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Zero Touch Provisioning for NETCONF or RESTCONF based Management
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Abstract

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

Editorial Note (To be removed by RFC Editor)

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

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

- o "OPTION_V4_ZEROTOUCH_REDIRECT" --> the option code assigned for the "DHCPv4 Zero Touch Option" option
- o "OPTION_V6_ZEROTOUCH_REDIRECT" --> the option code assigned for the "DHCPv6 Zero Touch Option" option

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

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

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

- o "2017-10-19" --> the publication date of this draft

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

- o I-D.ietf-netconf-netconf-client-server
- o I-D.ietf-anima-voucher

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

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. However, the zerotouch solution may be extensible to virtual machines or other such logical constructs. Details for how this can be accomplished is left for future work.

[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 zerotouch 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 the network element that needs to be bootstrapped. See

[Section 5](#) for more information about devices.

Initial Secure Device Identifier (IDevID): The term "IDevID" is defined in [[Std-802.1AR-2009](#)] as the globally unique secure device identifier (DevID) installed on the device by the manufacturer. This identifier is used in this document to enable a bootstrap server to securely identify and authenticate the device.

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

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

Onboarding Information: The term "onboarding information" is used herein to refer to one of the two types of "zero touch information" defined in this document, the other being "redirect information". Onboarding information is formally defined by the "onboarding-information" YANG-data structure in [Section 6.3](#).

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

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

certificate is one of the three bootstrapping artifacts described in [Section 3](#).

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

Redirect Information: The term "redirect information" is used herein to refer to one of the two types of "zero touch information" defined in this document, the other being "onboarding information". 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 either redirect information or onboarding information that has been signed, specifically by a private key possessed by a device's owner.

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

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

[1.3](#). Requirements Language

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

[1.4](#). Tree Diagram Notation

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

- o Brackets "[" and "]" enclose list keys.

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

[2.](#) Types of Bootstrapping Information

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

[2.1.](#) Redirect Information

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

Redirect information is YANG modeled data formally defined by the "redirect-information" container in the YANG module presented in [Section 6.3](#). This container has the tree diagram shown below. Please see [Section 1.4](#) for tree diagram notation.

```

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

```

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

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

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

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

[2.2](#). Onboarding Information

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

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. Please see [Section 1.4](#) for tree diagram notation.

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

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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 formally 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 a means for providing each of 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 PKCS#7 SignedData structure, as specified by [Section 9.1 of \[RFC2315\]](#), encoded using ASN.1 distinguished encoding rules (DER), as specified in ITU-T X.690 [\[ITU.X690.1994\]](#). The PKCS#7 structure MUST contain JSON-encoded content conforming to the YANG module specified in [Section 6.3](#).

In order for the zero touch information artifact to be trusted when conveyed over an untrusted transport, the PKCS#7 structure MUST also contain a "signerInfo" structure, as described in [Section 9.1 of \[RFC2315\]](#), containing a signature generated over the content using the private key associated with the owner certificate ([Section 3.2](#)). In order to simplify the verification process, the PKCS#7 structure SHOULD also contain the signing X.509 certificate (i.e. the owner

certificate).

[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 MUST either have no Key Usage specified, or the Key Usage MUST at least set the "digitalSignature" bit. The values for

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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 an unsigned PKCS #7 SignedData structure, as specified by [Section 9.1 in \[RFC2315\]](#), encoded using ASN.1 distinguished encoding rules (DER), as specified in ITU-T X.690 [[ITU.X690.1994](#)].

The owner certificate PKCS#7 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.

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

[3.3.](#) Ownership Voucher

The ownership voucher artifact is used to securely identify a

device's owner, as it is known to the manufacturer. The ownership voucher is signed by the device's manufacturer.

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'), even if it is itself (e.g., self-signed certificate).

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

[3.4.](#) Artifact Groupings

This section lists all the possible bootstrapping artifacts, but only certain groupings of these artifacts make sense to return in the various bootstrapping situations described in this document. 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: The grouping is useful when signed information is needed, because it's 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: The grouping is useful when signed information is needed, because it's 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 doesn't 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 MUST either be signed, or 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.pk7).

Owner Certificate: Mapped to a file containing the binary artifact described in [Section 3.2](#) (e.g., owner-certificate.pk7).

Ownership Voucher: Mapped to a file containing the binary artifact described in [Section 3.3](#) (e.g., ownership-voucher.pk7).

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

[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.

When onboarding information (not redirect information) is provided,

the URL for the boot-image the device can download would have to point to another server (e.g., <http://>, <ftp://>, etc.), as DNS servers do not themselves distribute files.

[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 limited in the amount of data that can be conveyed, to the extent that signed data cannot be communicated. Thus only unsigned redirect information can be conveyed.

Since the redirect information is unsigned, it SHOULD NOT include the optional trust anchor certificate, as the device would have to discard it anyway. The DHCP options defined in [Section 9](#) do not enable the certificate to be communicated.

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 redirect information (not onboarding information) is mapped to the DHCP fields 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, in lieu of signed data, which may be easier to deploy in some situations. Additionally, the bootstrap server is able to receive progress updates from devices, which may be critical to some deployments (e.g., the passing of the device's SSH host keys).

A bootstrap server may be 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 MUST either be signed or be information that can be processed provisionally (e.g., unsigned redirect information).

From an artifact perspective, since a bootstrap server presents data as a YANG-modeled data, the bootstrapping artifacts need to be mapped to the YANG module. The three artifacts defined in [Section 3](#) are mapped to 'output' node 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.

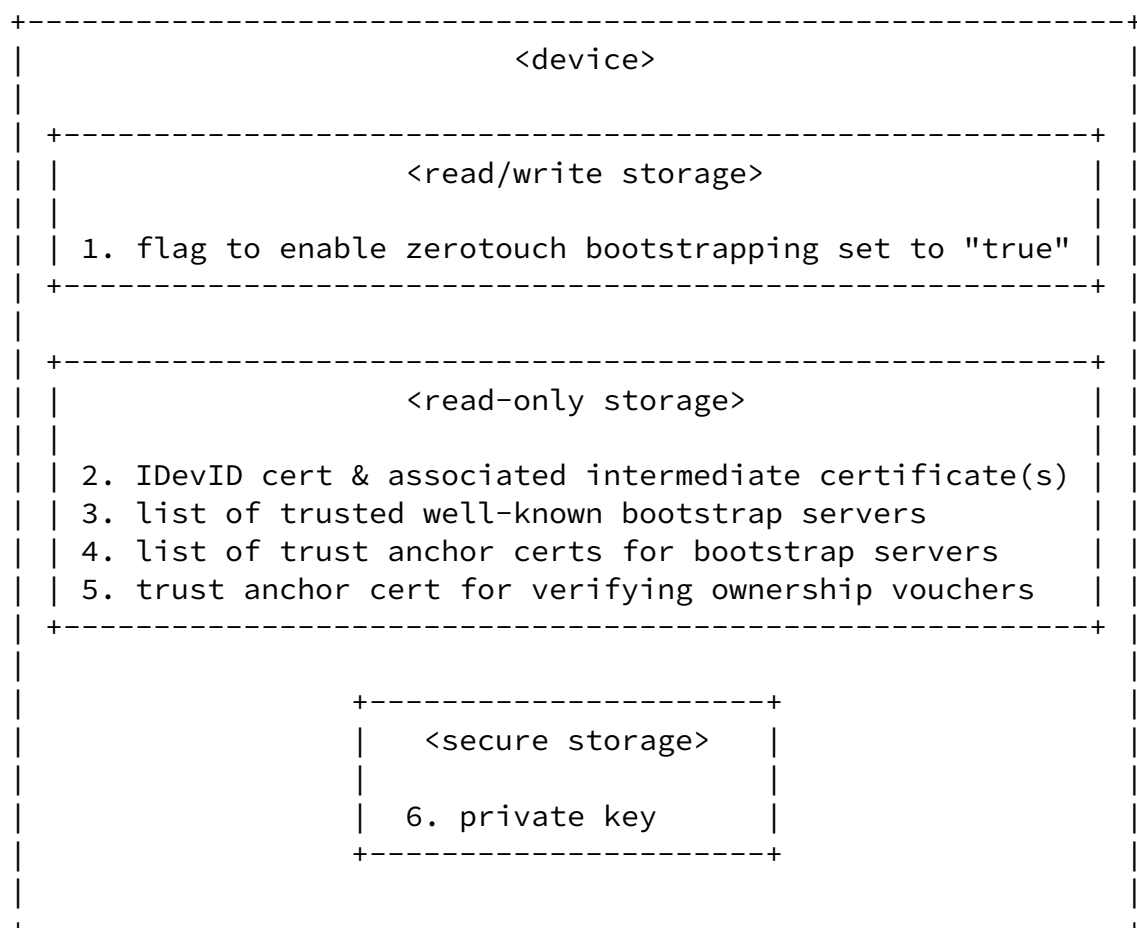
Owner Certificate: Mapped to the 'owner-certificate' leaf in the output of the 'get-bootstrapping-data' RPC.

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

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 completion status information (e.g., the device's SSH host-keys).

5. Device Details

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 the 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 is able to

disable zerotouch bootstrapping, and because said 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.

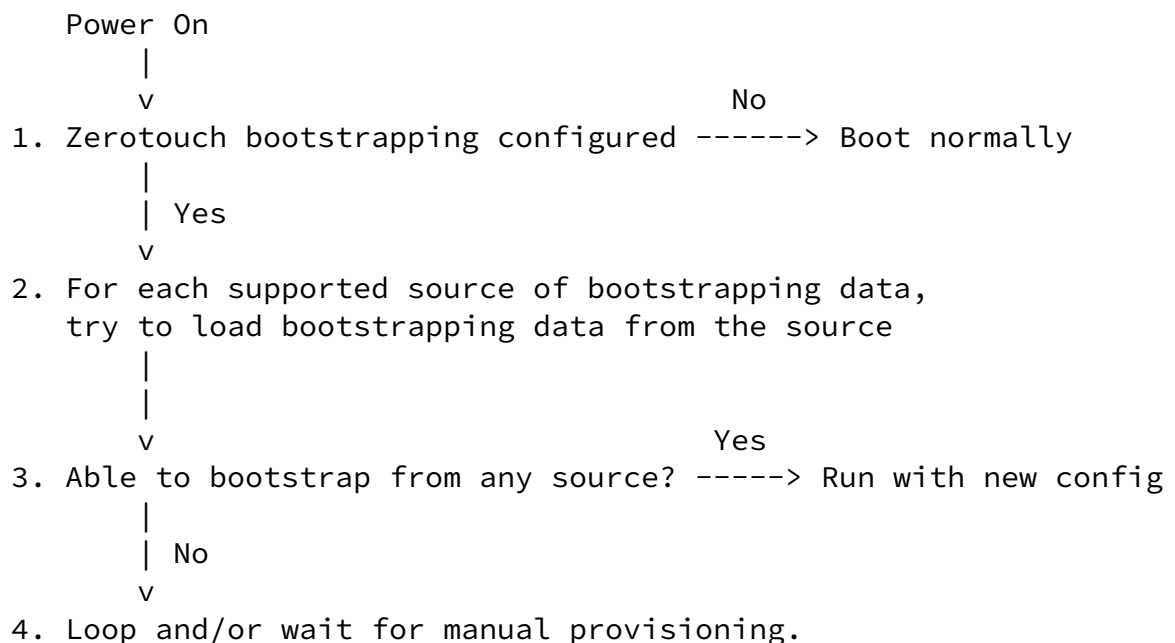
2. Devices that support loading bootstrapping data from bootstrap servers (see [Section 4.4](#)), whether preconfigured or learned through the bootstrapping process, MUST possess an initial device identifier (IDevID), as defined in [[Std-802.1AR-2009](#)]. The IDevID is an X.509 certificate encoding, amongst other things, the device's serial number and hardware manufacturer. The device MUST also possess any intermediate certificates between the IDevID certificate and the manufacturer's IDevID trust anchor certificate provided to prospective owners separately (e.g., [Appendix A.1](#)).
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 MAY 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 secure the TLS connection to the well-known bootstrap servers.
5. Devices that support loading signed data (see [Section 1.2](#)) MUST possess the manufacturer's trust anchor certificate for validating ownership vouchers.
6. Devices MUST possess a private key that corresponds to the public key encoded in the device's IDevID 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 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.

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, else the device MUST set trust-state to FALSE. Note, this is worded to cover the special case when signed data is returned even from a trusted bootstrap server.

If the 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 defined in [Section 4](#).

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 ensure that the ownership voucher was created in the past (i.e., 'created-on' < now). If the 'expires-on' leaf is present, the device MUST verify that the ownership voucher has not yet expired (i.e., now < 'expires-on'), which requires an accurate clock. 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-certificate' 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 signature over the information artifact was generated by the private key matching the public key from the owner certificate.

If any of these steps fail, then the device MUST invalidate the 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 RESTCONF TLS server certificate using X.509 certificate path validation ([\[RFC6125\]](#), [Section 6](#)) to the specified trust anchor. If the device is unable to authenticate the bootstrap server to the specified trust anchor, the device MAY attempt a provisional connection to the bootstrap server (i.e., by blindly accepting its server certificate) and setting 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, then execute the pre-configuration script (if any), then commit the initial configuration, 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 was obtained from a trusted bootstrap server, the device SHOULD send progress reports throughout the bootstrapping process using the bootstrap server's 'report-progress' RPC.

First the device MUST determine if the image it is running satisfies the specified boot image criteria (e.g., name and/or fingerprint match). If it does not, the device MUST download (using the supplied URI), verify, and install the specified boot image, and then reboot. To verify the downloaded boot image, the device MUST check that the boot image file matches the fingerprint (e.g., sha256) 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's running image will satisfy the specified criteria, and thus the device will move to processing the next step.

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

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

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

At this point, the device has completely processed the bootstrapping data and is ready to be managed. If the device obtained the 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.

At this point, the device is 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.

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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 [RFC 8040](#). 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. The syntax used for this tree diagram is described in [Section 1.4](#).

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?    binary
    +---:(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?         <anydata>
        +---- post-configuration-script? script
```

6.2. Example Usage

The following example illustrates how redirect information ([Section 2.1](#)) can be encoded using JSON, as is needed by the zero

touch information artifact.

```
{
  "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, as is needed by the zero touch information artifact.

Note: the sample configuration used in the below example configures an administrator account with an SSH public key, configures keystore with an authentication certificate, configures NETCONF Call Home and, lastly, disables the zerotouch bootstrapping service. This is achieved through use of YANG modules "ietf-system" from [[RFC7317](#)], "ietf-keystore" from [[I-D.ietf-netconf-keystore](#)], "ietf-netconf-server" from [[I-D.ietf-netconf-netconf-client-server](#)] and "ietf-zerotouch-device" from this document.

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

```
{
  "ietf-zero-touch-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-zero-touch-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",
```

```
"configuration" : {
```

```
  "ietf-system:system" : {
```

```
    "authentication" : {
```

```
      "user" : {
```

```
        "name" : "admin",
```

```
        "authorized-key" : {
```

```
          "name" : "admin's rsa ssh host-key",
```

```
          "algorithm" : "ssh-rsa",
```

```
          "key-data" : "base64encodedvalue=="
```

```
        }
```

```
      }
```

```
    }
```

```
  },
```

```
  "ietf-keystore:keystore" : {
```

```
    "pinned-certificates" : {
```

```
      "name" : "deployment-specific-ca-certs",
```

```
      "description" : "Certs used to auth client connections.",
```

```
      "pinned-certificate" : {
```

```
        "name" : "ca.example.com",
```

```
        "data" : "base64encodedvalue=="
```

```
      }
```

```

    },
    "pinned-certificates" : {
      "name" : "explicitly-trusted-client-certs",
      "description" : "Certs for explicitly-trusted clients.",
      "pinned-certificate" : {
        "name" : "Fred Flintstone",
        "data" : "base64encodedvalue=="
      }
    }
  },
  "ietf-netconf-server:netconf-server" : {
    "call-home" : {
      "netconf-client" : {
        "name" : "config-mgr",
        "endpoints" : {
          "endpoint" : {
            "name" : "east-data-center",
            "ssh" : {
              "address" : "east.config-mgr.example.com",
              "host-keys" : {

```

```

      "host-key" : {
        "name" : "certificate",
        "certificate" : "builtin-idevid-cert"
      }
    },
    "client-cert-auth" : {
      "trusted-ca-certs" :
        "deployment-specific-ca-certs",
      "trusted-client-certs" :
        "explicitly-trusted-client-certs"
    }
  }
},
"endpoint" : {
  "name" : "west-data-center",
  "ssh" : {
    "address" : "west.config-mgr.example.com",
    "host-keys" : {
      "host-key" : {
        "name" : "certificate",
        "certificate" : "builtin-idevid-cert"

```

```

    }
  },
  "client-cert-auth" : {
    "trusted-ca-certs" :
      "deployment-specific-ca-certs",
    "trusted-client-certs" :
      "explicitly-trusted-client-certs"
  }
}
},
"connection-type" : {
  "periodic" : {
    "idle-timeout" : 300,
    "reconnect-timeout" : 60
  }
},
"reconnect-strategy" : {
  "start-with" : "last-connected",
  "max-attempts" : 3
}
}
},
"ietf-device:zerotouch" : {
  "enabled" : false
}

```

```

    }
  }
}

```

[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 [[RFC8040](#)], and an encoding defined in [[ITU.X690.1994](#)].

<CODE BEGINS> file "ietf-zerotouch-information@2017-10-19.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-restconf {
    prefix rc;
    description
      "This import statement is only present to access
       the yang-data extension defined in RFC 8040.";
    reference "RFC 8040: RESTCONF Protocol";
  }

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

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

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

```

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

```
revision 2017-10-19 {
  description
    "Initial version";
  reference
    "RFC XXXX: Zero Touch Provisioning for NETCONF or RESTCONF based
    Management";
}

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

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

rc: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 NETCONF or RESTCONF
    based Management";
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 binary;
        description
            "An X.509 v3 certificate structure as specified by RFC
            5280, Section 4, encoded using ASN.1 distinguished
            encoding rules (DER), as specified in ITU-T X.690. A
            certificate that the device can use as the trust anchor
            to authenticate the bootstrap server the device is
            being redirected to. If not specified, the device may
            establish a provisional connection to the bootstrap
            server, as described in RFC XXXX.";
        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).
            RFC XXXX:
            Zero Touch Provisioning for NETCONF or RESTCONF
            based Management.";
    }
}
}
}

```

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```
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 NETCONF or RESTCONF
    based Management";
  container boot-image {
    description
      "Specifies criteria for the boot image the device MUST
      be running.";
    leaf os-name {
      type string;
      mandatory true;
      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;
      mandatory true;
      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 {
        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";
        }
        mandatory true;
        description
            "Identifies the hash algorithm used.";
    }
    leaf hash-value {
        type yang:hex-string;
        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.";
}
anydata configuration {
    must '../configuration-handling';
    description
        "Any configuration data model known to the device. It may
        contain manufacturer-specific and/or standards-based data
        models.";
}

```

```

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

```

```

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

```

No attempt is made to standardize the contents, running context, or programming language of the script, 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, the device SHOULD send a 'script-warning' progress report, but otherwise continue processing the bootstrapping data as if the script had not been present.

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

If the exit status code is greater than zero, then the device should assume that the script had a soft error, which the script believes does not affect manageability. If the device obtained the bootstrap information from a bootstrap server, it SHOULD send a 'script-warning' progress report.

If the exit status code is less than zero, the device should assume the script had a hard error, which the script believes will affect manageability. In this case, the device SHOULD send a 'script-error' progress report followed by a reset that will wipe out anything the script may have done and restart the entire bootstrapping process again.";

```
}  
}
```

<CODE ENDS>

[7.](#) The Zero Touch Bootstrap Server API

This section defines the API for bootstrap servers. The API is defined as the API 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. The syntax used for this tree diagram is described in [Section 1.4](#).

module: ietf-zerotouch-bootstrap-server

rpcs:

```
+---x get-bootstrapping-data  
|   +---w input  
|   |   +---w untrusted-connection?   empty  
|   |   +---w os-name?                 string  
|   |   +---w os-version?              string
```

```

| | +---w remote-id?          string
| | +---w circuit-id?        string
| | +---w nonce?             string
| +--ro output
|   +--ro bootstrapping-data
|     +--ro zerotouch-information pkcs7
|     +--ro owner-certificate?   pkcs7
|     +--ro ownership-voucher?   pkcs7
+---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 pkcs7

```

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 a 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-zero-touch-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-zero-touch-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 additional input parameters that the bootstrap server can use when formulating its response to the device.

REQUEST

['\ ' line wrapping added for formatting only]

POST /restconf/operations/ietf-zero-touch-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-zero-touch-bootstrap-server">
  <os-name>VendorOS</os-name>
  <os-version>17.3R2.1</os-version>
  <remote-id>32</remote-id>
  <circuit-id>2</circuit-id>
  <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-zero-touch-bootstrap-server">
  <zerotouch-information>base64encodedvalue==</zerotouch-information>
</output>
```

The following example illustrates a device using the API to post a progress update 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 [[RFC2315](#)], [[RFC5280](#)], [[RFC6960](#)], and [[I-D.ietf-anima-voucher](#)], and uses an encoding defined in [[ITU.X690.1994](#)].

```
<CODE BEGINS> file "ietf-zerotouch-bootstrap-server@2017-10-19.yang"  
module ietf-zerotouch-bootstrap-server {
```

```
yang-version 1.1;
namespace
  "urn:ietf:params:xml:ns:yang:ietf-zero-touch-bootstrap-server";
prefix ztbs;

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

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

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

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

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

revision 2017-10-19 {
  description
    "Initial version";
  reference
    "RFC XXXX: Zero Touch Provisioning for NETCONF or RESTCONF based
    Management";
}

// typedefs

typedef pkcs7 {
```

type binary;
description

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

// RPCs

rpc get-bootstrapping-data {
    description
        "This RPC enables a device, as identified by its 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 did not send
                any of the other input parameters. The bootstrap server
                needs to return either unsigned redirect information or
                signed data.";
        }
        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 IDevID certificate,
```

```

        to 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 useful

```

```

        to a server that wants to return a response optimized
        for the device, negating, for instance, the need for
        a potentially expensive boot-image update.";
    }
    leaf remote-id {
        type string;
        must "../circuit-id";
        description
            "This optional input parameter enables a device to
            communicate to the bootstrap server the 'remote-id'
            value it learned from a DHCP server via Option 82,
            as described in Section 2.0 or RFC 3046.

            This information, along with the circuit-id, enables
            the bootstrap server to return a deployment-specific
            response independent of the device's IDevID identity.";
        reference
            "RFC 3046: DHCP Relay Agent Information Option";
    }
    leaf circuit-id {
        type string;
        must "../remote-id";
        description
            "This optional input parameter enables a device to
            communicate to the bootstrap server the 'circuit-id'
            value it learned from a DHCP server via Option 82,
            as described in Section 2.0 or RFC 3046.

            This information, along with the remote-id, enables
            the bootstrap server to return a deployment-specific
            response independent of the device's IDevID identity.";
        reference

```

```

    "RFC 3046: DHCP Relay Agent Information Option";
}
leaf nonce {
    type string;
    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
        then 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.";
}
}

```

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```

output {
    container bootstrapping-data {
        description
            "Top-level node for the bootstrapping data.";
        leaf zerotouch-information {
            type pkcs7;
            mandatory true;
            description
                "A 'zerotouch-information' artifact, as described in
                Section 4.1 of RFC XXXX. In order to be processed by a
                device, when conveyed over an untrusted transport, the
                PKCS#7 SignedData structure MUST contain a 'signerInfo'
                structure, described in Section 9.1 of RFC 2315,
                containing a signature generated using the private key
                associated with the 'owner-certificate'.";
            reference
                "RFC XXXX: Zero Touch Provisioning for NETCONF or
                RESTCONF based Management.
                RFC 2315:
                PKCS #7: Cryptographic Message Syntax Version 1.5";
        }
        leaf owner-certificate {
            type pkcs7;
            must '../ownership-voucher' {
                description

```

```

        "An ownership voucher must be present whenever an owner
        certificate is presented.";
    }
    description
        "This PKCS#7 structure MUST contain the owner certificate
        and all intermediate certificates leading up to, and
        optionally including, the trust anchor certificate
        specified in the ownership voucher. Additionally, if
        needed by the device, this structure MAY also contain
        suitably fresh CRL and/or OCSP Responses with which 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 2315:
        PKCS #7: Cryptographic Message Syntax Version 1.5.
        RFC 5280:
        Internet X.509 Public Key Infrastructure Certificate
        and Certificate Revocation List (CRL) Profile.
        RFC 6960:
        X.509 Internet Public Key Infrastructure Online
        Certificate Status Protocol - OCSP."

```

```

    ITU-T X.690:
        Information technology - ASN.1 encoding rules:
        Specification of Basic Encoding Rules (BER),
        Canonical Encoding Rules (CER) and Distinguished
        Encoding Rules (DER).";
    }
    leaf ownership-voucher {
        type pkcs7;
        must '../owner-certificate' {
            description
                "An owner certificate must be present whenever an
                ownership voucher is presented.";
        }
        description
            "A 'voucher' artifact, as described in Section 5 of
            I-D.ietf-anima-voucher. The voucher informs the device
            who 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.";
    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 its RESTCONF
        username, to report its bootstrapping progress to the
        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' field
                        below MAY contain any additional information that
                        the manufacturer thinks might be useful.";
                }
                enum "parsing-warning" {
                    description
                        "Indicates that the device had a non-fatal error when
                        parsing the response from the bootstrap server. The

```

```

        'message' field below SHOULD indicate the specific
        warning that occurred.";
    }
    enum "parsing-error" {
        description
            "Indicates that the device encountered a fatal error
            when parsing the response from the bootstrap server.
            For instance, this could be due to malformed
            encoding, the device expecting signed data when
            only unsigned data is provided, because the
            ownership voucher didn't include the device's

```



```

        unique identifier, or because the signature didn't
        match. The 'message' field below SHOULD indicate
        the specific error. This 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' field
            below SHOULD indicate any warning messages that were
            generated.";
    }
    enum "boot-image-error" {
        description
            "Indicates that the device encountered an error when
            trying to install a boot-image, which could be for
            reasons such as a file server being unreachable,
            file not found, signature mismatch, etc. The
            'message' field SHOULD indicate the specific error
            that occurred. This 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' field below SHOULD indicate
            both the resulting exit status code, as well as
            capture any stdout/stderr messages the script may
            have produced.";
    }
    enum "pre-script-error" {
        description

```

```

"Indicates that the device obtained a less than
zero exit status code from the script when it was
executed. The 'message' field below SHOULD indicate
both the resulting exit status code, as well as

```

```

        capture any stdout/stderr messages the script may
        have produced. This 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' field below SHOULD indicate any warning
            messages that were generated.";
    }
    enum "config-error" {
        description
            "Indicates that the device obtained error messages
            when it committed the initial configuration. The
            'message' field below SHOULD indicate the error
            messages that were generated. This 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' field below SHOULD indicate
            both the resulting exit status code, as well as
            capture any stdout/stderr messages the script may
            have produced.";
    }
    enum "post-script-error" {
        description
            "Indicates that the device obtained a less than
            zero exit status code from the script when it was
            executed. The 'message' field below SHOULD indicate
            both the resulting exit status code, as well as
            capture any stdout/stderr messages the script may
            have produced. This 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' field 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' field 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
                        "ssh-dss";
                }
                enum "ssh-rsa" {
```

```
        "ssh-rsa";
    }
}
mandatory true;
description
    "The format of the SSH host key.";
}
leaf key-data {
    type string;
    mandatory true;
    description
        "The key data for the SSH host key";
}
}
}
container trust-anchors {
    when "../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).";
    reference
        "RFC 6187:
        X.509v3 Certificates for Secure Shell Authentication.";
    list trust-anchor {
        description
            "A trust anchor.";
        leaf certificate {
            type pkcs7;
            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),

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Canonical Encoding Rules (CER) and Distinguished
Encoding Rules (DER).";

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

[8.](#) The Zero Touch Device Data Model

This section defines a data model that devices can implement to enable the configuration of zerotouch bootstrapping and discovery of what parameters are used by its bootstrapping logic.

[8.1.](#) Data Model Overview

The following tree diagram provides an overview for the zerotouch device data model. The syntax used for this tree diagram is described in [Section 1.4](#).

```
module: ietf-zerotouch-device  
  +--rw zerotouch  
    +--rw enabled?                               boolean  
    +--ro devid-certificate?                     pkcs7  
    |      {bootstrap-servers}?  
    +--ro bootstrap-servers {bootstrap-servers}?  
    |   +--ro bootstrap-server* [address]  
    |   |   +--ro address      inet:host  
    |   |   +--ro port?       inet:port-number  
    +--ro bootstrap-server-ta-certificates?  
    |   -> /ks:keystore/pinned-certificates/name
```

```

|           {bootstrap-servers}?
+--ro voucher-ta-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="urn:ietf:params:xml:ns:yang:ietf-zerotouch-device">
    <enabled>true</enabled>
    <devid-certificate>base64encodedvalue==</devid-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-ta-certificates>manufacturers-root-ca-certs</bootstrap-server-ta-certificates>
    <voucher-ta-certificates>manufacturers-root-ca-certs</voucher-ta-certificates>
  </zerotouch>

```

8.3. YANG Module

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

Note: the module defined herein uses data types defined in [[RFC2315](#)] and [[RFC6991](#)], and uses an encoding defined in [[ITU.X690.1994](#)].

```
<CODE BEGINS> file "ietf-zerotouch-device@2017-10-19.yang"
module ietf-zerotouch-device {
  yang-version 1.1;
  namespace
    "urn:ietf:params:xml:ns:yang:ietf-zerotouch-device";
  prefix ztd;

  import ietf-inet-types {
    prefix inet;
    reference "RFC 6991: Common YANG Data Types";
  }
  import ietf-keystore {
    prefix ks;
    reference 'RFC YYYY: 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.

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

```
revision 2017-10-19 {
  description
    "Initial version";
  reference
    "RFC XXXX: Zero Touch Provisioning for NETCONF or RESTCONF based
    Management";
}

// 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 pkcs7 {
  type binary;
  description
    "A PKCS #7 SignedData structure, as specified by Section 9.1
    in RFC 2315, encoded using ASN.1 distinguished encoding rules
    (DER), as specified in ITU-T X.690.";
  reference
```



```

"RFC 2315:
    PKCS #7: Cryptographic Message Syntax Version 1.5.
    ITU-T X.690:
        Information technology - ASN.1 encoding rules:
        Specification of Basic Encoding Rules (BER),
        Canonical Encoding Rules (CER) and Distinguished
        Encoding Rules (DER).";
}

// protocol accessible 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
            needs to be returned.";
    }
    leaf devid-certificate {
        if-feature bootstrap-servers;
        type pkcs7;
        config false;
        description
            "An unsigned PKCS #7 SignedData structure, as specified by
            Section 9.1 in RFC 2315, encoded using ASN.1 distinguished
            encoding rules (DER), as specified in ITU-T X.690.

            This structure contains the IDevID certificate and all
            intermediate certificates leading up to the manufacturer's
            well-known trust anchor certificate. IDevID certificates
            are described in IEEE 802.1AR-2009.";
    }
}

```

reference

```

"RFC 2315:
    PKCS #7: Cryptographic Message Syntax Version 1.5.
    ITU-T X.690:
        Information technology - ASN.1 encoding rules:

```

```

        Specification of Basic Encoding Rules (BER),
        Canonical Encoding Rules (CER) and Distinguished
        Encoding Rules (DER).
    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
        "Default list of bootstrap servers this device is
        configured 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-ta-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-ta-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.";
    }
}
}
}

```

<CODE ENDS>

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 (TBD)										option-length					
bootstrap-server-list (variable length)															

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

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DHCPv4 Client Behavior

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

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

1. Check the contents of the DHCPv4 message for at least one valid URI. If there is more than one valid URI in the list, a candidate list of possible URIs is created.
2. Attempt to connect to the one of the URIs in the candidate list. The order in which these are processed by the client is implementation specific and not defined here.
3. If a successful connection to the zerotouch bootstrap server, then the client stops processing entries in the list and proceeds according to [Appendix A.3](#), step(3).
4. If the zerotouch bootstrap server does not respond, provides an invalid response, or the transaction otherwise fails, the client SHOULD attempt to contact another server from the candidate list.

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

DHCPv4 Server Behavior

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

[9.2.](#) DHCPv6 Zero Touch Option

The DHCPv6 Zero Touch Option is used to provision the client with one

3. If a successful connection to the zerotouch bootstrap server, then the client stops processing entries in the list and proceeds according to [Appendix A.3](#), step(3).
4. If the zerotouch bootstrap server does not respond, provides and invalid response or the transaction otherwise fails, the client SHOULD attempt to contact another server from the candidate list.

Any invalid URI entries received in the uri-data field are ignored by the client. If OPTION_V6_ZEROTOUCH_REDIRECT does not contain at

least one valid URI entry in the uri-data field, then the client MUST discard the option.

DHCPv6 Server Behavior

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

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

[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. Entropy loss over time

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

10.5. 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 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.

Already this document requires devices send their IDevID certificate to untrusted bootstrap servers, which means that the device's serial number and hardware manufacturer 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 IDevID certificate, there are other potentially identifying values that may be disclosed to an untrusted server, including 'os-name', 'os-version', 'remote-id', 'circuit-id', and progress reports. In order to address this issue, it is RECOMMENDED

that implementations first promote the untrusted connection to a trusted connection, as described in [Appendix B](#).

[10.6](#). Sequencing Sources of Bootstrapping Data

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

[10.7](#). 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 PKCS#7 structure. When accessed by a secure mechanism (e.g., protected by TLS), then the PKCS#7 structure may be unsigned. However, when accessed by an insecure mechanism (e.g., removable storage device), then the PKCS#7 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 PKCS#7 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 PKCS#7 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.

10.8. 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 IDevID certificate, can only obtain its own data. NACM is not needed to further constrain access to this RPC.

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

10.9. The "ietf-zerotouch-device" YANG Module

The ietf-zerotouch-device module defined in this document is designed to be accessed via network management protocols such as NETCONF [[RFC6241](#)] or RESTCONF [[RFC8040](#)]. The lowest NETCONF layer is the secure transport layer, and the mandatory-to-implement secure transport is Secure Shell (SSH) [[RFC6242](#)]. The lowest RESTCONF layer

is HTTPS, and the mandatory-to-implement secure transport is TLS [[RFC5246](#)].

The NETCONF access control model [[RFC6536](#)] provides the means to restrict access for particular NETCONF or RESTCONF users to a preconfigured subset of all available NETCONF or RESTCONF protocol operations and content.

There is a data node defined in this YANG module that is writable/creatable/deletable (i.e., config true, which is the default). This data node may be considered sensitive or vulnerable in some network environments. Write operations (e.g., edit-config) to this data node without proper protection can have a negative effect on network operations. This is the data node and its sensitivity/vulnerability:

/enabled: This data node is used to enable/disable the zerotouch bootstrapping mechanism on a device. NACM rules or equivalent should be used to restrict write-access to this node to authenticated clients.

[11.](#) IANA Considerations

[11.1.](#) The BOOTP Manufacturer Extensions and DHCP Options Registry

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

TBD for OPTION_V4_ZEROTOUCH_REDIRECT

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

TBD for OPTION_V6_ZEROTOUCH_REDIRECT

[11.2.](#) The IETF XML Registry

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

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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.

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

[11.3.](#) The YANG Module Names Registry

This document registers three 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

name: ietf-zerotouch-device
namespace: urn:ietf:params:xml:ns:yang:ietf-zerotouch-device
prefix: ztd
reference: RFC XXXX

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Special thanks goes to Steve Hanna, Russ Mundy, and Wes Hardaker for brainstorming the original I-D's solution during the IETF 87 meeting in Berlin.

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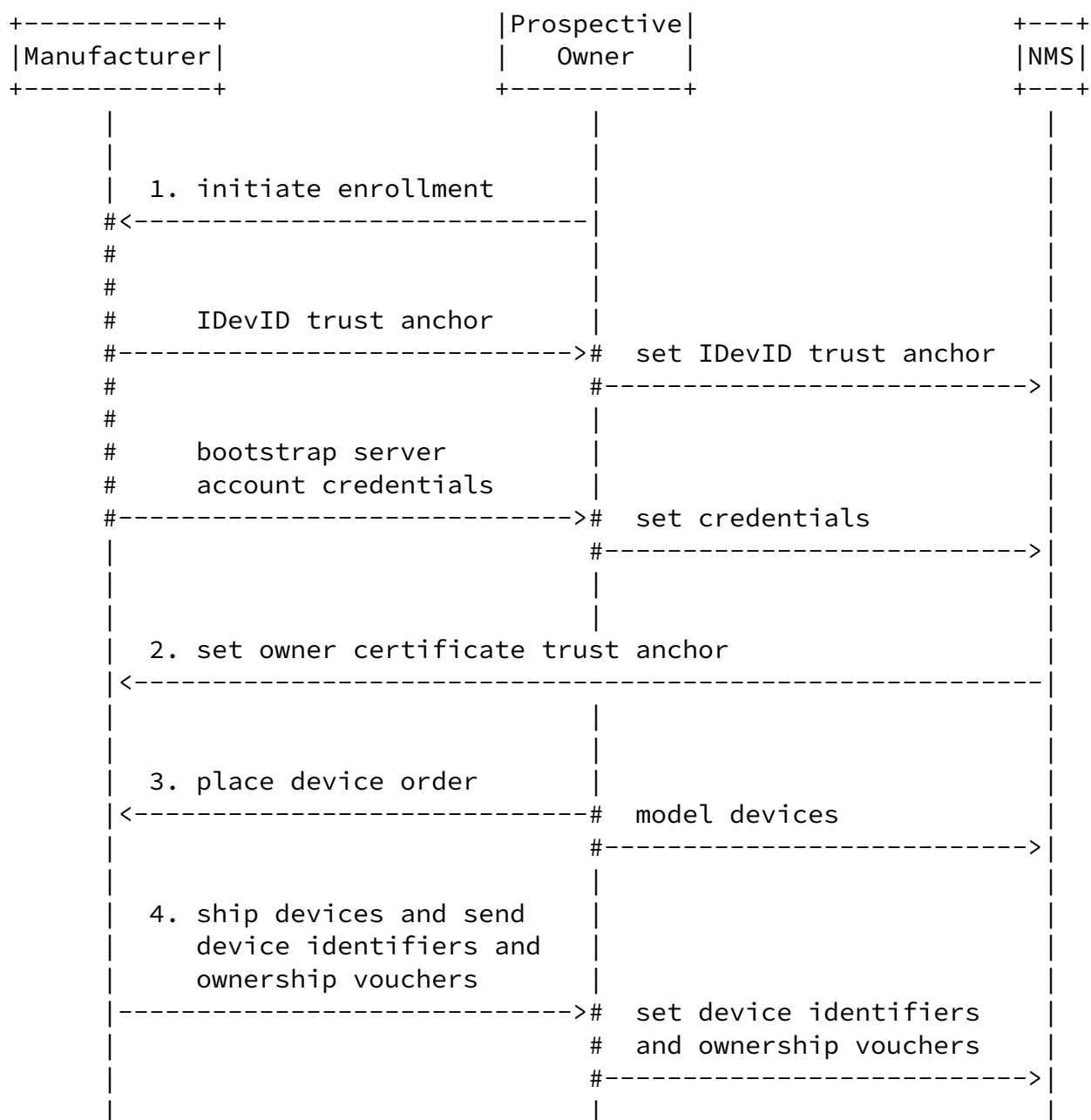
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[Appendix A](#). Workflow Overview

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

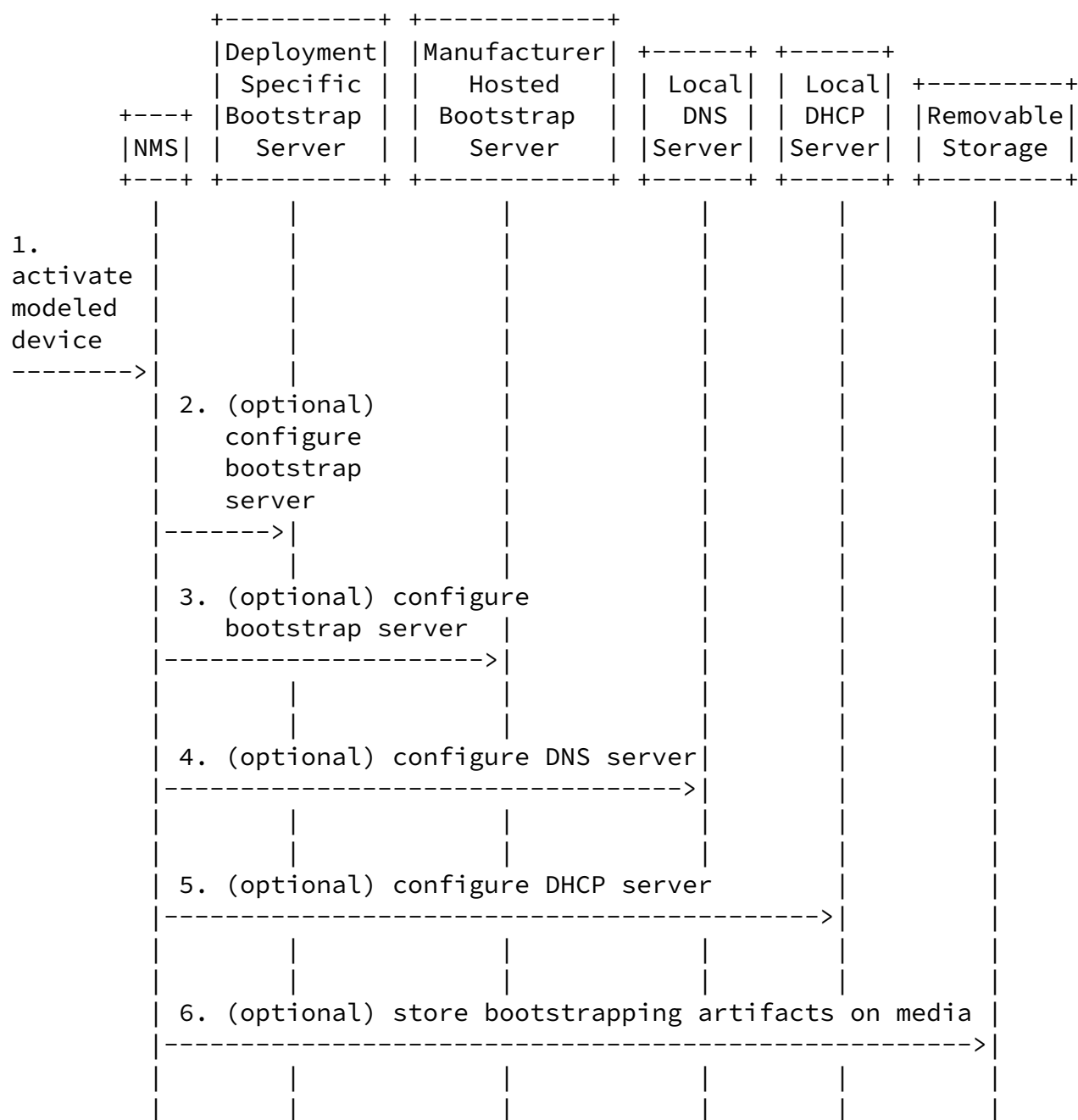
The following diagram illustrates how an owner might stage the

network for bootstrapping devices.

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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

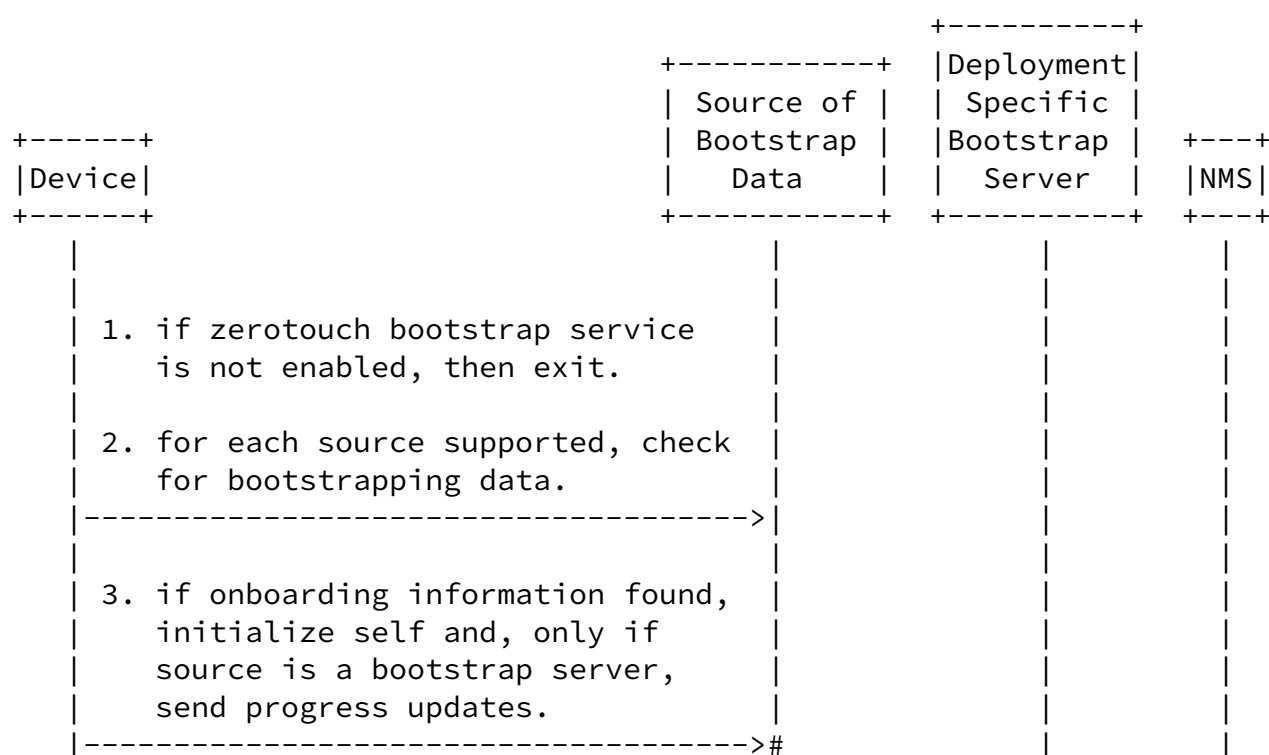
is depicted that an NMS performs the steps, but they may be performed manually or through some other mechanism.

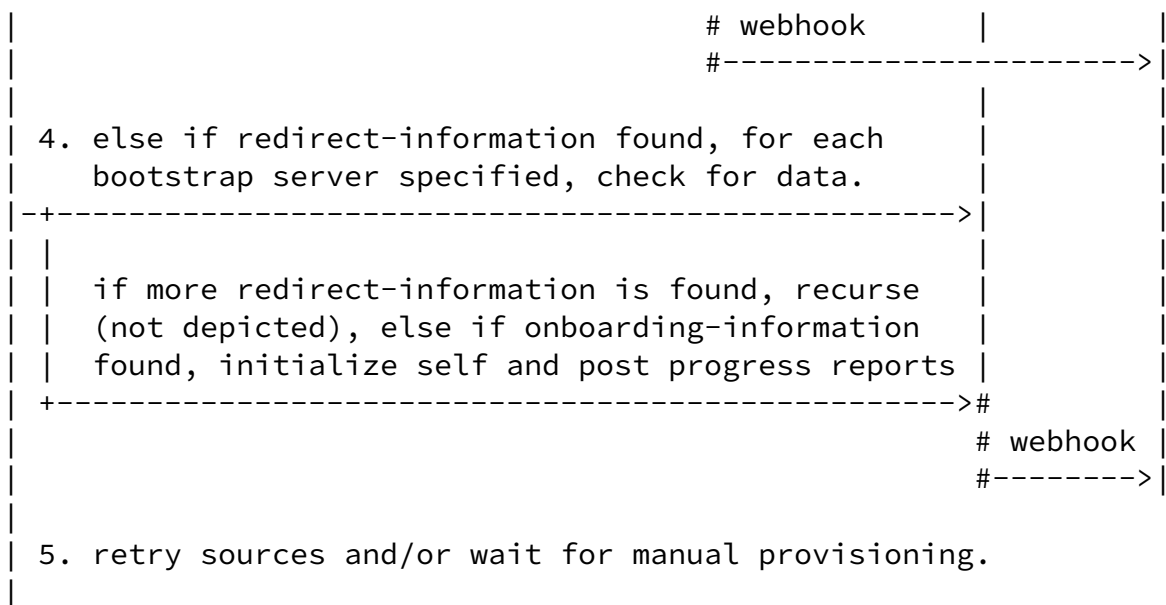
2. If it is desired to use a deployment specific bootstrap server, it must be configured to provide the bootstrapping information for the specific devices. Configuring the bootstrap server may occur via a programmatic API not defined by this document. Illustrated here as an external component, the bootstrap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

- * If the bootstrap server supports forwarding device progress updates 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 update 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. IDevID certificates do not need to be sent as they do not need to be pinned by an NMS in order for the NMS to trust the IDevID certificate.

If the device successfully completes the bootstrapping process, it exits the bootstrapping logic without considering any additional sources of bootstrapping data.

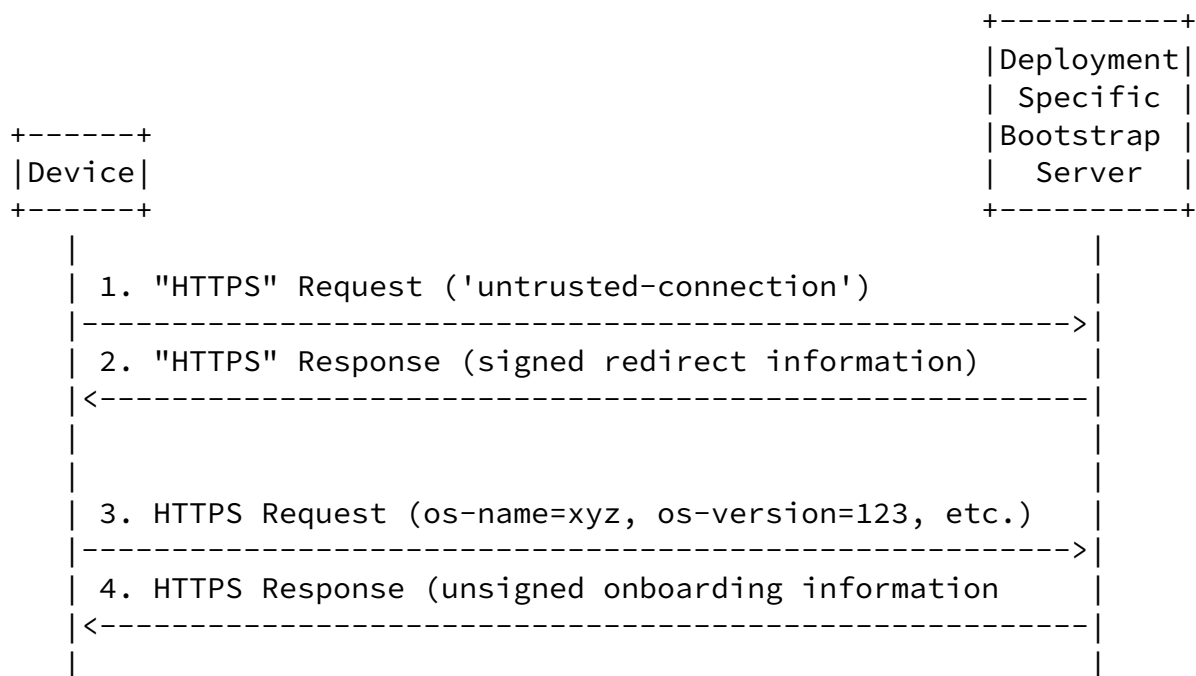
4. Otherwise, if redirect information is found, the device iterates through the list of specified bootstrap servers, checking to see if it has bootstrapping data for the device. If the bootstrap server returns more redirect information, then the device processes it recursively. Otherwise, if the bootstrap 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.

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- 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.

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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.

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[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.

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[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.

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