ability for devices to also download images from configuration servers
- Added an ability for configlets to be encrypted
- Now configuration servers only have to support HTTP/S - no other schemes possible

A.2. 00 to 01

- Added boot-image and validate-owner annotations to the "Actors and Roles" diagram.
- Fixed 2nd paragraph in section 7.1 to reflect current use of anyxml.
- Added encrypted and signed-encrypted examples
- Replaced YANG module with XSD schema
- Added IANA request for the Zero Touch Information DHCP Option
- Added IANA request for media types for boot-image and configuration

A.3. 01 to 02

- Replaced the need for a configuration signer with the ability for each NMS to be able to sign its own configurations, using manufacturer signed ownership vouchers and owner certificates.

- Renamed configuration server to bootstrap server, a more representative name given the information devices download from it.
- Replaced the concept of a configlet by defining a southbound interface for the bootstrap server using YANG.
- Removed the IANA request for the boot-image and configuration media types

A.4. 02 to 03

- Minor update, mostly just to add an Editor's Note to show how this draft might integrate with the draft-pritikin-anima-bootstrapping-keyinfra.

A.5. 03 to 04

- Major update formally introducing unsigned data and support for Internet-based redirect servers.
- Added many terms to Terminology section.
- Added all new "Guiding Principles" section.
- Added all new "Sources for Bootstrapping Data" section.
- Rewrote the "Interactions" section and renamed it "Workflow Overview".

A.6. 04 to 05

- Semi-major update, refactoring the document into more logical parts
- Created new section for information types
- Added support for DNS servers
- Now allows provisional TLS connections
- Bootstrapping data now supports scripts
- Device Details section overhauled
- Security Considerations expanded
- Filled in enumerations for notification types

A.7. 05 to 06

- Minor update
- Added many Normative and Informative references.
- Added new section Other Considerations.

A.8. 06 to 07

- Minor update
- Added an Editorial Note section for RFC Editor.
- Updated the IANA Considerations section.

A.9. 07 to 08

- Minor update
- Updated to reflect review from Michael Richardson.

A.10. 08 to 09

- Added in missing "Signature" artifact example.
- Added recommendation for manufacturers to use interoperable formats and file naming conventions for removable storage devices.
- Added configuration-handling leaf to guide if config should be merged, replaced, or processed like an edit-config/yang-patch document.
- Added a pre-configuration script, in addition to the post-configuration script from -05 (issue #15).

A.11. 09 to 10

- Factored ownership vocher and voucher revocation to a separate document: draft-kwatsen-netconf-voucher. (issue #11)
- Removed <configuration-handling> options 'edit-config' and yang-patch'. (issue #12)
- Defined how a signature over signed-data returned from a bootstrap server is processed. (issue #13)

- Added recommendation for removable storage devices to use open/ standard file systems when possible. (issue #14)

- Replaced notifications "script-[warning/error]" with "[pre/post]-script-[warning/error]". (goes with issue #15)

- switched owner-certificate to be encoded using the pkcs#7 format. (issue #16)

- Replaced md5/sha1 with sha256 inside a choice statement, for future extensibility. (issue #17)

- A ton of editorial changes, as I went thru the entire draft with a fine-toothed comb.

A.12. 10 to 11

- fixed yang validation issues found by IETFYANGPageCompilation. note: these issues were NOT found by pyang --ietf or by the submission-time validator...

- fixed a typo in the yang module, someone the config false statement was removed.

A.13. 11 to 12

- fixed typo that prevented Appendix B from loading the examples correctly.

- fixed more yang validation issues found by IETFYANGPageCompilation. note: again, these issues were NOT found by pyang --ietf or by the submission-time validator...

- updated a few of the notification enumerations to be more consistent with the other enumerations (following the warning/ error pattern).

- updated the information-type artifact to state how it's encoded, matching the language that was in Appendix B.

A.14. 12 to 13

- defined a standalone artifact to encode the old information-type into a PKCS#7 structure.

- standalone information artifact hardcodes JSON encoding (to match the voucher draft).

- combined the information and signature PKCS#7 structures into a single PKCS#7 structure.
- moved the certificate-revocations into the owner-certificate's PKCS#7 structure.
- eliminated support for voucher-revocations, to reflect the voucher-draft's switch from revocations to renewals.

A.15. 13 to 14

- Renamed "bootstrap information" to "onboarding information".
- Rewrote DHCP sections to address the packet-size limitation issue, as discussed in Chicago.
- Added Ian as an author for his text-contributions to the DHCP sections.
- Removed the Guiding Principles section.

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