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Zero Touch Provisioning for Networking Devices
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Abstract

This draft presents a technique to securely provision a networking device when it is booting in a factory-default state. Variations in the solution enables it to be used on both public and private networks. The provisioning steps are able to update the boot image, commit an initial configuration, and execute arbitrary scripts to address auxiliary needs. The updated device is subsequently able to establish secure connections with other systems. For instance, a device may establish NETCONF [[RFC6241](#)] and/or RESTCONF [[RFC8040](#)] connections with deployment-specific network management systems.

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. No other RFC Editor instructions are specified elsewhere in this document.

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

- o "TBD1" --> the assigned value for id-ct-zerotouchInformationXML
- o "TBD2" --> the assigned value for id-ct-zerotouchInformationJSON

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

- o "XXXX" --> the assigned numerical RFC value for this draft
- o "ZZZZ" --> the assigned numerical RFC value for [[I-D.ietf-anima-voucher](#)]

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

- o "2018-02-28" --> the publication date of this draft

Please update the following informative references to reflect its final RFC assignment:

- o I-D.ietf-netmod-yang-tree-diagrams

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

- o [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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[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 Secure Zero Touch Provisioning (SZTP), a bootstrapping strategy enabling devices to securely obtain bootstrapping data with no installer action beyond physical placement and connecting network and power cables. As such, SZTP enables non-technical personnel to bring up devices in remote locations without the need for any operator input.

The SZTP solution includes updating the boot image, committing an initial configuration, and executing arbitrary scripts to address auxiliary needs. The updated device is subsequently able to establish secure connections with other systems. For instance, a devices may establish NETCONF [[RFC8040](#)] and/or RESTCONF [[RFC6241](#)] connections with deployment-specific network management systems.

This document primarily regards physical devices, where the setting of the device's initial state, described in [Section 5.1](#), occurs during the device's manufacturing process. The SZTP solution may be extended to support virtual machines or other such logical constructs, but details for how this can be accomplished is left for future work.

[1.1.1.](#) Use Cases

- o 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 from.

- o 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 from. If no such information is available, or the device is unable to use the information provided, it can then reach out to the network just as it would for the remotely administered network use-case.

Conceptual workflows for how SZTP might be deployed are provided in [Appendix A](#).

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 during the bootstrapping process. Specifically, it refers to the three artifacts zero touch information, owner certificate, and ownership voucher, as described 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 7.3](#).

Device: The term "device" is used throughout this document to refer to a network element that needs to be bootstrapped. See [Section 5](#) for more information about devices.

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". Onboarding information is formally defined by the "onboarding-information" YANG-data structure in [Section 6.3](#).

Onboarding Server: The term "onboarding server" is used herein to refer to a bootstrap server that only returns onboarding information.

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 artifact. The owner certificate may be communicated along with its chain of intermediate certificates leading up to a known trust anchor. 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". Redirect information is formally defined by the "redirect-information" YANG-data structure in [Section 6.3](#).

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 a well-known (e.g., Internet-based) resource to redirect devices to deployment-specific bootstrap servers.

Signed Data: The term "signed data" is used throughout to mean zero touch 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 zero touch information that has not been signed.

Zero Touch Information: The term "zero touch information" is used 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 Diagrams

Tree diagrams used in this document follow the notation defined in [\[I-D.ietf-netmod-yang-tree-diagrams\]](#).

2. Types of Bootstrapping Information

This document defines two types of information that devices can access during the bootstrapping process. These information types are described in this section. Examples are provided in [Section 6.2](#)

2.1. Redirect Information

Redirect information redirects a device to another bootstrap server. Redirect information encodes a list of bootstrap servers, each specifying the bootstrap server's hostname (or IP address), an optional port, and an optional trust anchor certificate that the device can use to authenticate the bootstrap server with.

Redirect information is YANG modeled data formally defined by the "redirect-information" container in the YANG module presented in [Section 6.3](#). This container has the tree diagram shown below.

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

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 specified bootstrap server, which is possible when the redirect information includes the bootstrap server's trust anchor certificate.

Untrusted redirect information is useful for directing a device to a bootstrap server where signed data has been staged for it to obtain. Note that, when the redirect information is untrusted, devices discard any potentially included trust anchor certificates.

How devices process redirect information is described in [Section 5.5](#).

2.2. Onboarding Information

Onboarding information provides data necessary for a device to bootstrap itself and establish secure connections with other systems. As defined in this document, onboarding information can specify details about the boot image a device must be running, specify an initial configuration the device must commit, and specify scripts that the device must successfully execute.

Onboarding information is YANG modeled data formally defined by the "onboarding-information" container in the YANG module presented in [Section 6.3](#). This container has the tree diagram shown below.

```
+--:(onboarding-information)
  +---- onboarding-information
    +---- boot-image
      | +---- os-name?          string
      | +---- os-version?      string
      | +---- download-uri*    inet:uri
      | +---- image-verification* [hash-algorithm]
      |   +---- hash-algorithm  identityref
      |   +---- hash-value      yang:hex-string
    +---- configuration-handling? enumeration
    +---- pre-configuration-script? script
    +---- configuration?       binary
    +---- post-configuration-script? script
```

Onboarding 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.

Onboarding 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 in [Section 5.6](#).

3. Artifacts

This document defines three artifacts that can be made available to devices while they are bootstrapping. Each source of bootstrapping information specifies how it provides the artifacts defined in this section (see [Section 4](#)).

[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 CMS structure, as described in [\[RFC5652\]](#), encoded using ASN.1 distinguished encoding rules (DER), as specified in ITU-T X.690 [\[ITU.X690.1994\]](#). The CMS structure MUST contain content conforming to the YANG module specified in [Section 6.3](#).

The zero touch information CMS structure may encode signed or unsigned bootstrapping data.

When the zero touch information artifact is unsigned, as it might be when communicated over trusted channels, the CMS structure's top-most content type MUST be one of the OIDs described in [Section 11.3](#), or the OID `id_data` (1.2.840.113549.1.7.1), in which case the encoding (JSON, XML, etc.) SHOULD be communicated externally. In either case, the associated content is an octet string containing 'zerotouch-information' data in the expected encoding.

When the zero touch information artifact is signed, as it might be when communicated over untrusted channels, the CMS structure's top-most content type MUST be the OID `id-signedData` (1.2.840.113549.1.7.2), and its inner `eContentType` MUST be one of the OIDs described in [Section 11.3](#), or the OID `id_data` (1.2.840.113549.1.7.1), in which case the encoding (JSON, XML, etc.) SHOULD be communicated externally. In either case, the associated content or `eContent` is an octet string containing 'zerotouch-information' data in the expected encoding.

[3.2.](#) Owner Certificate

The owner certificate artifact is an X.509 certificate [\[RFC5280\]](#) that is used to identify an "owner" (e.g., an organization). The owner certificate can be signed by any certificate authority (CA). The owner certificate either MUST have no Key Usage specified or the Key Usage MUST at least set the "digitalSignature" bit. The values for the owner certificate's "subject" and/or "subjectAltName" are not constrained by this document.

The owner certificate is used by a device to verify the signature over the zero touch information artifact ([Section 3.1](#)) that the device should have also received, as described in [Section 3.4](#). In particular, the device verifies the signature using the public key in

the owner certificate over the content contained within the zero touch information artifact.

The owner certificate artifact is formally a CMS structure, as specified by [\[RFC5652\]](#), encoded using ASN.1 distinguished encoding rules (DER), as specified in ITU-T X.690 [\[ITU.X690.1994\]](#). This CMS structure's top-most content type MUST be the OID id-signedData (1.2.840.113549.1.7.2). The inner SignedData structure is the degenerate form, whereby there are no signers, that is commonly used to disseminate certificates, CRLs, and OCSP Responses.

The owner certificate CMS structure MUST contain the owner certificate itself, as well as all intermediate certificates leading up to the 'pinned-domain-cert' certificate specified in the ownership voucher. The owner certificate artifact MAY optionally include the 'pinned-domain-cert' as well.

In order to support devices deployed on private networks, the owner certificate CMS structure MAY also contain suitably fresh, as determined by local policy, CRLs [\[RFC5280\]](#) and/or OCSP Responses [\[RFC6960\]](#). Having these revocation objects stapled to the owner certificate may obviate 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.

The ownership voucher is used to verify the owner certificate ([Section 3.2](#)) that the device should have also received, as described in [Section 3.4](#). In particular, the device verifies that the owner certificate has a chain of trust leading to the trusted certificate included in the ownership voucher ('pinned-domain-cert'). Note that this relationship holds even when the owner certificate is a self-signed certificate, and hence also the pinned-domain-cert.

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

[3.4.](#) Artifact Groupings

The previous sections discussed the bootstrapping artifacts, but only certain groupings of these artifacts make sense to return in the various bootstrapping situations described in this document. These groupings are:

Unsigned Information: This grouping 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).

Signed Information, without revocations: This grouping is useful when signed information is needed, because it is obtained from an untrusted source, and it cannot be processed provisionally, and yet either revocations are not needed or they can be obtained dynamically.

Signed Information, with revocations: This grouping is useful when signed information is needed, because it is obtained from an untrusted source, and it cannot be processed provisionally, and revocations are needed and cannot be obtained dynamically.

The artifacts associated with these groupings are described below:

Grouping	Zero Touch Information	Ownership Voucher	Owner Certificate
-----	-----	-----	-----
Unsigned Information	Yes, no sig	No	No
Signed Information, without revocations	Yes, with sig	Yes, without revocations	Yes, without revocations
Signed Information, with revocations	Yes, with sig	Yes, with revocations	Yes, with revocations

4. Sources of Bootstrapping Data

This section defines some sources for 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 bootstrapping data.

For each source of bootstrapping data defined in this section, details are given for how the three artifacts listed in [Section 3](#) are provided.

4.1. 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.

Use of a removable storage device is compelling, as it does not require any external infrastructure to work. It is notable that the raw boot image file can also be located on the removable storage

device, enabling a removable storage device to be a fully self-standing bootstrapping solution.

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.

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 **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.cms).

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

Ownership Voucher: Mapped to a file containing the binary artifact described in [Section 3.3](#) (e.g., ownership-voucher.cms or ownership-voucher.vcj).

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 (i.e., for different devices) to exist on a removable storage device. The file naming convention **SHOULD** additionally be unique to the manufacturer, in order to enable bootstrapping data from multiple manufacturers to exist on a removable storage device.

[4.2.](#) 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 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.

[4.3.](#) 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 very limited in the amount of data that can be conveyed, to the extent that signed data cannot be communicated. This means that only unsigned redirect information can be conveyed via DHCP.

Since the redirect information is unsigned, it SHOULD NOT include the optional trust anchor certificate, as it takes up space in the DHCP message, and the device would have to discard it anyway. For this reason, the DHCP options defined in [Section 9](#) do not enable the trust anchor certificate to be encoded.

From an artifact perspective, the three artifacts defined in [Section 3](#) are mapped to the DHCP fields specified in [Section 9](#) as follows:

Zero Touch Information: This artifact is not supported directly. Instead, the essence of unsigned redirect information is mapped to the DHCP options described in [Section 9](#).

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.

[4.4.](#) 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 7](#).

Using a bootstrap server as a source of bootstrapping data is a compelling option as it MAY use transport-level security, obviating the need for signed data, which may be easier to deploy in some situations.

Unlike any other source of bootstrapping 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 'report-progress' RPC defined in the YANG module ([Section 7.3](#)). The 'report-progress' RPC enables visibility into the bootstrapping process (e.g., warnings and errors), and provides potentially useful information upon completion (e.g., the device's SSH host-keys).

A bootstrap server may be a trusted or an untrusted source of bootstrapping data, depending on if 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 either MUST be signed or MUST be information that can be processed provisionally (e.g., unsigned redirect information).

From an artifact perspective, since a bootstrap server presents data conforming to a YANG data model, the bootstrapping artifacts need to be mapped to YANG nodes. The three artifacts defined in [Section 3](#) are mapped to 'output' nodes of the 'get-bootstrapping-data' RPC defined in [Section 7.3](#) below.

Artifact to Bootstrap Server Mapping:

Zero Touch Information: Mapped to the 'zerotouch-information' leaf in the output of the 'get-bootstrapping-data' RPC.

Owner Certificate: Mapped to the 'owner-certificate' leaf in the output of the 'get-bootstrapping-data' RPC.

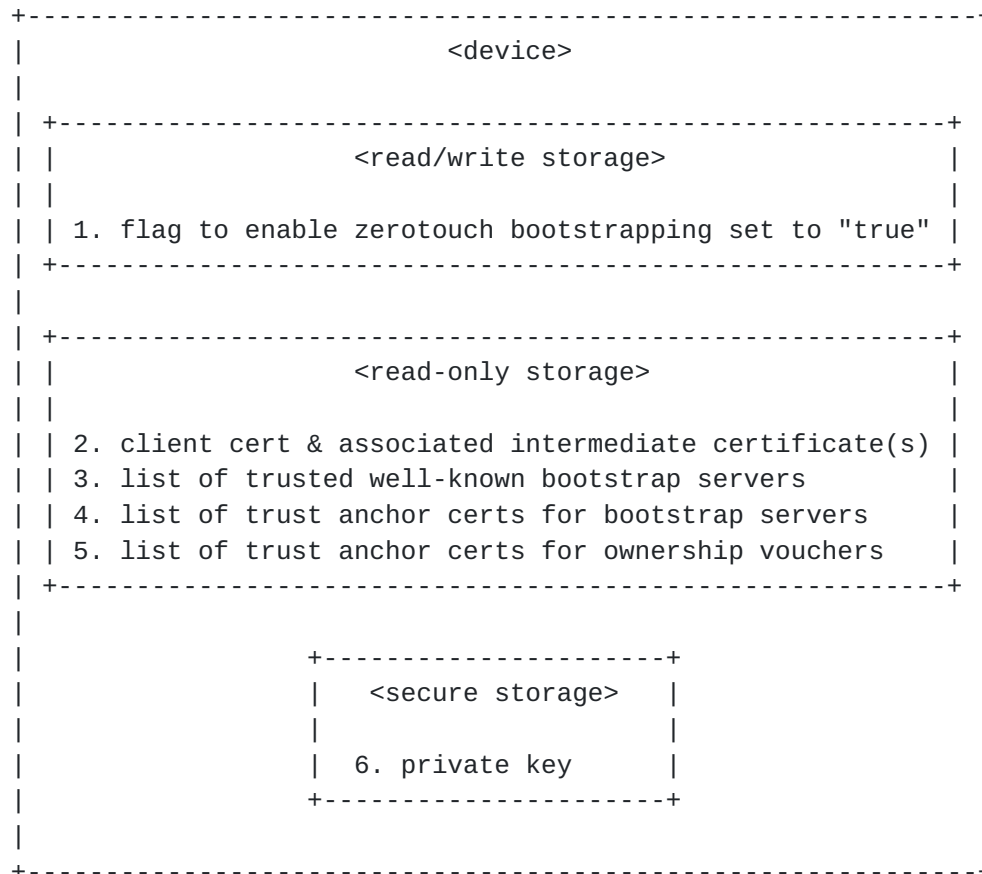
Ownership Voucher: Mapped to the 'ownership-voucher' leaf in the output of the 'get-bootstrapping-data' RPC.

Zero touch bootstrap servers have only two endpoints, one for the 'get-bootstrapping-data' RPC and one for the 'report-progress' RPC. These RPCs use the authenticated RESTCONF username to isolate the execution of the RPC from other devices.

5. Device Details

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

5.1. Initial State



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

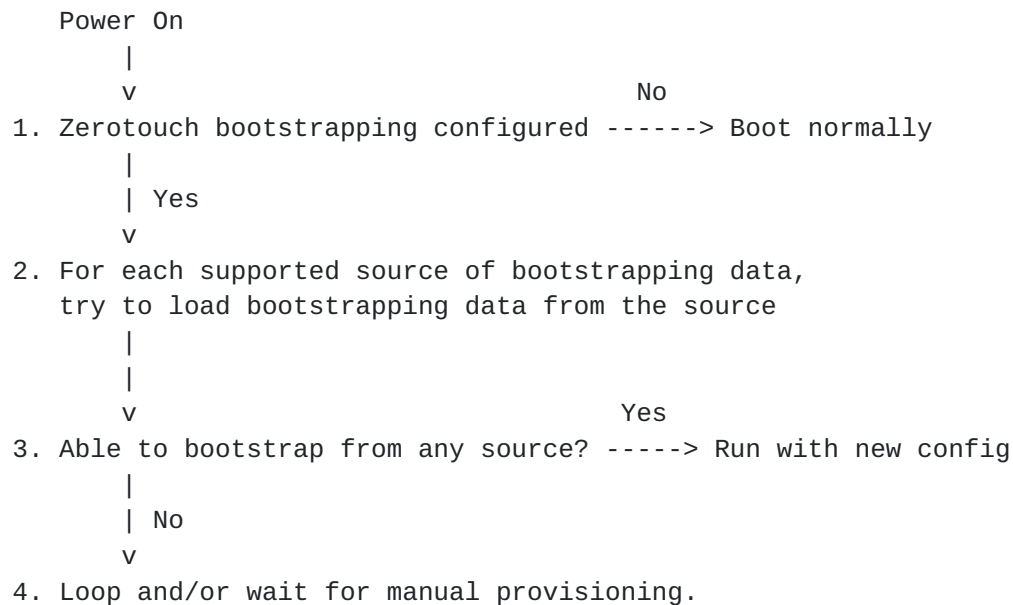
1. Devices MUST have a configurable variable that is used to enable/disable zerotouch bootstrapping. This variable MUST be enabled by default in order for zerotouch bootstrapping to run when the device first powers on. Because it is a goal that the configuration installed by the bootstrapping process disables zerotouch bootstrapping, and because the configuration may be merged into the existing configuration, using a configuration node that relies on presence is NOT RECOMMENDED, as it cannot be removed by the merging process.

2. Devices that support loading bootstrapping data from bootstrap servers (see [Section 4.4](#)) SHOULD possess a client certificate (e.g. IDevID, as defined in [[Std-802.1AR-2009](#)]), and any intermediate certificates leading to the certificate's well-known trust-anchor. Note that the well-known trust anchor certificate may be an intermediate certificate or a self-signed root certificate. To support devices not having a client certificate, devices MAY alternatively, or in addition to, identify and authenticate themselves to the bootstrap server using an HTTP authentication scheme, as allowed by [Section 2.5 in \[RFC8040\]](#); however, this document does not define any mechanisms for operator input enabling, for example, the entering of a password.
3. Devices that support loading bootstrapping data from well-known bootstrap servers MUST possess a list of the well-known bootstrap servers. Consistent with redirect information ([Section 2.1](#), each bootstrap server can be identified by its hostname or IP address, and an optional port.
4. Devices that support loading bootstrapping data from well-known bootstrap servers MUST also possess a list of trust anchor certificates that can be used to authenticate the well-known bootstrap servers. For each trust anchor certificate, if it is not itself a self-signed root certificate, the device SHOULD also possess the chain of intermediate certificates leading up to and including the self-signed root certificate.
5. Devices that support loading signed data (see [Section 1.2](#)) MUST possess the trust anchor certificates for validating ownership vouchers. For each trust anchor certificate, if it is not itself a self-signed root certificate, the device SHOULD also possess the chain of intermediate certificates leading up to and including the self-signed root certificate.
6. Devices that support using a client certificate to authenticate to a bootstrap servers MUST possess the private key that corresponds to the public key encoded in the client certificate. This private key SHOULD be securely stored, ideally in a cryptographic processor (e.g., a TPM).

A YANG module representing this data is provided in [Section 8](#).

[5.2](#). 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 zerotouch bootstrapping is configured, as is expected to be the case for the device's preconfigured initial state. If zerotouch bootstrapping is not configured, then the device boots normally.
2. The device iterates over its list of sources for bootstrapping data ([Section 4](#)). Details for how to process a source of bootstrapping data are provided in [Section 5.3](#).
3. If the device is able to bootstrap itself from 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.

[5.3. 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 because sources of bootstrapping data may return redirect information, which causes the algorithm to run again, for the newly discovered sources of bootstrapping information. An expression that captures all possible successful sequences of bootstrapping information is zero or more redirect information responses, followed by one onboarding 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	Trusted Source
		Can Provide?	Can Provide?
Unsigned Redirect Info	:	Yes+	Yes
Signed Redirect Info	:	Yes	Yes*
Unsigned Onboarding Info	:	No	Yes
Signed Onboarding 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.

The recursive algorithm uses a conceptual global-scoped 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 source of bootstrapping data ([Section 4](#)) is a bootstrap server ([Section 4.4](#)), and the device is able to authenticate the bootstrap 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.

When establishing a connection to a trusted bootstrap server (i.e. trust-state is TRUE), the device MAY, per [Section 2.5 in \[RFC8040\]](#), identify and authenticate itself to the bootstrap server using a TLS-level client certificate and/or an HTTP authentication scheme. If both mechanisms are used, they MUST both identify the same device using its serial number.

When establishing a connection to an untrusted bootstrap server (i.e. trust-state is FALSE), it is still necessary for the device to identify itself, in order to receive device-specific signed data, due to the ownership voucher encoding the device's serial number. The device MAY identify and authenticate itself to the bootstrap server using a TLS-level client certificate and/or an HTTP authentication scheme. However, because the bootstrap server is untrusted, the device MUST NOT use an authentication scheme that conveys a shared secret, such as a password.

When sending a client certificate, the device MUST also send all the intermediate certificates leading up to, and optionally including, the client certificate's well-known trust anchor certificate.

For any source of bootstrapping data (e.g., [Section 4](#)), if the bootstrapping data returned is signed and the device is able to validate the signed data using the algorithm described in [Section 5.4](#), then the device MUST set trust-state to TRUE; otherwise, if the device is unable to validate the signed data, 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 bootstrapping data is onboarding information, and trust-state is FALSE, the device MUST exit the recursive algorithm (as this is not allowed, see the figure above), returning to the state machine described in [Section 5.2](#). Otherwise, the device MUST attempt to process the onboarding information as described in [Section 5.6](#). In either case, success or failure, the device MUST exit the recursive algorithm, returning to the state machine described in [Section 5.2](#), the only difference being in how it responds to the "Able to bootstrap from any source?" conditional described in the figure in the section.

If the bootstrapping data is redirect information, the device MUST process the redirect information as described in [Section 5.5](#). This is the recursion step, it will cause the device to reenter this algorithm, but this time the data source will definitely be a bootstrap server, as that is all redirect information is able to redirect a device to.

5.4. Validating Signed Data

Whenever a device is presented signed data, it MUST validate the signed data as described in this section. This includes the case where the signed data is provided by a trusted source.

Whenever there is signed data, the device MUST also be provided an ownership voucher and an owner certificate. How all the needed artifacts are provided for each source of bootstrapping data is described in [Section 4](#).

In order to validate signed data, the device MUST first authenticate the ownership voucher by validating its signature to one of its preconfigured trust anchors (see [Section 5.1](#)), which may entail using additional intermediate certificates attached to the ownership voucher. If the device has an accurate clock, it MUST verify that the ownership voucher was created in the past (i.e., 'created-on' <

now) and, if the 'expires-on' leaf is present, the device MUST verify that the ownership voucher has not yet expired (i.e., $\text{now} < \text{'expires-on'}$). The device MUST verify that the ownership voucher's 'assertion' value is acceptable (e.g., some devices may only accept the assertion value 'verified'). The device MUST verify that the ownership voucher specifies the device's serial number in the 'serial-number' leaf. If the 'idevid-issuer' leaf is present, the device MUST verify that the value is set correctly. If the authentication of the ownership voucher is successful, the device extracts the 'pinned-domain-cert' node, an X.509 certificate, that is needed to verify the owner certificate in the next step.

The device MUST next authenticate the owner certificate by performing X.509 certificate path verification to the trusted certificate extracted from the ownership voucher's 'pinned-domain-cert' node. This verification may entail using additional intermediate certificates attached to the owner certificate artifact. If the ownership voucher's 'domain-cert-revocation-checks' node's value is set to "true", the device MUST verify the revocation status of the certificate chain used to sign the owner certificate and, if the revocation status is not attainable or if it is determined that a certificate has been revoked, the device MUST not validate the owner certificate.

Finally the device MUST verify the zero touch information artifact was signed by the validated owner certificate.

If any of these steps fail, the device MUST invalidate the signed data and not perform any subsequent steps.

5.5. 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 from.

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 specified bootstrap server's TLS server certificate using X.509 certificate path validation ([\[RFC6125\]](#), [Section 6](#)) to the specified trust anchor. If the bootstrap server entry does not contain a trust anchor certificate device, the device MUST establish a provisional connection to the bootstrap server (i.e., by blindly accepting its server certificate), and set trust-state to FALSE.

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).

5.6. 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 (if any), then execute the pre-configuration script (if any), then commit the initial configuration (if any), and then execute the post-configuration script (if any), in that order. If the device encounters an error at any step, it MUST NOT proceed to the next step.

When the onboarding information is obtained from a trusted bootstrap server, the device SHOULD send progress reports throughout the bootstrapping process using the bootstrap server's 'report-progress' RPC. When the onboarding information was obtained from an untrusted bootstrap server, the device SHOULD NOT send any progress reports to the bootstrap server, even after validating any signed data it may have receive from the bootstrap server.

If boot image criteria is specified, the device MUST first determine if the boot image it is running satisfies the specified boot image criteria. If the device is not running the specified boot image, then it MUST install the specified boot image or fail processing the onboarding information. In order to install the specified boot image, the device MUST download, verify, and install the specified boot image, and then reboot. To verify the downloaded boot image, the device MUST check that the boot image file matches the verification fingerprint supplied by the onboarding information. Upon rebooting, the bootstrapping process runs again, which will eventually come to this very point, but this time the device will be

running the specified boot image, and thus 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 it had any warnings or errors. In the case of errors, the device MUST reset itself in such a way that wipes out any bad state the script may have left behind.

Next, if an initial configuration has been supplied, the device MUST commit the provided initial configuration, using the approach specified by the 'configuration-handling' leaf. If there is an error, and the device previously executed a pre-configuration script, the device does not need to reset itself in order to wipe out any state the script may have left behind; this implies that the pre-configuration script must be idempotent.

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 wipes out any bad state the script may have left behind.

At this point, the device has completely processed the bootstrapping data. If the device obtained the onboarding information from a trusted bootstrap server, the device MUST post the 'bootstrap-complete' progress report now, using the bootstrap server's 'report-progress' RPC.

The device is now running its initial configuration. Notably, if NETCONF Call Home or RESTCONF Call Home [[RFC8071](#)] is configured, the device initiates trying to establish a call home connection at this time.

6. The Zero Touch Information Data Model

This section defines a YANG 1.1 [[RFC7950](#)] module that is used to define the data model for the zero touch information artifact described in [Section 3.1](#). This data model uses the 'yang-data' extension statement defined in [[I-D.ietf-netmod-yang-data-ext](#)]. Examples illustrating this data model are provided in [Section 6.2](#).

6.1. Data Model Overview

The following tree diagram provides an overview of the data model for the zero touch information artifact.

module: ietf-zerotouch-information

```

yang-data zerotouch-information:
  +---- (information-type)
    +--:(redirect-information)
      | +---- redirect-information
      |   +---- bootstrap-server* [address]
      |     +---- address          inet:host
      |     +---- port?           inet:port-number
      |     +---- trust-anchor?   cms
    +--:(onboarding-information)
      +---- onboarding-information
        +---- boot-image
          | +---- os-name?          string
          | +---- os-version?       string
          | +---- download-uri*     inet:uri
          | +---- image-verification* [hash-algorithm]
          |   +---- hash-algorithm  identityref
          |   +---- hash-value      yang:hex-string
        +---- configuration-handling? enumeration
        +---- pre-configuration-script? script
        +---- configuration?        binary
        +---- post-configuration-script? script

```

6.2. Example Usage

The following example illustrates how redirect information ([Section 2.1](#)) can be encoded using JSON.


```
{
  "ietf-zerotouch-information:redirect-information" : {
    "bootstrap-server" : [
      {
        "address" : "phs1.example.com",
        "port" : 8443,
        "trust-anchor" : "base64encodedvalue=="
      },
      {
        "address" : "phs2.example.com",
        "port" : 8443,
        "trust-anchor" : "base64encodedvalue=="
      },
      {
        "address" : "phs3.example.com",
        "port" : 8443,
        "trust-anchor" : "base64encodedvalue=="
      }
    ]
  }
}
```

The following example illustrates how onboarding information ([Section 2.2](#)) can be encoded using JSON.

[note: '\\' line wrapping for formatting only]

```
{
  "ietf-zerotouch-information:onboarding-information" : {
    "boot-image" : {
      "os-name" : "VendorOS",
      "os-version" : "17.2R1.6",
      "download-uri" : [ "http://some/path/to/raw/file" ],
      "image-verification" : [
        {
          "hash-algorithm" : "ietf-zerotouch-information:sha-256",
          "hash-value" : "ba:ec:cf:a5:67:82:b4:10:77:c6:67:a6:22:ab:\
7d:50:04:a7:8b:8f:0e:db:02:8b:f4:75:55:fb:c1:13:b2:33"
        }
      ]
    },
    "configuration-handling" : "merge",
    "pre-configuration-script" : "base64encodedvalue==",
    "configuration" : "base64encodedvalue==",
    "post-configuration-script" : "base64encodedvalue=="
  }
}
```


6.3. YANG Module

The zero touch information data model is defined by the YANG module presented in this section.

Note: the module defined herein uses data types defined in [[RFC5280](#)], [[RFC6234](#)], and [[RFC6991](#)], and an extension statement from [[I-D.ietf-netmod-yang-data-ext](#)], and an encoding defined in [[ITU.X690.1994](#)].

```
<CODE BEGINS> file "ietf-zerotouch-information@2018-02-28.yang"
module ietf-zerotouch-information {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-zerotouch-information";
  prefix zti;

  import ietf-yang-types {
    prefix yang;
    reference "RFC 6991: Common YANG Data Types";
  }
  import ietf-inet-types {
    prefix inet;
    reference "RFC 6991: Common YANG Data Types";
  }
  import ietf-yang-data-ext {
    prefix yd;
    reference "I-D.ietf-netmod-yang-data-ext: YANG Data Extensions";
  }

  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 in RFC XXXX: Zero Touch Provisioning for
    Networking Devices.

    The key words 'MUST', 'MUST NOT', 'REQUIRED', 'SHALL',
    'SHALL NOT', 'SHOULD', 'SHOULD NOT', 'RECOMMENDED', 'MAY',
    and 'OPTIONAL' in the module text are to be interpreted as
    described in RFC 2119."

  Copyright (c) 2018 IETF Trust and the persons identified as
```


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

```
revision 2018-02-28 {
  description
    "Initial version";
  reference
    "RFC XXXX: Zero Touch Provisioning for Networking Devices";
}

// identities

identity hash-algorithm {
  description
    "A base identity for hash algorith verification";
}

identity sha-256 {
  base "hash-algorithm";
  description "The SHA-256 algorithm.";
  reference "RFC 6234: US Secure Hash Algorithms.";
}

// typedefs

typedef cms {
  type binary;
  description
    "A CMS structure, as specified in RFC 5652, encoded using
    ASN.1 distinguished encoding rules (DER), as specified in
    ITU-T X.690.";
  reference
    "RFC 5652:
    Cryptographic Message Syntax (CMS)
    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).";
}
```



```
// yang-data
```

```
yd:yang-data "zerotouch-information" {  
  choice information-type {  
    mandatory true;  
    description  
      "This choice statement ensures the response contains  
      redirect-information or onboarding-information.";  
    container redirect-information {  
      description  
        "Redirect information is 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 Networking Devices";  
      list bootstrap-server {  
        key "address";  
        min-elements 1;  
        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. If no  
            port is specified, the IANA-assigned port for 'https'  
            (443) is used.";  
        }  
      }  
      leaf trust-anchor {  
        type cms;  
        description  
          "A CMS structure that MUST contain the chain of X.509  
          certificates needed to authenticate the TLS certificate  
          presented by this bootstrap server. In all cases, the  
          chain MUST include a self-signed root certificate.  
          In the case where the root certificate is itself the  
          issuer of the bootstrap server's TLS certificate, only  
          one X.509 certificate is present. If needed by the  
          device, this CMS structure MAY also contain suitably  
          fresh CRL and/or OCSP Responses with which the device  
          can use to verify the revocation status of the
```


certificates.

X.509 certificates and CRLs are described in [RFC 5280](#).
OCSP Responses are described in [RFC 6960](#).";

reference

"[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.";

}

}

}

container onboarding-information {

description

"Onboarding information is 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 Networking Devices";

container boot-image {

description

"Specifies criteria for the boot image the device MUST
be running, as well as information enabling the device
to install the required boot image.";

leaf os-name {

type string;

description

"The name of the operating system software the device
MUST be running in order to not require a software
image upgrade (ex. VendorOS).";

}

leaf os-version {

type string;

description

"The version of the operating system software the device
MUST be running in order to not require a software
image upgrade (ex. 17.3R2.1).";

}

leaf-list download-uri {

type inet:uri;

must '../image-verification' {

description

"Image verification information must be provided if
the device is going to download an image.";

}

ordered-by user;


```
    description
      "An ordered list of URIs to where the necessary
      boot-image file may be obtained. Deployments must
      know through out-of-band means which URI schemes
      (http, ftp, etc.) the bootstrapping device supports.
      If a secure scheme (e.g., https) is provided, a
      device MAY establish an untrusted connection to the
      remote server to obtain the boot-image.";
  }
  list image-verification {
    must '../download-uri' {
      description
        "Download URIs must be provided if an image is to
        be verified.";
    }
    key hash-algorithm;
    description
      "A list of hash values that a device can use to verify
      boot image files with.";
    leaf hash-algorithm {
      type identityref {
        base "hash-algorithm";
      }
      description
        "Identifies the hash algorithm used.";
    }
    leaf hash-value {
      type yang:hex-string;
      mandatory true;
      description
        "The hex-encoded value of the specified hash algorithm
        over the contents of the boot image file.";
    }
  }
}
leaf configuration-handling {
  type enumeration {
    enum "merge" {
      description
        "Merge configuration into the running datastore.";
    }
    enum "replace" {
      description
        "Replace the existing running datastore with the
        passed configuration.";
    }
  }
}
must '../configuration';
```



```
    description
      "This enumeration indicates how the server should process
        the provided configuration.";
  }
  leaf pre-configuration-script {
    type script;
    description
      "A script that, when present, is executed before the
        configuration has been processed.";
  }
  leaf configuration {
    type binary;
    must '../configuration-handling';
    description
      "Any configuration known to the device. The use of the
        'binary' type enables e.g., XML-content to be embedded
        into a JSON document. The exact encoding of the content,
        as with the scripts, is vendor specific.";
  }
  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, other than that it can emit an exit status code and stderr/stdout. 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, and the device obtained the onboarding information from a trusted bootstrap server, the device SHOULD send either a 'pre-script-warning' or 'post-script-warning' progress report, based on which kind of script was presented, but otherwise continue processing the

bootstrapping data as if the script had not been present.

The script returns exit status code zero on success and non-zero otherwise, with accompanying stderr/stdout for logging purposes.

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 trusted bootstrap server, it SHOULD either send a 'pre-script-warning' or 'post-script-warning' progress report, based on which kind of script was executed.

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. If the device obtained the bootstrap information from a trusted bootstrap server, it SHOULD send a 'pre-script-error' or 'post-script-error' progress report, based on which kind of script was executed, followed by a reset that will wipe out any bad state left by the script, and restart the entire bootstrapping process.";

```
}  
}  
<CODE ENDS>
```

7. The Zero Touch Bootstrap Server API

This section defines the API for bootstrap servers. The API is defined as that produced by a RESTCONF [\[RFC8040\]](#) server that supports the YANG 1.1 [\[RFC7950\]](#) module defined in this section.

7.1. API Overview

The following tree diagram provides an overview for the bootstrap server RESTCONF API.


```
module: ietf-zerotouch-bootstrap-server
```

```
rpcs:
```

```

+---x get-bootstrapping-data
| +---w input
| | +---w untrusted-connection?    empty
| | +---w hw-model?                string
| | +---w os-name?                 string
| | +---w os-version?              string
| | +---w nonce?                   binary
| +--ro output
|   +--ro zerotouch-information    cms
|   +--ro owner-certificate?       cms
|   +--ro ownership-voucher?       cms
+---x report-progress
  +---w input
    +---w progress-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 certificate            cms

```

7.2. Example Usage

This section presents three examples illustrating the bootstrap server's API. Two examples are provided for the 'get-bootstrapping-data' RPC (once to an untrusted bootstrap server, and again to a trusted bootstrap server), and one example for the 'report-progress' RPC.

The following example illustrates a device using the API to fetch its bootstrapping data from an untrusted bootstrap server. In this example, the device sends the 'untrusted-connection' input parameter and receives signed data in the response.

REQUEST

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

```
POST /restconf/operations/ietf-zerotouch-bootstrap-server:get-boot\
strapping-data HTTP/1.1
```

```
HOST: example.com
```

```
Content-Type: application/yang.data+xml
```

```
<input
```

```
  xmlns="urn:ietf:params:xml:ns:yang:ietf-zerotouch-bootstrap-server">
```

```
  <untrusted-connection/>
```

```
</input>
```

RESPONSE

```
HTTP/1.1 200 OK
```

```
Date: Sat, 31 Oct 2015 17:02:40 GMT
```

```
Server: example-server
```

```
Content-Type: application/yang.data+xml
```

```
<output xmlns="urn:ietf:params:xml:ns:yang:ietf-zerotouch-bootstrap-server">
```

```
  <zerotouch-information>base64encodedvalue==</zerotouch-information>
```

```
  <owner-certificate>base64encodedvalue==</owner-certificate>
```

```
  <ownership-voucher>base64encodedvalue==</ownership-voucher>
```

```
</output>
```

The following example illustrates a device using the API to fetch its bootstrapping data from a trusted bootstrap server. In this example, the device sends addition input parameters to the bootstrap server, which it may use when formulating its response to the device.

REQUEST

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

```
POST /restconf/operations/ietf-zerotouch-bootstrap-server:get-boot\
strapping-data HTTP/1.1
```

```
HOST: example.com
```

```
Content-Type: application/yang.data+xml
```

```
<input
  xmlns="urn:ietf:params:xml:ns:yang:ietf-zerotouch-bootstrap-server">
  <hw-model>model-x</hw-model>
  <os-name>vendor-os</os-name>
  <os-version>17.3R2.1</os-version>
  <nonce>base64encodedvalue==</nonce>
</input>
```

RESPONSE

```
HTTP/1.1 200 OK
```

```
Date: Sat, 31 Oct 2015 17:02:40 GMT
```

```
Server: example-server
```

```
Content-Type: application/yang.data+xml
```

```
<output xmlns="urn:ietf:params:xml:ns:yang:ietf-zerotouch-bootstrap-server">
  <zerotouch-information>base64encodedvalue==</zerotouch-information>
</output>
```

The following example illustrates a device using the API to post a progress report to a bootstrap server. Illustrated below is the 'bootstrap-complete' message, but the device may send other progress reports to the server while bootstrapping. In this example, the device is sending both its SSH host keys and a TLS server certificate, which the bootstrap server may, for example, pass to an NMS, as discussed in [Appendix A.3](#).

REQUEST

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

```
POST /restconf/operations/ietf-zerotouch-bootstrap-server:report-\
progress HTTP/1.1
HOST: example.com
Content-Type: application/yang.data+xml
```

```
<input xmlns=
  "urn:ietf:params:xml:ns:yang:ietf-zerotouch-bootstrap-server">
  <progress-type>bootstrap-complete</progress-type>
  <message>example message</message>
  <ssh-host-keys>
    <ssh-host-key>
      <format>ssh-rsa</format>
      <key-data>base64encodedvalue==</key-data>
    </ssh-host-key>
    <ssh-host-key>
      <format>ssh-dss</format>
      <key-data>base64encodedvalue==</key-data>
    </ssh-host-key>
  </ssh-host-keys>
  <trust-anchors>
    <trust-anchor>
      <certificate>base64encodedvalue==</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
```

7.3. 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 [[RFC5652](#)], [[RFC5280](#)], [[RFC6960](#)], and [[I-D.ietf-anima-voucher](#)], and uses an encoding defined in [[ITU.X690.1994](#)].

```
<CODE BEGINS> file "ietf-zerotouch-bootstrap-server@2018-02-28.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 Networking
  Devices.

  The key words 'MUST', 'MUST NOT', 'REQUIRED', 'SHALL',
  'SHALL NOT', 'SHOULD', 'SHOULD NOT', 'RECOMMENDED', 'MAY',
  and 'OPTIONAL' in the module text are to be interpreted as
  described in RFC 2119.

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  authors of the code. All rights reserved.

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  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 2018-02-28 {
  description
    "Initial version";
  reference
    "RFC XXXX: Zero Touch Provisioning for Networking Devices";
}

// typedefs

typedef cms {
  type binary;
  description
    "A CMS structure, as specified in RFC 5652, encoded using
```



```
ASN.1 distinguished encoding rules (DER), as specified in
ITU-T X.690.";
reference
  "RFC 5652:
    Cryptographic Message Syntax (CMS)
    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).";
}

// RPCs

rpc get-bootstrapping-data {
  description
    "This RPC enables a device, as identified by the RESTCONF
    username, to obtain bootstrapping data that has been made
    available for it.";
  input {
    leaf untrusted-connection {
      type empty;
      description
        "This optional input parameter enables a device to
        communicate to the bootstrap server that it is unable to
        authenticate the bootstrap server's TLS certificate. In
        such circumstances, the device likely does not send any
        of the other input parameters. Upon receiving this input
        parameter, the bootstrap server should return unsigned
        redirect information or signed data of any type.";
    }
    leaf hw-model {
      type string;
      description
        "This optional input parameter enables a device to
        communicate to the bootstrap server its vendor specific
        hardware model number. This parameter may be needed,
        for instance, when a device's IDevID certificate does
        not include the 'hardwareModelName' value in its
        subjectAltName field, as is allowed by 802.1AR-2009.";
      reference
        "IEEE 802.1AR-2009: IEEE Standard for Local and
        metropolitan area networks - Secure Device Identity";
    }
    leaf os-name {
      type string;
      description
        "This optional input parameter enables a device to
```



```
        communicate to the bootstrap server the name of its
        operating system. This parameter may be useful if
        the device, as identified by its serial number, can
        run more than one type of operating system (e.g.,
        on a white-box system.");
    }
    leaf os-version {
        type string;
        description
            "This optional input parameter enables a device to
            communicate to the bootstrap server the version of its
            operating system. This parameter may be used by a
            bootstrap server to return an operating system specific
            response to the device, thus negating the need for a
            potentially expensive boot-image update.";
    }
    leaf nonce {
        type binary {
            length "8..32";
        }
        description
            "This optional input parameter enables a device to
            communicate to the bootstrap server a nonce value.
            This may be especially useful for devices lacking
            an accurate clock, as then the bootstrap server
            can dynamically obtain from the manufacturer a
            voucher with the nonce value in it, as described
            in I-D.ietf-anima-voucher.";
        reference
            "RFC ZZZZ: Voucher Profile for Bootstrapping Protocols.";
    }
}
output {
    leaf zerotouch-information {
        type cms;
        mandatory true;
        description
            "A 'zerotouch-information' artifact, as described in
            Section 4.1 of RFC XXXX. The CMS structure may either
            contain just a contentInfo structure, with effectively
            unsigned data, or a SignedData structure (per Section
            5.1 of RFC 5652) that signs the content using the
            private key associated with the 'owner-certificate'.";
        reference
            "RFC XXXX:
            Zero Touch Provisioning for Networking Devices
            RFC 5652:
            Cryptographic Message Syntax (CMS)";
```



```
}
leaf owner-certificate {
  type cms;
  must '../ownership-voucher' {
    description
      "An ownership voucher must be present whenever an owner
        certificate is presented.";
  }
  description
    "This CMS structure MUST contain the owner certificate
      and all intermediate certificates leading up to (and
      optionally including) the trust anchor certificate
      specified by the 'pinned-domain-cert' node in the
      ownership voucher. This structure MAY also include
      suitably fresh CRL and/or OCSP Responses that the
      device can use to verify the revocation status of the
      certificates. This leaf is optional because it is
      only needed when the 'zerotouch-information' CMS
      structure is signed.";
  reference
    "RFC 5652:
      Cryptographic Message Syntax (CMS)
    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 cms;
  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 its owner is. The voucher encodes the device's
      serial number, so that the device can ensure the
      voucher applies to it. The voucher is signed by the
      device's manufacturer. This leaf is optional because
```



```
        it is only needed when the 'zerotouch-information'
        CMS structure is signed.";
    reference
        "I-D.ietf-anima-voucher:
        Voucher and Voucher Revocation Profiles for
        Bootstrapping Protocols";
    }
}
}

rpc report-progress {
    description
        "This RPC enables a device, as identified by the RESTCONF
        username, to report its bootstrapping progress to the
        bootstrap server. This RPC is expected to be used when
        the device obtains onboarding-information from a trusted
        bootstrap server.";
    input {
        leaf progress-type {
            type enumeration {
                enum "bootstrap-initiated" {
                    description
                        "Indicates that the device just used the
                        'get-bootstrapping-data' RPC. The 'message' node
                        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' node 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, the ownership voucher not listing
                        the device's serial number, or because the signature
                        didn't match. The 'message' node below SHOULD indicate
                        the specific error. This progress type 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' node
  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' node SHOULD indicate the specific error
    that occurred. This progress type 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' node 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' node below SHOULD indicate
    both the resulting exit status code, as well as
    capture any stdout/stderr messages the script may
    have produced. This progress type 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' node 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' node below SHOULD indicate the error
        messages that were generated. This progress type
        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' node 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' node below SHOULD indicate
        both the resulting exit status code, as well as
        capture any stdout/stderr messages the script may
        have produced. This progress type also indicates
        that the device has abandoned trying to bootstrap
        off this bootstrap server.";
    }
    enum "bootstrap-complete" {
        description
        "Indicates that the device successfully processed all
        'onboarding-information' provided, and that it is ready
        to be managed. The 'message' node below MAY contain
        any additional information that the manufacturer thinks
        might be useful. After sending this progress type,
        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 progress types. For instance, a
        message indicating that the device is about to
        reboot after having installed a boot-image could
        be provided. The 'message' node below SHOULD
        contain information that the manufacturer thinks
        might be useful.";
    }
}
```



```
    mandatory true;
    description
      "The type of progress report provided.";
  }
  leaf message {
    type string;
    description
      "An optional arbitrary value.";
  }
  container ssh-host-keys {
    when "../progress-type = 'bootstrap-complete'" {
      description
        "SSH host keys are only sent when the progress type
        is 'bootstrap-complete'.";
    }
    description
      "A list of trust anchor certificates an NMS may use to
      authenticate subsequent SSH-based connections to this
      device (e.g., netconf-ssh, netconf-ch-ssh).";
    list ssh-host-key {
      description
        "An SSH host-key.";
      leaf format {
        type enumeration {
          enum "ssh-dss" {
            description
              "The SSH host key is a ssh-dss based key.";
          }
          enum "ssh-rsa" {
            description
              "The SSH host key is a ssh-rsa based key.";
          }
        }
      }
      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 "../progress-type = 'bootstrap-complete'" {
    description
```



```

        "Trust anchors are only sent when the progress type
        is 'bootstrap-complete'.";
    }
    description
        "A list of trust anchor certificates an NMS may use to
        authenticate subsequent certificate-based connections
        to this device (e.g., restconf-tls, netconf-tls, or
        even netconf-ssh with X.509 support from RFC 6187).
        In practice, trust anchors for IDevID certificates do
        not need to be conveyed using this mechanism.";
    reference
        "RFC 6187:
        X.509v3 Certificates for Secure Shell Authentication.";
    list trust-anchor {
        description
            "A trust anchor.";
        leaf certificate {
            type cms;
            mandatory true;
            description
                "An X.509 v3 certificate structure, as specified
                by Section 4 in RFC 5280, 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).";
        }
    }
}
}
}
}
}
}
}
}
}
<CODE ENDS>

```

8. The Zero Touch Device Data Model

This section defines a non-normative data model that enables the configuration of zerotouch bootstrapping and discovery of what parameters are used by a device's bootstrapping logic.

[8.1.](#) Data Model Overview

The following tree diagram provides an overview for the zerotouch device data model.

```
module: example-zerotouch-device
  +--rw zerotouch
    +--rw enabled?                               boolean
    +--ro idevid-certificate?                     cms
    | {bootstrap-servers}?
    +--ro bootstrap-servers {bootstrap-servers}?
    | +--ro bootstrap-server* [address]
    |   +--ro address      inet:host
    |   +--ro port?        inet:port-number
    +--ro bootstrap-server-pinned-certificates?
    |   -> /ks:keystore/pinned-certificates/name
    |   {bootstrap-servers}?
    +--ro voucher-pinned-certificates?
    |   -> /ks:keystore/pinned-certificates/name {signed-data}?
```

In the above diagram, notice that there is only one configurable node 'enabled'. The expectation is that this node would be set to 'true' in device's factory default configuration and that it would either be set to 'false' or deleted when the zerotouch bootstrapping is longer needed.

[8.2.](#) Example Usage

Following is an instance example for this data model.

[note: '\' line wrapping for formatting only]

```
<zerotouch
  xmlns="https://example.com/zerotouch-device">
  <enabled>true</enabled>
  <idevid-certificate>base64encodedvalue==</idevid-certificate>
  <bootstrap-servers>
    <bootstrap-server>
      <address>phs1.example.com</address>
      <port>8443</port>
    </bootstrap-server>
    <bootstrap-server>
      <address>phs2.example.com</address>
      <port>8443</port>
    </bootstrap-server>
    <bootstrap-server>
      <address>phs3.example.com</address>
      <port>8443</port>
    </bootstrap-server>
  </bootstrap-servers>
  <bootstrap-server-pinned-certificates>manufacturers-root-ca-certs<\
/bootstrap-server-pinned-certificates>
  <voucher-pinned-certificates>manufacturers-root-ca-certs</voucher-\
pinned-certificates>
</zerotouch>
```

8.3. YANG Module

The device model is defined by the YANG module defined in this section.

Note: the module defined herein uses data types defined in [[RFC5652](#)], [[RFC6991](#)], and [[I-D.ietf-netconf-keystore](#)], and uses an encoding defined in [[ITU.X690.1994](#)].

```
module example-zerotouch-device {
  yang-version 1.1;
  namespace "https://example.com/zerotouch-device";
  prefix ztd;

  import ietf-inet-types {
    prefix inet;
    reference "RFC 6991: Common YANG Data Types";
  }
  import ietf-keystore {
    prefix ks;
    revision-date 2017-10-30;
    description
```



```
"This revision is defined in draft-ietf-netconf-keystore-04.";
reference
  "I-D.ietf-netconf-keystore:
    YANG Data Model for a Keystore Mechanism";
}

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 a data model to enable zerotouch
  bootstrapping and discover what parameters are used.

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  authors of the code. All rights reserved.

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  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 2018-02-28 {
  description
    "Initial version";
  reference
    "RFC XXXX: Zero Touch Provisioning for for Networking Devices";
}

// features

feature bootstrap-servers {
  description
    "The device supports bootstrapping off bootstrap servers.";
}

feature signed-data {
  description
    "The device supports bootstrapping off signed data.";
}
```



```
// typedefs

typedef cms {
    type binary;
    description
        "A CMS structure, as specified in RFC 5652, encoded using
        ASN.1 distinguished encoding rules (DER), as specified in
        ITU-T X.690.";
    reference
        "RFC 5652:
        Cryptographic Message Syntax (CMS)
        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 nodes

container zerotouch {
    description
        "Top-level container for zerotouch data model.";
    leaf enabled {
        type boolean;
        default false;
        description
            "The 'enabled' leaf controls if zerotouch bootstrapping is
            enabled or disabled. The default is 'false' so that, when
            not enabled, which is most of the time, no configuration
            is needed.";
    }
    leaf idevid-certificate {
        if-feature bootstrap-servers;
        type cms;
        config false;
        description
            "An CMS SignedData structure, as specified by Section 5 of
            RFC 5652, encoded using ASN.1 distinguished encoding rules
            (DER), as specified in ITU-T X.690. This is the degenerate
            form of SignedData, whereby there are no signers, that is
            commonly used to disseminate certificates.</t>

            This structure contains the IEEE 802.1AR-2009 IDevID
            certificate itself, and all intermediate certificates leading
            up to, and optionally including, the manufacturer's well-known
            trust anchor certificate for IDevID certificates. The well-
            known trust anchor may not be a self-signed certificate.";
```



```
reference
  "RFC 5652:
    Cryptographic Message Syntax (CMS)
  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).
  IEEE 802.1AR-2009:
    IEEE Standard for Local and metropolitan area
    networks - Secure Device Identity.";
}
container bootstrap-servers {
  if-feature bootstrap-servers;
  config false;
  description
    "List of bootstrap servers this device will attempt
    to reach out to when bootstrapping.";
  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. If no
        port is specified, the IANA-assigned port for 'https'
        (443) is used.";
    }
  }
}
}
leaf bootstrap-server-pinned-certificates {
  if-feature bootstrap-servers;
  type leafref {
    path "/ks:keystore/ks:pinned-certificates/ks:name";
  }
  config false;
  description
    "A reference to a list of pinned certificate authority (CA)
    certificates that the device uses to validate bootstrap
```



```

        servers with.";
    }
    leaf voucher-pinned-certificates {
        if-feature signed-data;
        type leafref {
            path "/ks:keystore/ks:pinned-certificates/ks:name";
        }
        config false;
        description
            "A reference to a list of pinned certificate authority (CA)
            certificates that the device uses to validate ownership
            vouchers with.";
    }
}
}

```

9. 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.

9.1. 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

```

      0                                     1
      0  1  2  3  4  5  6  7  8  9  0  1  2  3  4  5
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
|  option-code (143)  |  option-length  |
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
.
.  bootstrap-server-list (variable length)  .
.
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+

```

- o option-code: OPTION_V4_ZEROTOUCH_REDIRECT (143)
- 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].

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 processes the response according to [Section 5.5](#), with the understanding that the 'address' and 'port' values are encoded in the URIs.

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.

As the list of URIs may exceed the maximum allowed length of a single DHCPv4 option (255 octets), the client MUST implement [\[RFC3396\]](#), allowing the URI list to be split across a number of `OPTION_V4_ZEROTOUCH_REDIRECT` option instances.

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.

As the list of URIs may exceed the maximum allowed length of a single DHCPv4 option (255 octets), the server MUST implement [\[RFC3396\]](#), allowing the URI list to be split across a number of `OPTION_V4_ZEROTOUCH_REDIRECT` option instances.

[9.2.](#) 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

```

      0                   1                   2                   3
      0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
|           option-code (136)           |           option-length       |
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
.           bootstrap-server-list (variable length)           .
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+

```

- o option-code: `OPTION_V6_ZEROTOUCH_REDIRECT` (136)
- 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 processes the response according to [Section 5.5](#), with the understanding that the 'address' and 'port' values are encoded in the URIs.

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.

9.3. 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:

```
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+...+---+---+---+---+
|      uri-length      |          URI          |
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+...+---+---+---+---+
```

o uri-length: variable, in octets.

o URI: URI of zerotouch bootstrap server, using the HTTPS URI scheme defined in [Section 2.7.2 of RFC7230](#). URI MUST be in form "https://<ip-address-or-hostname>[:<port>]".

10. Security Considerations

10.1. 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.

10.2. 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 SHOULD 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, ownership vouchers, and owner certificates never expire and are not revokable. From an ownership voucher perspective, manufacturers SHOULD issue a single ownership voucher for the lifetime of such devices.

Implementations SHOULD NOT rely on NTP for time, as NTP is not a secure protocol.

10.3. 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, assert that data downloaded from the server is signed.

10.4. Disclosing Information to Untrusted Servers

This document enables devices to establish provisional connections to bootstrap servers, in order for the bootstrap server to provide either unsigned redirect information or signed data of any type to the device. However, since the server is untrusted, it may be under the control of an adversary, and therefore devices should be cautious about the data they send in such cases.

This document requires devices identify and authenticate themselves to untrusted bootstrap servers. Depending on the authentication mechanisms used, this means that, at a minimum, the device's serial number may be disclosed to an adversary. Serial numbers 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 manufacturing sequence number. Knowledge of this information may provide an adversary with details needed to launch an attack.

In addition to the information relayed during the authentication, other potentially identifying values that may be disclosed to an untrusted server, including 'os-name', 'os-version', 'hw-model', and progress reports. In order to address this issue, it is RECOMMENDED that bootstrap server implementations promote the untrusted connection to a trusted connection, as described in [Appendix B](#).

10.5. 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.

10.6. The "ietf-zerotouch-information" YANG Module

The ietf-zerotouch-information module defined in this document defines a data structure that is always wrapped by a CMS structure. When accessed by a secure mechanism (e.g., protected by TLS), then the CMS structure may be unsigned. However, when accessed by an insecure mechanism (e.g., removable storage device), then the CMS structure must be signed, in order for the device to trust it.

Implementations should be aware that signed bootstrapping data only protects the data from modification, the contents are still visible to others. This doesn't affect Security so much as Privacy. That the contents may be read by unintended parties when accessed by insecure mechanisms is considered next.

The ietf-zerotouch-information module defines a top-level 'choice' statement that declares the contents are either "redirect-information" or "onboarding-information". Each of these two cases are now considered.

When the contents of the CMS structure are redirect-information, an observer can learn about the bootstrap servers the device is being directed, their IP addresses or hostnames, ports, and trust anchor certificates. Knowledge of this information could provide an observer some insight into a network's inner structure.

When the contents of the CMS structure are onboarding-information, as observer could learn considerable information about how the device is to be provisioned. This information includes the specific operating system version, the initial configuration, and the specific scripts that the device is to run. All of this information should be considered highly sensitive and precautions should be taken to protect it from falling into the wrong hands.

10.7. The "ietf-zerotouch-bootstrap-server" YANG Module

The ietf-zerotouch-bootstrap-server module defined in this document specifies an API for a RESTCONF [[RFC8040](#)]. The lowest RESTCONF layer is HTTPS, and the mandatory-to-implement secure transport is TLS [[RFC5246](#)].

The NETCONF Access Control Model (NACM) [[RFC6536](#)] provides the means to restrict access for particular users to a preconfigured subset of all available protocol operations and content.

This module presents no data nodes (only RPCs). There is no need to discuss the sensitivity of data nodes.

This module defines two RPC operations that may be considered sensitive in some network environments. These are the operations and their sensitivity/vulnerability:

get-bootstrapping-data: This RPC is used by devices to obtain their bootstrapping data. By design, each device, as identified by its authentication credentials (e.g. client certificate), can only obtain its own data. NACM is not needed to further constrain access to this RPC.

report-progress: This RPC is used by devices to report their bootstrapping progress. By design, each device, as identified by its authentication credentials (e.g. client certificate), can only report data for itself. NACM is not needed to further constrain access to this RPC.

11. IANA Considerations

11.1. 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.

11.2. 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: zti

reference: RFC XXXX

name: ietf-zerotouch-bootstrap-server

namespace: urn:ietf:params:xml:ns:yang:ietf-zerotouch-bootstrap-
server (note: '\\' used for formatting reasons only)

prefix: ztbs

reference: RFC XXXX

11.3. The SMI Security for S/MIME CMS Content Type Registry

IANA is kindly requested to two entries in the "SMI Security for S/MIME CMS Content Type" registry (1.2.840.113549.1.9.16.1), with values as follows:

Decimal	Description	References
-----	-----	-----
TBD1	id-ct-zerotouchInformationXML	[RFCXXXX]
TBD2	id-ct-zerotouchInformationJSON	[RFCXXXX]

11.4. The BOOTP Manufacturer Extensions and DHCP Options Registry

IANA is kindly requested to make permanent the following early code point allocation in the "BOOTP Manufacturer Extensions and DHCP Options" registry maintained at <http://www.iana.org/assignments/bootp-dhcp-parameters>:

Tag: 143

Name: OPTION_V4_ZEROTOUCH_REDIRECT

Data Length: N

Meaning: This option provides a list of URIs
for zerotouch bootstrap servers

Reference: [RFCXXXX]

And the following early code point allocation in the "Dynamic Host Configuration Protocol for IPv6 (DHCPv6)" registry maintained at <http://www.iana.org/assignments/dhcpv6-parameters>:

Value: 136

Description: OPTION_V6_ZEROTOUCH_REDIRECT

Reference: [RFCXXXX]

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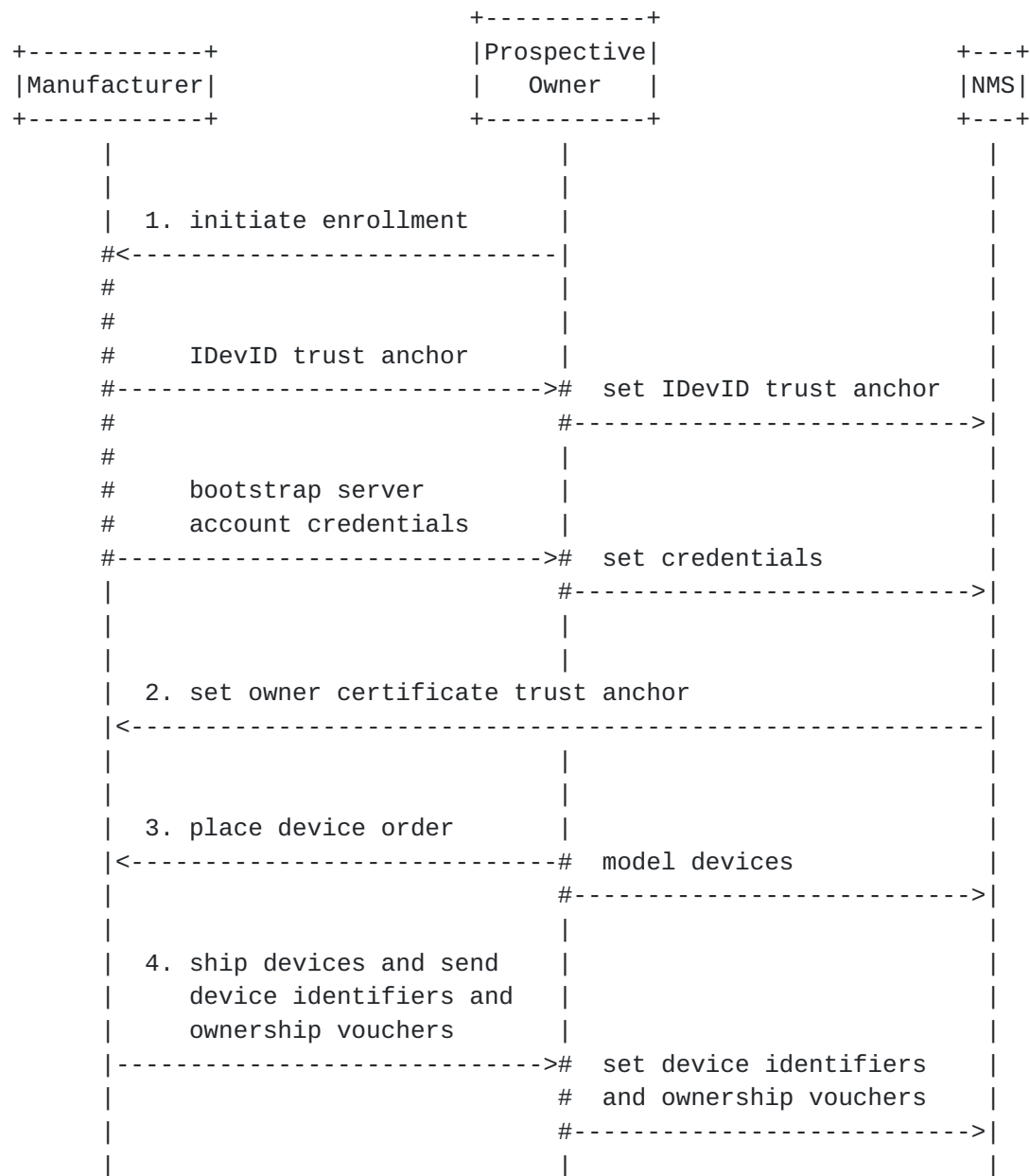
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Appendix A. Workflow Overview

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

A.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 initiates an enrollment process with the manufacturer. This process includes the following:

- * Regardless how the prospective owner intends to bootstrap their devices, they will always obtain from the manufacturer the trust anchor certificate for the IDevID certificates. This certificate will be installed on the prospective owner's

NMS so that the NMS can authenticate the IDevID certificates when they're presented to subsequent steps.

- * If the manufacturer hosts an Internet based bootstrap server (e.g., a redirect server) such as described in [Section 4.4](#), 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 5.4](#)), 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 certificate is used to enable devices to validate signed bootstrapping data is described in [Section 5.4](#).
 3. Some time later, the prospective owner places an order with the manufacturer, 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 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.

[A.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.

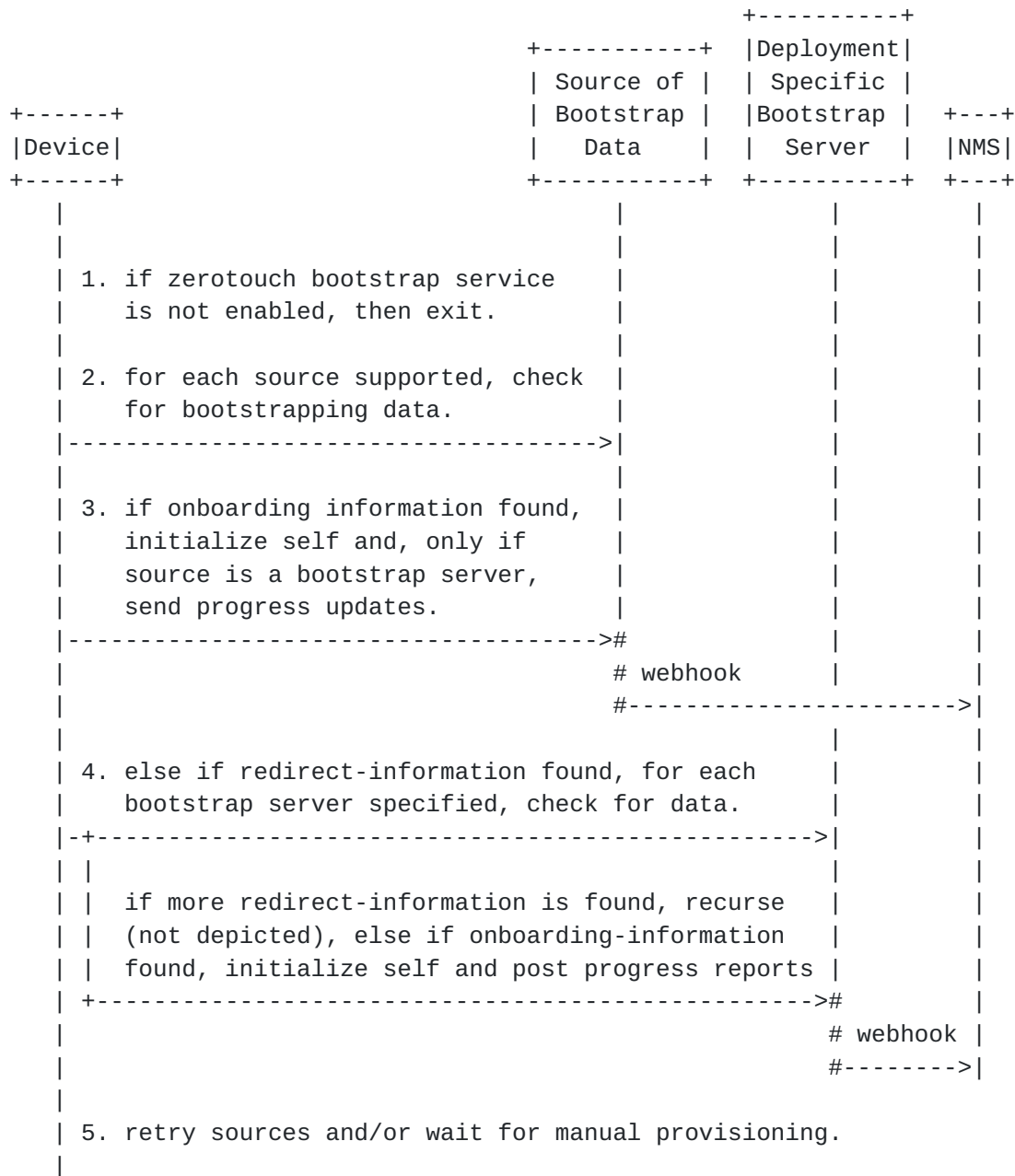
1. Having previously modeled the devices, including setting their fully operational configurations and associating device serial numbers and (optionally) ownership vouchers, the owner might "activate" one or more modeled devices. That is, the owner tells the NMS to perform the steps necessary to prepare 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 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 the onboarding 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 4.2](#) 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 4.3](#) 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 4.1](#) for more information about how to configure a removable storage device.

A.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 checks to see if zerotouch bootstrapping is configured, such as must be the case when running its "factory default" configuration. If zerotouch

bootstrapping is not configured, 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 reports 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](#)], and should disable the zerotouch bootstrapping service (e.g., the 'enabled' leaf in data model presented in [Section 8](#)).
 - * If the bootstrap server supports forwarding device progress reports to external systems (e.g., via a webhook), a "bootstrap-complete" progress report ([Section 7.3](#)) informs the external system to know when it can, for instance, initiate a connection to the device. To support this scenario further, the 'bootstrap-complete' progress report 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 successfully completes the bootstrapping process, 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 it has bootstrapping data for the device. 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 configuration should also disable the zerotouch bootstrapping service, as the need for bootstrapping would no longer be present.

Appendix B. Promoting a Connection from Untrusted to Trusted

The following diagram illustrates a sequence of bootstrapping activities that promote an untrusted connection to a bootstrap server to a trusted connection to the same bootstrap server. This enables a device to limit the amount of information it might disclose to an adversary hosting an untrusted bootstrap server.



The interactions in the above diagram are described below.

1. The device initiates an untrusted connection to a bootstrap server, as is indicated by putting "HTTPS" in double quotes above. It is still an HTTPS connection, but the device is unable to authenticate the bootstrap server's TLS certificate. Because the device is unable to trust the bootstrap server, it purposely only sends the 'untrusted-connection' input parameter to the 'get-bootstrapping-data' RPC, informing the bootstrap server that it doesn't trust it and may be holding back some information from the server (e.g., other input parameters, progress reports, etc.).
2. The bootstrap server, seeing the 'untrusted-connection' input parameters, knows that it can either send unsigned redirect information or signed data of any type. But, in this case, the

bootstrap server has the ability to sign data and chooses to respond with signed redirect information, not signed onboarding information as might be expected, securely redirecting the device back to it again.

3. Upon validating the signed redirect information, the device establishes a secure connection to the bootstrap server. Unbeknownst to the device, it is the same bootstrap server it was connected to previously but, because the device is able to authenticate the bootstrap server this time, it sends its normal 'get-bootstrapping-data' request (i.e., with additional input parameters) as well as its progress reports (not depicted).
4. This time, because the 'untrusted-connection' parameter was not passed, having access to all of the device's input parameters, the bootstrap server returns unsigned onboarding information to the device.

[Appendix C.](#) Change Log

[C.1.](#) ID to 00

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

[C.2.](#) 00 to 01

- o Added boot-image and validate-owner annotations to the "Actors and Roles" diagram.

- o Fixed 2nd paragraph in [section 7.1](#) to reflect current use of anyxml.
- o Added encrypted and signed-encrypted examples
- o Replaced YANG module with XSD schema
- o Added IANA request for the Zero Touch Information DHCP Option
- o Added IANA request for media types for boot-image and configuration

[C.3.](#) 01 to 02

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

[C.4.](#) 02 to 03

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

[C.5.](#) 03 to 04

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

C.6. 04 to 05

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

C.7. 05 to 06

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

C.8. 06 to 07

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

C.9. 07 to 08

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

C.10. 08 to 09

- o Added in missing "Signature" artifact example.
- o Added recommendation for manufacturers to use interoperable formats and file naming conventions for removable storage devices.

- o Added configuration-handling leaf to guide if config should be merged, replaced, or processed like an edit-config/yang-patch document.
- o Added a pre-configuration script, in addition to the post-configuration script from -05 (issue #15).

C.11. 09 to 10

- o Factored ownership voucher and voucher revocation to a separate document: [draft-kwatsen-netconf-voucher](#). (issue #11)
- o Removed <configuration-handling> options 'edit-config' and 'yang-patch'. (issue #12)
- o Defined how a signature over signed-data returned from a bootstrap server is processed. (issue #13)
- o Added recommendation for removable storage devices to use open/standard file systems when possible. (issue #14)
- o Replaced notifications "script-[warning/error]" with "[pre/post]-script-[warning/error]". (goes with issue #15)
- o switched owner-certificate to be encoded using the PKCS #7 format. (issue #16)
- o Replaced md5/sha1 with sha256 inside a choice statement, for future extensibility. (issue #17)
- o A ton of editorial changes, as I went thru the entire draft with a fine-toothed comb.

C.12. 10 to 11

- o fixed yang validation issues found by IETFYANGPageCompilation. note: these issues were NOT found by pyang --ietf or by the submission-time validator...
- o fixed a typo in the yang module, someone the config false statement was removed.

C.13. 11 to 12

- o fixed typo that prevented [Appendix B](#) from loading the examples correctly.

- o fixed more yang validation issues found by IETFYANGPageCompilation. note: again, these issues were NOT found by pyang --ietf or by the submission-time validator...
- o updated a few of the notification enumerations to be more consistent with the other enumerations (following the warning/error pattern).
- o updated the information-type artifact to state how it's encoded, matching the language that was in [Appendix B](#).

[C.14](#). 12 to 13

- o defined a standalone artifact to encode the old information-type into a PKCS #7 structure.
- o standalone information artifact hardcodes JSON encoding (to match the voucher draft).
- o combined the information and signature PKCS #7 structures into a single PKCS #7 structure.
- o moved the certificate-revocations into the owner-certificate's PKCS #7 structure.
- o eliminated support for voucher-revocations, to reflect the voucher-draft's switch from revocations to renewals.

[C.15](#). 13 to 14

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

[C.16](#). 14 to 15

- o Renamed action 'notification' to 'update-progress' and, likewise 'notification-type' to 'update-type'.
- o Updated examples to use "base64encodedvalue==" for binary values.

- o Greatly simplified the "Artifact Groupings" section, and moved it as a subsection to the "Artifacts" section.
- o Moved the "Workflow Overview" section to the Appendix.
- o Renamed "bootstrap information" to "update information".
- o Removed "Other Considerations" section.
- o Tons of editorial updates.

[C.17.](#) 15 to 16

- o tweaked language to refer to "initial state" rather than "factory default configuration", so as accommodate white-box scenarios.
- o added a paragraph to Intro regarding how the solution primarily regards physical machines, but could be extended to VMs by a future document.
- o added a pointer to the Workflow Overview section (recently moved to the Appendix) to the Intro.
- o added a note that, in order to simplify the verification process, the "Zerotouch Information" PKCS #7 structure MUST also contain the signing X.509 certificate.
- o noted that the owner certificate's must either have no Key Usage or the Key Usage must set the "digitalSignature" bit.
- o noted that the owner certificate's subject and subjectAltName values are not constrained.
- o moved/consolidated some text from the Artifacts section down to the Device Details section.
- o tightened up some ambiguous language, for instance, by referring to specific leaf names in the Voucher artifact.
- o reverted a previously overzealous s/unique-id/serial-number/change.
- o modified language for when ZTP runs from when factory-default config is running to when ZTP is configured, which the factory-defaults should set .

[C.18.](#) 16 to 17

- o Added an example for how to promote an untrusted connection to a trusted connection.
- o Added a "query parameters" section defining some parameters enabling scenarios raised in last call.
- o Added a "Disclosing Information to Untrusted Servers" section to the Security Considerations.

[C.19.](#) 17 to 18

- o Added Security Considerations for each YANG module.
- o Reverted back to the device always sending its DevID cert.
- o Moved data tree to ac'get-bootstrapping-data' RPC.
- o Moved the 'update-progress' action to a 'report-progress' RPC.
- o Added an 'untrusted-connection' parameter to 'get-bootstrapping-data' RPC.
- o Added the "ietf-zerotouch-device" module.
- o Lots of small updates.

[C.20.](#) 18 to 19

- o Fixed 'must' expressions, by converting 'choice' to a 'list' of 'image-verification', each of which now points to a base identity called "hash-algorithm". There's just one algorithm currently defined (sha-256). Wish there was a standard crypto module that could identify such identities.

[C.21.](#) 19 to 20

- o Now references I-D.ietf-netmod-yang-tree-diagrams.
- o Fixed tree-diagrams in [Section 2](#) to always reflect current YANG (now they are now dynamically generated).
- o The "redirect-information" container's "trust-anchor" is now a CMS structure that can contain a chain of certificates, rather than a single certificate.

- o The "onboarding-information" container's support for image verification reworked to be extensible.
- o Added a reference to the "Device Details" section to the new example-zerotouch-device module.
- o Clarified that the device must always pass its IDevID certificate, even for untrusted bootstrap servers.
- o Fixed the description statement for the "script" typedef to refer to the [pre/post]-script-[warning/error] enums, rather than the legacy script-[warning/error] enums.
- o For the get-bootstrapping-data RPC's input, removed the "remote-id" and "circuit-id" fields, and added a "hw-model" field.
- o Improved DHCP error handling text.
- o Added MUST requirement for DHCPv6 client and server implementing [\[RFC3396\]](#) to handle URI lists longer than 255 octets.
- o Changed the "configuration" value in onboarding-information to be type 'binary' instead of 'anydata'.
- o Moved everything from PKCS#7 to CMS (this shows up as a big change).
- o Added the early code point allocation assignments for the DHCP Options in the IANA Considerations section, and updated the RFC Editor note accordingly.
- o Added RFC Editor request to replace the assigned values for the CMS content types.
- o Relaxed auth requirements from device needing to always send IDevID cert to device needing to always send authentication credentials, as this better matches what [RFC 8040 Section 2.5](#) says.
- o Moved normative module "ietf-zerotouch-device" to non-normative module "example-zerotouch-device".
- o Updated Title, Abstract, and Introduction per discussion on list.

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