Deploy Router Using Secure ZTP

With Secure Zero Touch Provisioning, you can securely and seamlessly provision thousands of network devices accurately within minutes and without any manual intervention.

Table 1: Feature History Table

In a secured network such as datacenter, the zero-touch provisioning mechanism helps you provision hundreds of remote devices without your intervention. But, the access devices are typically in an insecure network. There is a high risk of malicious actions on the device, such as adding an unauthorized or infected device. Security is a critical aspect while remotely provisioning the network devices.

Secure ZTP combines seamless automation with security. Network devices can securely establish a connection with the ZTP server and authenticate the onboarding information that it receives. The process eliminates any security risks or malicious actions during the provisioning of remote devices.

- ZTP helps you remotely provision a router securely anywhere in the network. Thus, eliminate the risk of malicious attacks or unauthorized ownership claims.
- Secure ZTP authenticates not only the onboarding network device but also validates the server authenticity and provisioning information that it is receiving from the ZTP server.

The following are the topics covered in this chapter:

On board Devices Using Three-Step Validation

The Cisco IOS XR software implements the secure zero touch provisioning capabilities as described in RFC 8572. Secure ZTP uses a three-step validation process to on board the remote devices securely:

1. **Router Validation**: The ZTP server authenticates the router before providing bootstrapping data using the Trust Anchor Certificate (SUDI certificate). Ensure that you have preinstalled the CA certificate chain for Cisco, as this is a prerequisite for the Cisco CA on ZTP server to verify the client/router SUDI certificates. The required certificates are:
    - subject=O = Cisco, CN = ACT2 SUDI CA
    - subject=O = Cisco Systems, CN = Cisco Root CA 2048

- subject=CN = High Assurance SUDI CA, O = Cisco
- subject=O = Cisco, CN = Cisco Root CA 2099

2. **Server Validation**: The router device in turn validates the ZTP server to make sure that the on board happens to the correct network. Upon completion, the ZTP server sends the bootstrapping data (for example, a YANG data model) or artifact to the router. See Secure ZTP Components , on page 2.
3. **Artifact Validation**: The configuration validates the bootstrapping data or artifact that is received from the ZTP server.

Secure ZTP Components

Let's first understand the components required for secure ZTP.

Table 2: Components used in Secure ZTP

Components	Description
Onboarding Device (Router)	The router is a Cisco device that you want to provision and connect to your network. Secure ZTP is supported only on platforms that have Hardware TAM support. Routers with HW TAM have the SUDI embedded in TAM.
DHCP Server	The secure ZTP process relies on the DHCP server to provide the URL to access the bootstrapping information.

Components	Description
ZTP Server	A ZTP server is any server used as a source of secure ZTP bootstrapping data and can be a RESTCONF or HTTPs server. **Note** Currently, ZTP only supports single name-server. When the DHCP server has more than one server address configured, ZTP fails to apply the server configuration. The ZTP server contains the following artifacts: • Cisco IOS XR software images: You can download Cisco images, SMU, and patches using the Cisco Support & Downloads page. • ZTP scripts: Contains the following libraries and you can build a script to initiate the ZTP process. See the *Build your Configuration File* section. • Python library: Includes IOS XR CLI (show commands and configuration commands) and YANG-XML (ncclient, native Netconf client). • BASH library: Includes IOS XR CLI show commands, configuration commands • Bootstrapping Data

Components	Description
Bootstrapping Data	

Components	Description
	Bootstrapping data is the collection of data that the router obtains from the ZTP server during the secure ZTP process. You must create and upload the bootstrapping data in the ZTP server. For more information, refer RFC 8572. • The bootstrapping data mainly has three artifacts: • **Conveyed Information**: Conveyed Information contains the required bootstrapping data for the device. It contains either the redirect information or onboarding information to provision the device. For example:

```
module: ietf-sztp-conveyed-info

           yang-data
conveyed-information:
             +-- (information-type)

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

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

Components	Description

	• **Redirect Information**: Redirect information is used to redirect a device to another bootstrap server. The redirect information contains a list of bootstrap servers along with a hostname, an optional port, and an optional trust anchor certificate that the device uses to authenticate the bootstrap server.
	
	For Example:
	
	`{`
	`"ietf-sztp-conveyed-info:redirect-information"`
	`  : {`
	`       "bootstrap-server" : [`
	`         {`
	`           "address" :`
	`"sztp1.example.com",`
	`           "port" : 8443,`
	`            "trust-anchor" :`
	`"base64encodedvalue=="`
	`         },`
	`         {`
	`           "address" :`
	`"sztp2.example.com",`
	`           "port" : 8443,`
	`           "trust-anchor" :`
	`"base64encodedvalue=="`
	`         },`
	`         {`
	`           "address" :`
	`"sztp3.example.com",`
	`           "port" : 8443,`
	`           "trust-anchor" :`
	`"base64encodedvalue=="`
	`         }`
	`       ]`
	`     }`
	`   }`

Components	Description
	• **Onboarding Information:** Onboarding information provides data necessary for a device to bootstrap itself and establish secure connections with other systems. It specifies details about the boot image, an initial configuration the device must commit, and scripts that the device must execute. For Example: `{ "ietf-sztp-conveyed-info:onboarding-information" : { "boot-image" : { "os-name" : "VendorOS", "os-version" : "17.2R1.6", "download-uri" : ["https://example.com/path/to/image/file"], "image-verification" : [{ "hash-algorithm" : "ietf-sztp-conveyed-info:sha-256", "hash-value" : "ba:ec:cf:a5:67:82:b4:10:77:c6:67:a6:22:ab:\ 7d:50:04:a7:8b:8f:0e:db:02:8b:f4:75:55:fb:c1:13:b2:33" }] }, "configuration-handling" : "merge", "pre-configuration-script" : "base64encodedvalue==", "configuration" : "base64encodedvalue==", "post-configuration-script" : "base64encodedvalue==" } }`

Components	Description
	• **Owner Certificate**: The owner certificate is installed on the router with the public key of your organization. The router uses the owner certificate to verify the signature in the conveyed information artifact using the public key that is available in the owner certificate. • **Ownership Voucher**: Ownership Voucher is used to identify the owner of the device by verifying the owner certificate that is stored in the device. Cisco supplies Ownership Voucher in response to your request. You must submit the Pinned Domain Certificate and device serial numbers with the request. Cisco generates and provides the Ownership Voucher to you.

Components	Description

Report Progress	When the device obtains the onboarding information from a ZTP server, the router reports the bootstrapping progress to the ZTP server using the API calls.
	
	See RFC 8572 for the detailed report-progress messages that can be sent to the ZTP server.
	
	The following is the structure of the `report-progress` sent the progress message to a ZTP server.
	
	`+---x report-progress {onboarding-server}?`
	`          +---w input`
	`             +---w progress-type`
	`enumeration`
	`             +---w message?`
	`string`
	`             +---w ssh-host-keys`
	`             |  +---w ssh-host-key* []`
	`             |     +---w algorithm    string`
	`             |     +---w key-data     binary`
	`             +---w trust-anchor-certs`
	`                +---w trust-anchor-cert*`
	`cms`
	
	The following example illustrates a device using the Yang module to post a progress report to a ZTP server with a `bootstrap complete` message:
	
	`{`
	`       'progress-type': 'bootstrap-complete',`
	
	`        'message': 'example message',`
	`        'trust-anchor-certs': [{`
	`                'trust-anchor-cert':`
	`'base64encodedvalue=='`
	`        'ssh-host-keys': [{`
	`                'key-data':`
	`'base64encodedvalue==',`
	`                'algorithm': 'ssh-rsa'`
	`        }, {`
	`                'key-data':`
	`'base64encodedvalue==',`
	`                'algorithm': 'rsa-sha2-256'`
	`        }]`
	`}`
	
	`RESPONSE from the ZTP server`
	
	`   HTTP/1.1 204 No Content`
	`   Date: Sat, 31 Oct 2015 17:02:40 GMT`
	`   Server: example-server`

Initial Set Up for Secure ZTP

The network administrator performs the following tasks as part of the initial setup for secure ZTP:

1. Contact Cisco Support to obtain a voucher. Provide the following details to request for ownership voucher certificate:

- Pinned Domain Certificate: A trusted digital certificate issued by the Certificate Authority (CA) and pinned by the operator.
- Order details with the Serial numbers of the routers
- For example,

```
{
       "expires-on": "2016-10-21T19:31:42Z",
       "assertion": "verified",
       "serial-number": "JADA123456789",
       "idevid-issuer": "base64encodedvalue==",
       "pinned-domain-cert": "base64endvalue==",
       "last-renewal-date": "2017-10-07T19:31:42Z"
    }
```

2. Upload the following bootstrapping data to the ZTP server. Steps to upload may vary depending on the server that you're using, refer to the documentation provided by your vendor.

- Cisco IOS XR software images: You can download Cisco images, SMU, and patches using the Cisco Support & Downloads page.
- ZTP scripts that include IOS XR configurations, pre, and post configuration scripts. Build a script to initiate the ZTP process. See the *Build your Configuration File* section.
  - Python library: Includes IOS XR CLI (show commands and configuration commands) and YANG-XML (`ncclient`, `native Netconf client`).
  - BASH library: Includes IOS XR CLI show commands, configuration commands
- Serial numbers of the routers you plan to onboard using ZTP
- Owner certificates
- Pinned Domain Certificate (PDC)
- Ownership vouchers

3. Set up the DHCP server to provide the redirect URL to the router:

Before triggering the secure ZTP process, configure the DHCP server to provide the location of the IOS-XR image to the router. For information on how to configure the DHCP server, see your DHCP server documentation.

Configure the following parameters in the DHCP server:

- `option-code`: The DHCP SZTP redirect Option has the following parameters:
  - OPTION_V4_SZTP_REDIRECT (143): Use this DHCP v4 code for IPV4.
  - OPTION_V6_SZTP_REDIRECT (136): Use this DHCP v4 code for IPV6.

  For example, `option dhcp6.bootstrap-servers code 136 = text;`
- `option-length`: The option length in octets
- `bootstrap-servers`: A list of servers for the onboarding device to contact the servers for the bootstrapping data.

- `bootfile-url` : The URI of the SZTP bootstrap server should use the HTTPS URI scheme and it should be in the following format:

  `"https://<ip-address-or-hostname>[:<port>]".`

4. Power on the router.
5. Enable the secure ZTP option on the onboarding device. Execute the following command on your router to enable secure ZTP:

```
Router# ztp secure-mode enable
```

How Does Secure ZTP Work?

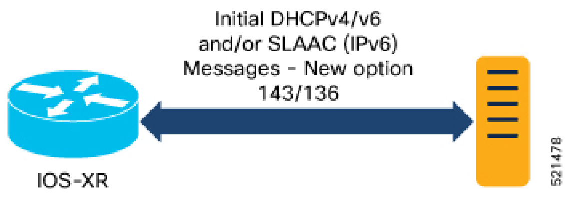
Before you begin, ensure that you configure the network with the DHCP and ZTP server. See Initial Set Up for Secure ZTP, on page 9.

1. When you boot the device with an IOS-XR image, the secure ZTP process verifies if the secure ZTP mode (`secure-ztp mode`) is enabled. If not enabled, the device boots normally.

Note When `secure-ztp mode` is enabled, the ZTP process accepts only the `secure-redirect-URL` and ignores the presence of boot file name option from the DHCP response.

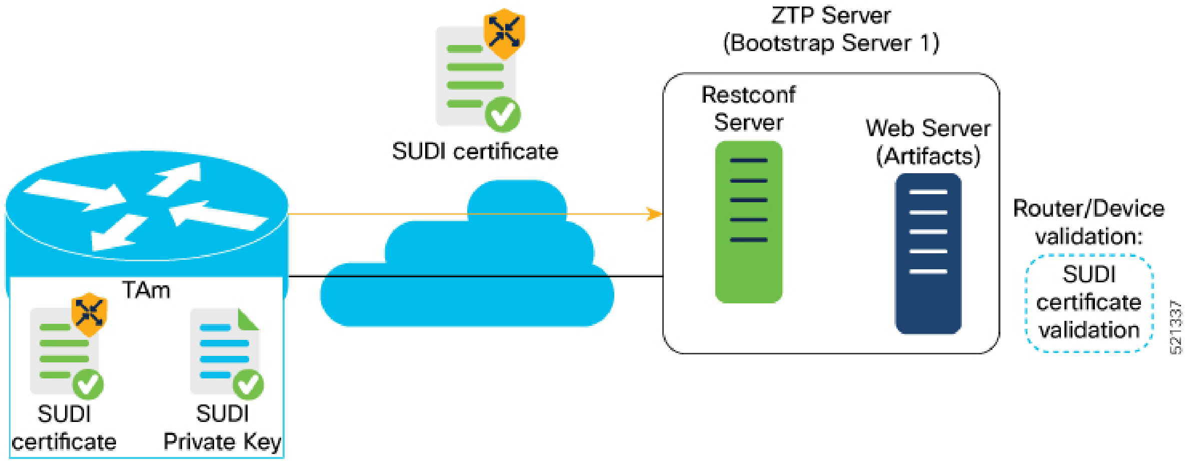
2. **DHCP discovery**:
   a. The router initiates a DHCP request to the DHCP server.
   b. The DHCP server responds with a DHCPv4 143 address option (for IPv4 addressing) or a DHCPv6 136 option (for IPv6 addressing). In addition, URLs to access bootstrap servers for further configuration is also listed.

Figure 1: DHCP discovery



3. **Router validation**:
   a. After receiving the URL from the DHCP server, the router sends an HTTPs request to the RESTCONF or HTTPs server using the specified URL. Along with the HTTPs request, the device sends the client certificate that is provided by the manufacturer (also called SUDI certificate). This certificate identifies and authenticates itself to the ZTP server.

Figure 2: Router Validation



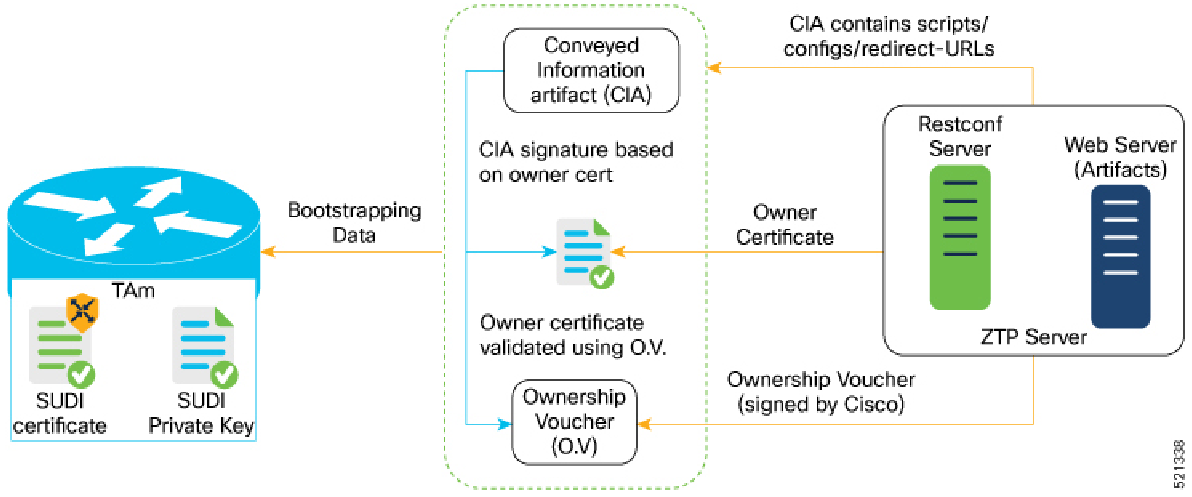
b. The RESTCONF or HTTPs server verifies the received SUDI certificate with the public certificate that it contains. Cisco issues the public certificate to ensure that the onboarding device is an authorized Cisco device.

c. After the onboarding device is authenticated, the web server sends the required artifacts along with the secure ZTP yang model to the onboarding device.

4. **Server validation** :

The router receives the yang model that contains Owner Certificate, Ownership Voucher, and Conveyed Information artifact. The router verifies the ownership voucher by validating its signature to one of its preconfigured trusts anchors and downloads the image. When the router obtains the onboarding information, it reports the bootstrapping progress to the ZTP server. See RFC 8572 for the progress information.

Figure 3: Server Validation



5. **Artifact Validation**:

The router validates the artifact received from the ZTP server.

   a. The device extracts the `pinned-domain-cert` node, an X.509 certificate from the ownership voucher to verify the owner certificate.

   b. The device authenticates the owner certificate by performing the X.509 certificate path verification process on the trusted certificate.

   c. Finally, the device verifies whether the conveyed information artifact is signed by the validated owner certificate.

6. **Provision the device**:

   a. The device first processes the boot image information.

   b. Executes the pre-configuration script and then commits the initial configuration

   c. Execute the post configuration script.

7. After the onboarding process is completed, the network device is operational.

The following figure illustrates the end-to-end sequence of the Secure ZTP process:

Figure 4: End-to-end sequence of the Secure ZTP process

Upgrade Image Using Secure ZTP

You can upgrade the system image using one of the following methods:

- Default installation method
- Preconfiguration script

Even though there are multiple ways of upgrading the software image using the default installation method, each router platform has a different installation behaviour. The default installation method uses a combination of `install add <>` and `install activate reload id <>` commands, which aren't optimized for all platforms. There's no single command in Cisco IOS XR that works on all platforms across all scenarios. Therefore, the recommended method is to use the preconfiguration script, which allows the use of any installation command. Also, this method allows you to modify traffic or rate-related configuration for download.

Here is a sample preconfiguration script:

```
[xr-vm_nodehost_CPU0:/misc/scratch]$ cat /disk0\:/ztp/customer/pre_config.candidate
#!/bin/bash

# !!!!!!!!!!!!!!!!!!!!!!!! WARNING !!!!!!!!!!!!!!!!!!!!!!!!
# For this script to work on Cisco IOSXR OS use Unix style
# EOL character - LF, not Windows style - CRLF

exec &> /dev/console # send logs to console
source /pkg/bin/ztp_helper.sh
export LOGFILE=/disk0:/ztp/user-script.log

#Set to 1 for GISO image upgrade
GISO_UPGRADE=0

# Crosswork parameters
HOST_IP="5.10.18.112"
PORT="5002"

# Software upgrade parameters
TARGET_SOFTWARE_VERSION="7.9.1.33I"
IMAGE_FILENAME="ncs5500-mini-x.iso"
IMAGE_MD5_CHECKSUM="20d020d9912eb01ce4b242532544cc0e"
#IMAGE_PACKAGE="ncs5500-mini-x-7.9.1.33I"
IMAGE_URL="http://${HOST_IP}:${PORT}/images/ncs7/${IMAGE_FILENAME}"

function ztp_log(){
    echo "$(date +"%b %d %H:%M:%S") "$1 >> $LOGFILE
}


function check_version(){
    # returns 0 is version matches, 1 otherwise
    local current_ver=`xrcmd "show version" | grep Version | grep Cisco | cut -d " " -f 6`;

    ztp_log "### ZTP version check current=$current_ver, target=$TARGET_SOFTWARE_VERSION
###";
    if [[ "$current_ver" = "$TARGET_SOFTWARE_VERSION" ]]; then
        ztp_log "### ZTP software version check result: match ###";
        return 0
    else
        ztp_log "### ZTP software version check result: mismatch ###";
        return 1
    fi
```

```
}

function download_image(){
    # Download image to harddisk:
    ztp_log "### IOS-XR INSTALL - downloading image $IMAGE_FILENAME from $IMAGE_URL ###"
    /usr/bin/wget ${IMAGE_URL} -O /harddisk:/$IMAGE_FILENAME 2>&1 >> $LOGFILE
    if [[ "$?" != 0 ]]; then
        ztp_log "### IOS-XR INSTALL - error downloading $IMAGE_FILENAME, check
/var/log/ztp_user_script.log for details ###"
        exit 1
    else
        ztp_log "### IOS-XR INSTALL - $IMAGE_FILENAME download completed ###";
    fi

    # check MD5 hash checksum
    ztp_log "### IOS-XR INSTALL - verifying image md5 checksum ###"
    local checksum=`xrcmd "show md5 file /harddisk:/$IMAGE_FILENAME"`;
    if [[ "$checksum" != *"$IMAGE_MD5_CHECKSUM"* ]]; then
        ztp_log "### IOS-XR INSTALL - error, image checksum $checksum does not match
$IMAGE_MD5_CHECKSUM, exiting ###"
        exit 1
    else
        ztp_log "### IOS-XR INSTALL - md5 checksum verification successful ###"
    fi
}

#optional
function install_commit_packages(){
    local output

    ztp_log "### IOS-XR INSTALL - Commit packages ###"
    output=$(xrcmd "install commit")
    ztp_log "$output"
}

#optional
function remove_inactive_packages(){
    local output

    # remove inactive packages if any
    ztp_log "### IOS-XR INSTALL - removing inactive packages ###"
    output=$(xrcmd "install remove inactive all synchronous")
    ztp_log "$output"
}

function install_giso_target_image(){
    local output
    touch /disk0\:/ztp/state/state_is_install_started
    # do GISO image install
    ztp_log "### IOS-XR INSTALL - doing GISO install replace ###"
    output=$(xrcmd "install replace /harddisk:/$IMAGE_FILENAME noprompt commit")
    ztp_log "$output"
    if [[ "$output" != *"aborted"* ]]; then
        ztp_log "### IOS-XR INSTALL - GISO install replace completed ###"
       ztp_log "### Upgraded IOS-XR to $TARGET_SOFTWARE_VERSION, device should reboot ###";

    else
       ztp_log "### IOS-XR INSTALL - error, GISO install replace failed, check 'show install
 log' ###"
        return 1
    fi
}

function install_add_image(){
    local output

    # do  image install add
    ztp_log "### IOS-XR INSTALL - doing  install add ###"
    output=$(xrcmd "install add source /misc/disk1/ $IMAGE_FILENAME")
    ztp_log "$output"
    install_add_id=$(echo $output | awk '{print $5}')
    if [[ "$output" != *"aborted"* ]]; then
        ztp_log "### IOS-XR INSTALL -  install add completed ###"
    else
        ztp_log "### IOS-XR INSTALL - error,  install add failed, check 'show install log'
 ###"
        return 1
    fi
}

function install_target_image(){
    local output
    touch /disk0\:/ztp/state/state_is_install_started
    # do  image install
    ztp_log "### IOS-XR INSTALL - doing  install activate ###"
    output=$(xrcmd "install activate id $install_add_id noprompt synchronous")
    ztp_log "$output"
    if [[ "$output" != *"aborted"* ]]; then
        ztp_log "### IOS-XR INSTALL -  install activate completed ###"
       ztp_log "### Upgraded IOS-XR to $TARGET_SOFTWARE_VERSION, device should reboot ###";

    else
        ztp_log "### IOS-XR INSTALL - error,  install activate failed, check 'show install
 log' ###"
        return 1
    fi
}

# ==== Script entry point ==== #
# run version check and decide if need to download target image
check_version;
if [[ "$?" = 1 ]]; then
    ztp_log "### Software Version mismatch, downloading IOS-XR $TARGET_SOFTWARE_VERSION
###";
    download_image;
    NEED_UPGRADE=1
    ztp_log "### Downloaded IOS-XR $TARGET_SOFTWARE_VERSION image ###";
else
    NEED_UPGRADE=0
    ztp_log "### Image Download: Software Version match $TARGET_SOFTWARE_VERSION, nothing
to do ###";
fi

# do software upgrade
if [[ $NEED_UPGRADE = 1 ]]; then
    ztp_log "### Software Version mismatch, upgrading IOS-XR to $TARGET_SOFTWARE_VERSION
###";
    install_commit_packages;
    remove_inactive_packages;
    if [[ $GISO_UPGRADE = 1 ]]; then
        install_giso_target_image;
    else
        install_add_image;
        install_target_image;
    fi
else
    ztp_log "### Upgrade: Software Version match $TARGET_SOFTWARE_VERSION, nothing to do
###";
```

```
fi

ztp_log "### ZTP DONE ###";
```