Using Two-Factor Authentication Configuration to Combat Cybersecurity Threats

Guidelines for Deploying Cisco IOS SSH with X.509v3 PIV and CAC Smartcards

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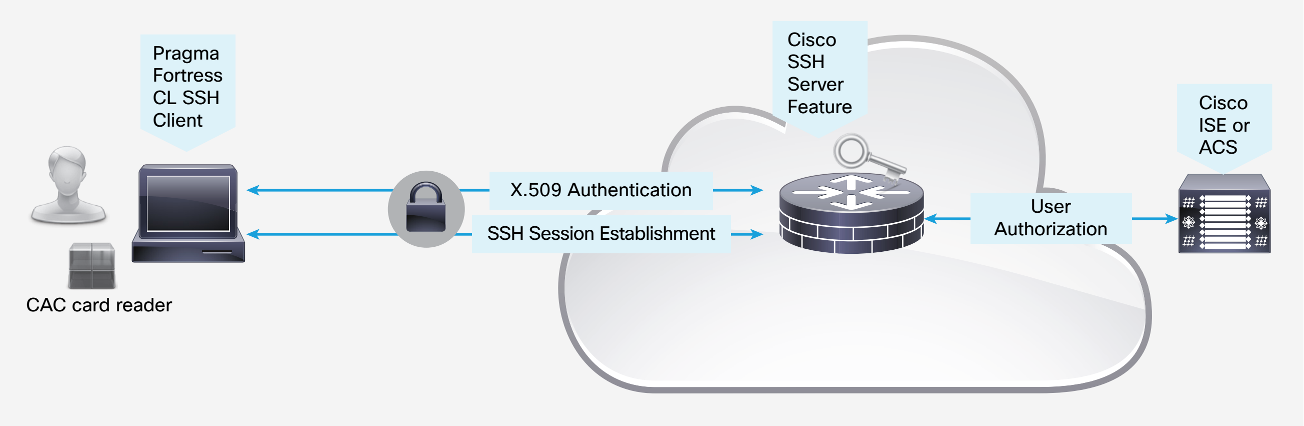
Introduction

Cybersecurity threats continue to evolve, compromising sensitive and confidential information across the network. To combat this threat, enterprises are taking mitigating actions to strengthen device access across their critical IT infrastructure. Two-factor authentication can significantly reduce the risk of adversaries penetrating strategic networks and systems. This approach requires the use of a Personal Identity Verification (PIV) card or Common Access Card (CAC). In this document, we will detail the basic procedures required to enable two-factor authentication for the Secure Shell Protocol (SSH) using government-issued PIV or CAC cards.

Figure 1 illustrates this process.

Figure 1. Two-Factor Authentication Using SSH



Requirements

Table 1 shows the Cisco® product families that support the X.509v3 certificates for the SSH authentication feature. The versions of Cisco IOS® Software shown in the table, or later, are recommended. These releases include the bug fixes identified in the next section.

Table 1. Recommended Cisco IOS Software Releases

Product Family	Cisco IOS Software Release
Cisco Integrated Services Routers Generation 2 (ISR-G2) (1900, 2900, or 3900 Series)	Cisco IOS 15.5(3)M2 or later
Cisco ASR 1000 Series Aggregation Services Routers	Cisco IOS XE 3.16.2 S or later
Cisco 4000 Series ISRs	Cisco IOS XE 3.16.2 S or later
Cisco Cloud Services Router (CSR) 1000V Series	Cisco IOS XE 3.16.2 S or later
Cisco Catalyst® 2000, 3000, and 4000 Series Switches	Cisco IOS 15.2(4)E1 or later
Cisco Catalyst 3850 Series Switches	Cisco IOS XE 16.1.2 or later
Cisco Catalyst 3650 Series Switches	Cisco IOS XE 16.1.2 or later

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Pragma Fortress CL SSH Client (version 5, build 10, rev 292 or later)

You can purchase or download a 14-day trial from http://www.pragmasys.com/ssh-client/download.

Department of Defense (DoD) CA certificates
Note for DoD customers: You can obtain the CA certificate here:
http://dodpki.c3pki.chamb.disa.mil/rootca.html

Cisco Identity Services Engine (ISE) 2.0 or Cisco Secure Access Control Server (ACS)

DoD CAC card or PIV card for civilian agencies

Smartcard reader

Resolved Bugs

The following defects have been resolved:

CSCuv89417: Cisco IOS SSH not prompting user PIN for verifying signature from client with X.509 certificate-based authentication.

CSCuw91205: PKI needs support for UPN extraction using OID.

Cisco IOS Software Configuration

1. Set up Network Time Protocol (NTP) with the proper time zone for the device This step is critical for the operation of the public key infrastructure (PKI).

```
service timestamps debug datetime msec localtime show-timezone
service timestamps log datetime msec localtime show-timezone
clock timezone EST -5 0
clock summer-time EDT recurring
ntp server 192.5.41.40
```

Configure PKI trustpoint for the certificate authority (CA). Specify the field from the user certificate that will be used as the SSH username that will pass to the TACACS server for authorization. The example below uses the common name from the subnet field for the username. The user principal name (UPN) from the Subject-Alternative name can also be used as a username for SSH login.

```
crypto pki trustpoint CA2
 enrollment terminal
 revocation-check none
 authorization username subjectname commonname
```

2. Manually authenticate and install the root CA's public certificate. It is not necessary to install the subordinate CA's certificate if the user's computer has the proper DoD certificate chain installed. See the Troubleshooting section for a screenshot example of the DoD certificate chain.

```
Router(config)#crypto pki authenticate CA2

Enter the base 64 encoded CA certificate.
End with a blank line or the word "quit" on a line by itself
```

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```
-----BEGIN CERTIFICATE-----
MIIDcDCCAligAwIBAgIBBTANBgkqhkiG9w0BAQUFADBbMQswCQYDVQQGEwJVUzEY
MBYGA1UEChMPVS5TLiBHb3Zlcm5tZW50MQwwCgYDVQQLEwNEb0QxDDAKBgNVBAsT
…<snip>
tX3h4NGW56E6LcyxnR8FRO2HmdNNGnA5wQQM5X7Z8a/XIA7xInolpHOZzD+kByeW
qKKV7YK5FtOeC4fCwfKI9WLfaN/HvGlR7bFc3FRUKQ8JOZqsA8HbDE2ubwp6Fknx
v5HSOJTT9pUst2zJQraNypCNhdk=
-----END CERTIFICATE-----

Certificate has the following attributes:
    Fingerprint MD5: 477892DB 8AEC1B53 68F01D00 9C34775E
    Fingerprint SHA1: 8C941B34 EA1EA6ED 9AE2BC54 CF687252 B4C9B561

% Do you accept this certificate? [yes/no]: yes
Trustpoint CA certificate accepted.
% Certificate successfully imported
```

3. Generate RSA signing and encryption keys for the SSH server.

   ```
   Router(config)#crypto key generate rsa modulus 2048 label SSH-RSA usage-keys
   The name for the keys will be: SSH-RSA

   % The key modulus size is 2048 bits
   % Generating 2048 bit RSA keys, keys will be non-exportable...
   [OK] (elapsed time was 3 seconds)
   % Generating 2048 bit RSA keys, keys will be non-exportable...
   [OK] (elapsed time was 2 seconds)
   ```

4. Enable the SSH server and specify the RSA keys to be used for signing and encryption.

   ```
   ip ssh rsa keypair-name SSH-RSA
   ip ssh version 2
   ```

5. Specify the number of authentication retries and the timeout interval for the SSH server (optional).

   ```
   ip ssh time-out 60
   ip ssh authentication-retries 2
   ```

6. Configure the Cisco IOS SSH server to verify the user’s X.509v3 digital credential for two-factor authentication.

   ```
   ip ssh server certificate profile
   user
     trustpoint verify CA2
   ip ssh server algorithm hostkey ssh-rsa
   ip ssh server algorithm authentication publickey
   ip ssh server algorithm publickey x509v3-ssh-rsa
   ```

7. Enable SSH for terminal line access, and enable X.509v3 validation.

   ```
   aaa new-model
   !
   line vty 0 4
   login
   transport input ssh
   ```

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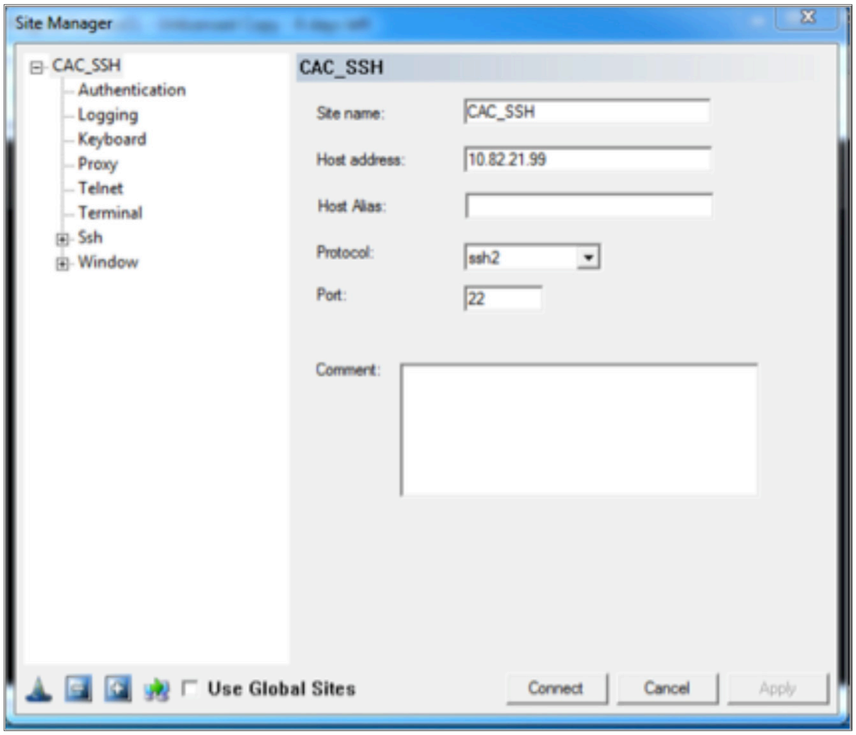
SSH Client Setup

1. Start up the Pragma Fortress CL SSH client (FortressCL.exe), and enter the Site Name and Host Address. Select ssh2 as the protocol.



Site name: CAC_SSH

Host address: 10.82.21.99

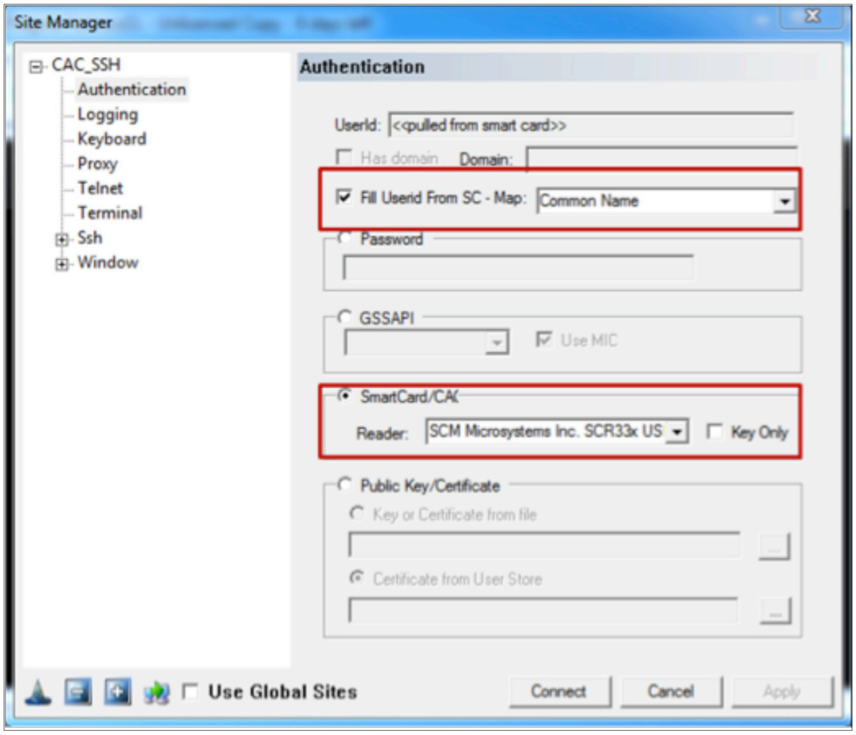
Host Alias:

Protocol: ssh2

Port: 22

Comment:

2. Select **Authentication** from the left panel. Click **SmartCard/CAC.** Check the **Fill UserID from SC** box, and select the field (Common Name or Principal Name) to use as the user ID. <u>DO NOT check the **Key Only** box</u>. Click **Connect.**



UserId: <<pulled from smart card>>

☐ Has domain Domain:

☑ Fill Userid From SC - Map: Common Name

○ Password

○ GSSAPI ☑ Use MIC

● SmartCard/CAC

Reader: SCM Microsystems Inc. SCR33x US ☐ Key Only

○ Public Key/Certificate

○ Key or Certificate from file

● Certificate from User Store

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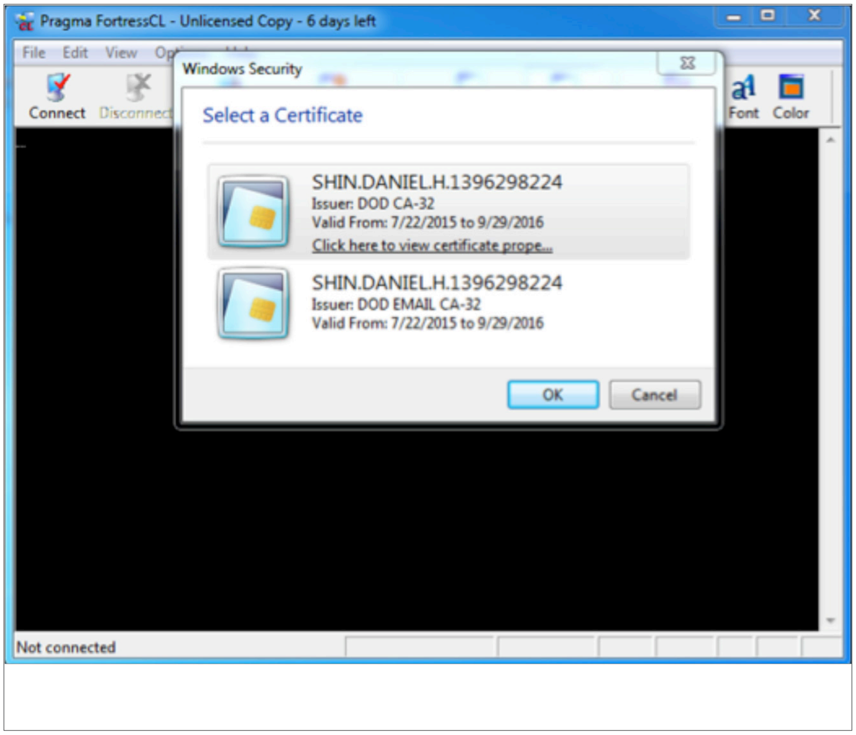
3. Select the proper user certificate from the CAC card in the popup window..



Windows Security

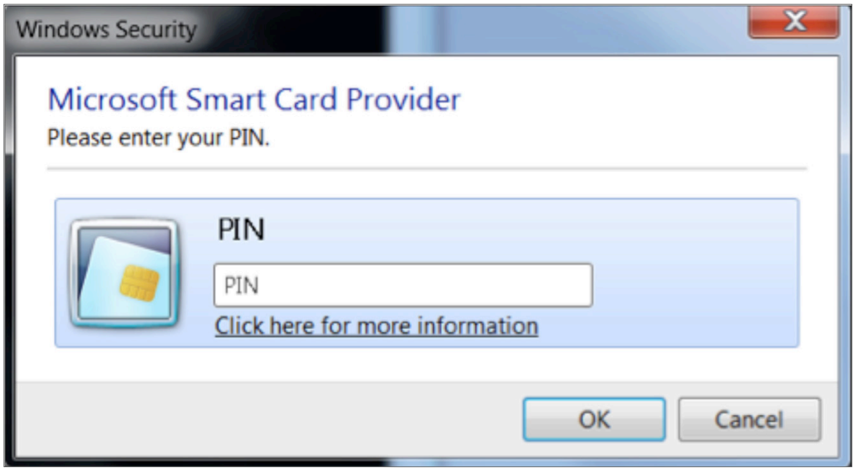
Select a Certificate

SHIN.DANIEL.H.1396298224
Issuer: DOD CA-32
Valid From: 7/22/2015 to 9/29/2016
Click here to view certificate prope...

SHIN.DANIEL.H.1396298224
Issuer: DOD EMAIL CA-32
Valid From: 7/22/2015 to 9/29/2016

Not connected

4. Enter the PIN associated with the smartcard credential.



Windows Security

Microsoft Smart Card Provider

Please enter your PIN.

PIN

PIN

Click here for more information

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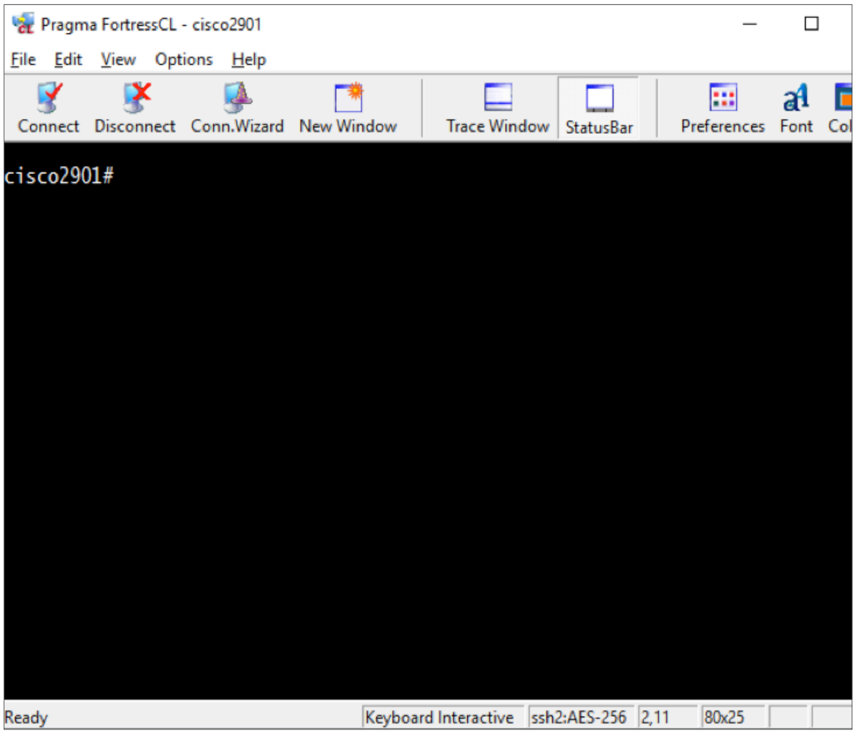
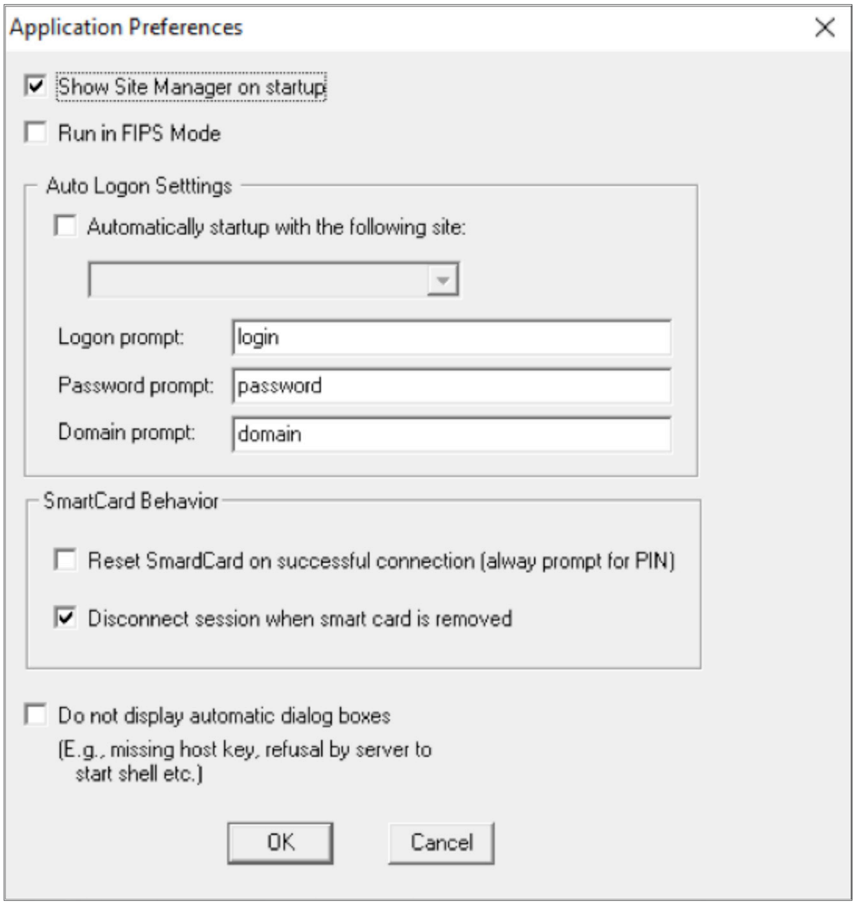
5. You are now at the router prompt.



```
cisco2901#
```

6. (Optional) There are two settings that govern smartcard/CAC behavior. These settings are in the **Application Preferences** dialog, which can be invoked from the **Options** menu.



☑ Show Site Manager on startup

☐ Run in FIPS Mode

Auto Logon Settings

☐ Automatically startup with the following site:

Logon prompt: login

Password prompt: password

Domain prompt: domain

SmartCard Behavior

☐ Reset SmardCard on successful connection (alway prompt for PIN)

☑ Disconnect session when smart card is removed

☐ Do not display automatic dialog boxes
(E.g., missing host key, refusal by server to start shell etc.)

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The two options are:

1. Reset SmartCard on successful connection (always prompt for PIN). This option will reset the smartcard after successfully connecting, clearing the PIN cache.
2. Disconnect session when smart card is removed. This option will monitor the smartcard and will disconnect the session if the card is removed.

These values can also be set by a domain policy, using the following registry value:

HKEY_CURRENT_USER\SOFTWARE\Pragma Systems\Pragma FortressCL\Preferences\SCardReset	DWORD	1 – Enabled 0 – Disabled
HKEY_CURRENT_USER\SOFTWARE\Pragma Systems\Pragma FortressCL\Preferences\SCardMonitor	DWORD	1 – Enabled 0 – Disabled

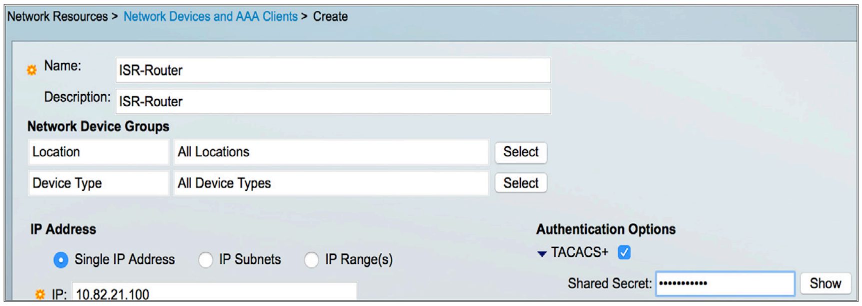
TACACS+ Authorization Setup

This section includes ISE 2.0 and ACS 5.x authentication, authorization, and accounting (AAA) setup procedures. Choose from one of the options for AAA server setup, depending on the AAA method used.

Cisco ACS 5.x Configuration (Option 1)

The following procedures outline the ACS 5.x or later TACACS+ configuration to support PKI AAA integration for SSH login.

1. Configure the TACACS+ authentication settings for a network device. **In ACS, go to Network Resources > Network Device Groups > Network Devices and AAA Clients > Create**. Enter the device information and shared secret.



Network Resources > Network Devices and AAA Clients > Create

Name: ISR-Router
Description: ISR-Router

Network Device Groups

Location: All Locations
Device Type: All Device Types

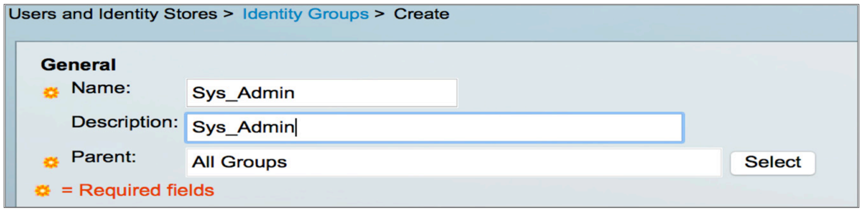
IP Address

● Single IP Address ○ IP Subnets ○ IP Range(s)
IP: 10.82.21.100

Authentication Options

TACACS+ ☑
Shared Secret: ••••••••••

2. Create user identity groups for the various user groups. In ACS, go to **Users and Identity Stores > Identity Groups > Create**. Create a System Administration group.



Users and Identity Stores > Identity Groups > Create

General

Name: Sys_Admin
Description: Sys_Admin
Parent: All Groups

= Required fields

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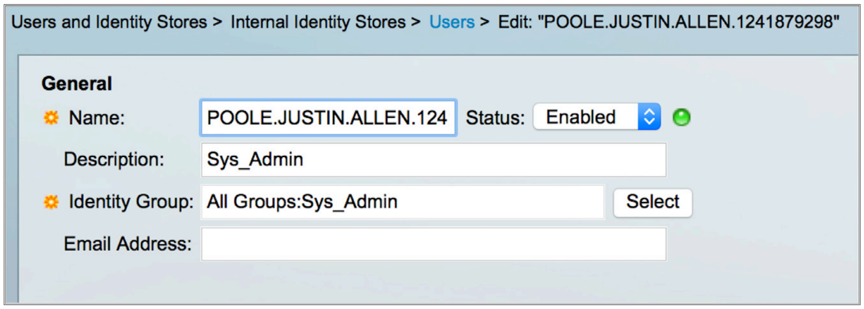
3. Create the users and include them in the proper user identity group. In ACS, go to **Users and Identity Stores > Internal Identity Stores > Users > Create**. The Name field is case sensitive and must match the field from the certificate exactly (for example, the common name, UPN). The password configured for the username in the AAA server is irrelevant because TACACS supports authorization without requiring authentication (the password is used for authentication). Select the user group from the list previously configured for the user.



Users and Identity Stores > Internal Identity Stores > Users > Edit: "POOLE.JUSTIN.ALLEN.1241879298"

General

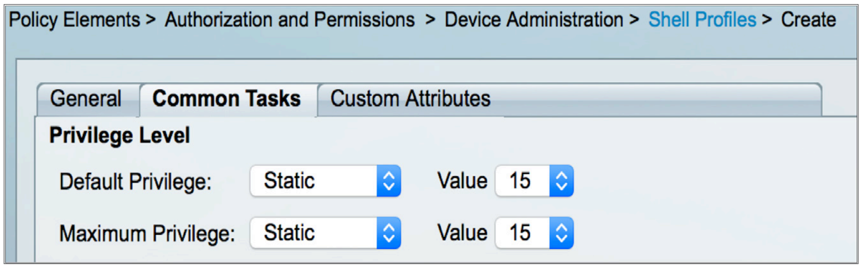
Name: POOLE.JUSTIN.ALLEN.124 Status: Enabled

Description: Sys_Admin

Identity Group: All Groups:Sys_Admin

Email Address:

4. Define the shell profile for the System Administrator group. In ACS, go to **Policy Elements > Authorization and Permissions > Device Administration > Shell Profiles > Create**. Enter the Name. Under Common Tasks, set the **Default Privilege** and **Maximum Privileg**e for the System Administrator profile.



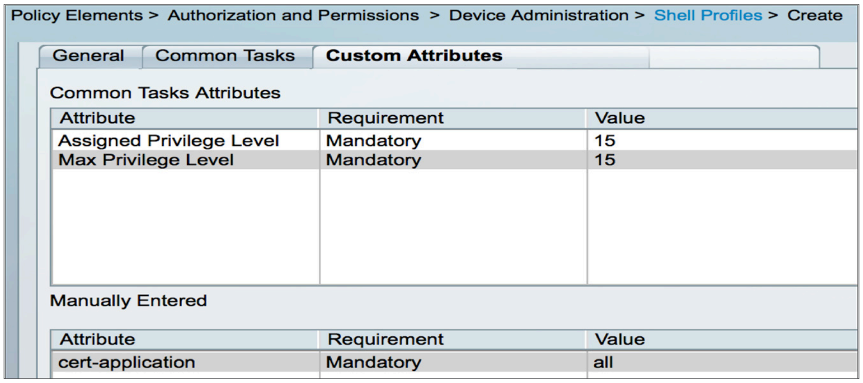
Policy Elements > Authorization and Permissions > Device Administration > Shell Profiles > Create

Privilege Level

Default Privilege: Static Value 15

Maximum Privilege: Static Value 15

5. Select the **Custom Attributes** tab, and add the following Cisco-av-pair to the profile: **"cert-application=all"**. This is needed for AAA integration with the PKI service to authorize the particular user or user group. The AV pairs must match the client configuration. If they do not match, the peer certificate is not authorized.



Policy Elements > Authorization and Permissions > Device Administration > Shell Profiles > Create

Common Tasks Attributes

Attribute	Requirement	Value
Assigned Privilege Level	Mandatory	15
Max Privilege Level	Mandatory	15

Manually Entered

Attribute	Requirement	Value
cert-application	Mandatory	all

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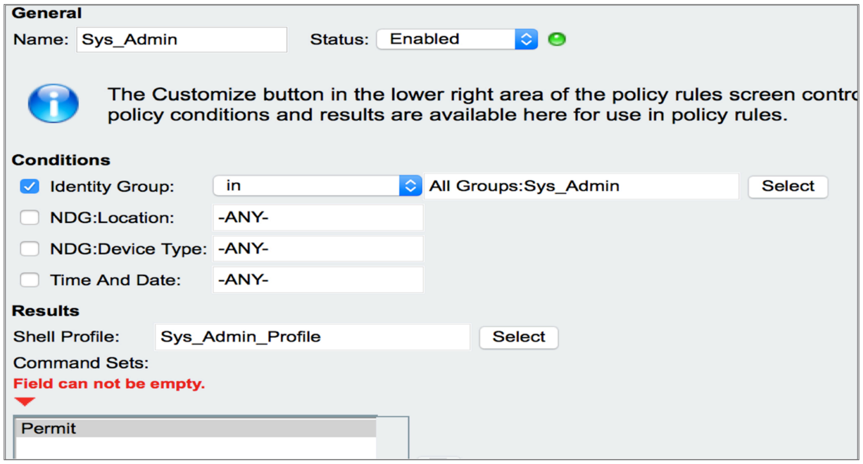
6. Create the device authorization policy for the System Administrator group. In ACS, go to **Access Policies > Access Services > Default Device Admin > Authorization > Create**. Name the rule, reference the identity group previously created, select the System Administrator shell profile, and select or create the command set required



General

Name: Sys_Admin

Status: Enabled

The Customize button in the lower right area of the policy rules screen contr
policy conditions and results are available here for use in policy rules.

Conditions

☑ Identity Group: in All Groups:Sys_Admin

☐ NDG:Location: -ANY-

☐ NDG:Device Type: -ANY-

☐ Time And Date: -ANY-

Results

Shell Profile: Sys_Admin_Profile

Command Sets:

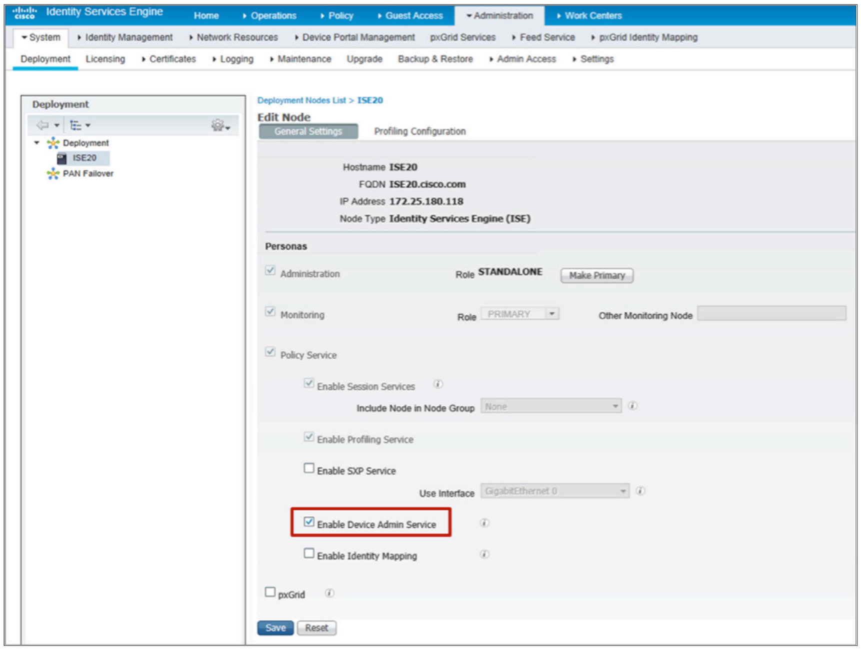
Field can not be empty.

Permit

Cisco ISE 2.0 Configuration (Option 2)

The following procedures outline the ISE 2.0 or later TACACS+ configuration to support PKI AAA integration for SSH login.

1. Enable TACACS+ operation on the ISE 2.0 server. Go to the **Administration > System > Deployment > General Settings** page and check the **Enable Device Admin Servic**e check box. Click Save to **save** the configuration.



Deployment Nodes List > ISE20

Edit Node

Hostname ISE20
FQDN ISE20.cisco.com
IP Address 172.25.180.118
Node Type Identity Services Engine (ISE)

Personas

☑ Administration Role STANDALONE

☑ Monitoring Role PRIMARY Other Monitoring Node

☑ Policy Service

☑ Enable Session Services

Include Node in Node Group None

☑ Enable Profiling Service

☐ Enable SXP Service

Use Interface GigabitEthernet 0

☑ Enable Device Admin Service

☐ Enable Identity Mapping

☐ pxGrid

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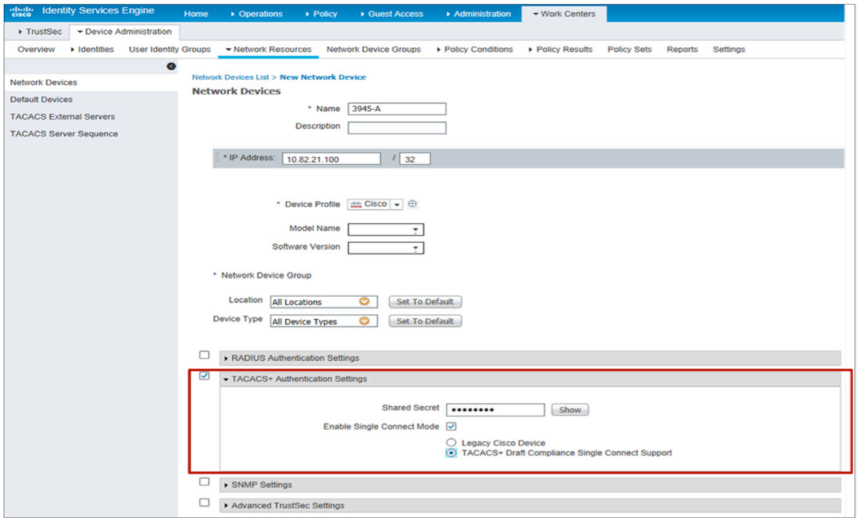
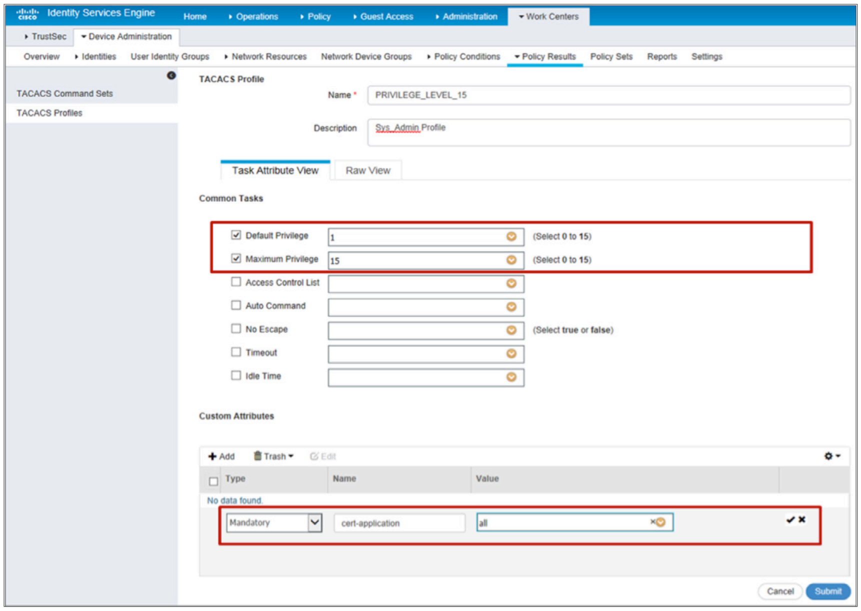
2. Configure the TACACS+ authentication settings for a network device. Go to **Work Centers > Device Administration > Network Resources > Network Devices > Add > TACACS+ Authentication Settings**. Enter the device information and shared secret.



* Name: 3945-A
Description:
* IP Address: 10.82.21.100 / 32
* Device Profile: Cisco
Model Name:
Software Version:
* Network Device Group
Location: All Locations
Device Type: All Device Types
☐ RADIUS Authentication Settings
☑ TACACS+ Authentication Settings
Shared Secret: ••••••••
Enable Single Connect Mode ☑
○ Legacy Cisco Device
● TACACS+ Draft Compliance Single Connect Support
☐ SNMP Settings
☐ Advanced TrustSec Settings

3. Define the TACACS+ profile for System Administrator. Go to **Work Centers > Device Administration > Policy Results > TACACS Profiles > Add**. Enter the **Name** and the **Default Privilege** and **Maximum Privilege** for the System Administrator profile.

   On the same page, under **Custom Attributes**, add the following Cisco-av-pair to the profile: **"cert-application=all".** This is needed for AAA integration with the PKI service to authorize the particular user or user group. The AV pairs must match the client configuration. If they do not match, the peer certificate is not authorized.



Name *: PRIVILEGE_LEVEL_15
Description: Sys_Admin Profile

☑ Default Privilege	1	(Select 0 to 15)
☑ Maximum Privilege	15	(Select 0 to 15)
☐ Access Control List		
☐ Auto Command		
☐ No Escape		(Select true or false)
☐ Timeout		
☐ Idle Time		

Type	Name	Value
Mandatory	cert-application	all

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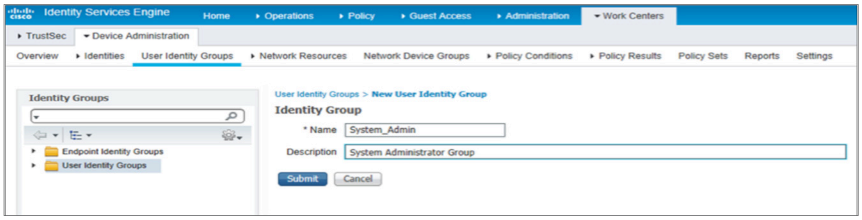
4. Create user identity groups for the various user groups. Go to **Work Centers > Device Administration > User Identity Groups > Add**. Add the user groups for role-based access; for example, System Admin, Helpdesk, and more.



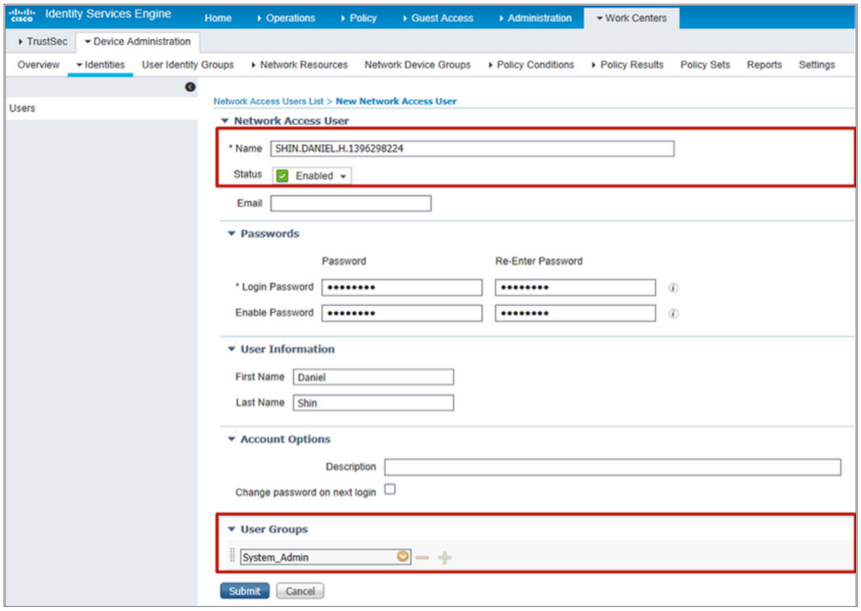
User Identity Groups > New User Identity Group

Identity Group

* Name: System_Admin

Description: System Administrator Group

5. Create the member users and include them in the proper user identity group. Go to **Work Centers > Device Administration > Identities > Users**. The Name field is case sensitive and must match the field from the certificate exactly (for example, the common name, UPN). The password configured for the username in the AAA server is irrelevant because TACACS supports authorization without requiring authentication (the password is used for authentication). Select the user group from the list previously configured for the user.



Network Access Users List > New Network Access User

Network Access User

* Name: SHIN.DANIEL.H.1396298224

Status: ☑ Enabled

Email:

Passwords

	Password	Re-Enter Password
* Login Password	••••••••	••••••••
Enable Password	••••••••	••••••••

User Information

First Name: Daniel

Last Name: Shin

Account Options

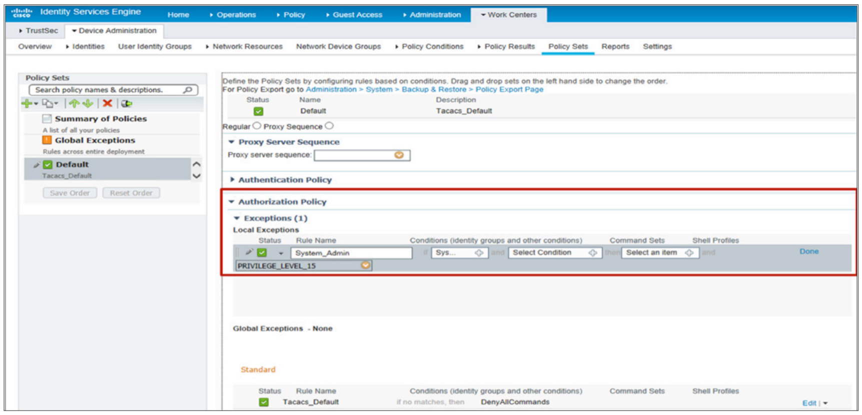
Description:

Change password on next login ☐

User Groups

System_Admin

6. Add TACACS policy for the user group defined. Go to **Work Centers > Device Administration > Policy Sets > Default > Authorization Policy > Exceptions > Create a New Rule**. Enter the name of the rule (for example, System_Admin), select a condition (User Identity Group > System_Admin), and then select shell profiles (e.g. PRIVILEGE_LEVEL_15). Click the **Save** button at the bottom of the page.



Define the Policy Sets by configuring rules based on conditions. Drag and drop sets on the left hand side to change the order.
For Policy Export go to Administration > System > Backup & Restore > Policy Export Page

Status	Name	Description
☑	Default	Tacacs_Default

Regular ○ Proxy Sequence ○

Proxy Server Sequence

Proxy server sequence:

Authentication Policy

Authorization Policy

Exceptions (1)

Local Exceptions

Status	Rule Name	Conditions (identity groups and other conditions)	Command Sets	Shell Profiles
☑	System_Admin	if Sys... and Select Condition	then Select an item	and PRIVILEGE_LEVEL_15

Global Exceptions - None

Standard

Status	Rule Name	Conditions (identity groups and other conditions)	Command Sets	Shell Profiles
☑	Tacacs_Default	if no matches, then	DenyAllCommands	

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Cisco IOS Configuration (Mandatory)

1. Add the TACACS+ server and provision the shared secret and IP address of the TACACS+ server.

```
tacacs server ACS
 address ipv4 172.25.180.117
 key cisco123
```

2. Configure TACACS+ for user authorization. TACACS+ uses the AAA architecture, which separates the authentication, authorization, and accounting functions. This allows separate authentication solutions that can still use TACACS+ for authorization and accounting. In this case, with TACACS+, we are using PKI for user credential validation and TACACS+ for authorization and accounting.

```
aaa group server tacacs+ ACS
  server name ACS
!
aaa authorization config-commands
aaa authorization exec ACS group tacacs+
aaa authorization commands 0 ACS group tacacs+ if-authenticated
aaa authorization commands 1 ACS group tacacs+ if-authenticated
aaa authorization commands 15 ACS group tacacs+ if-authenticated
aaa authorization network ACS group tacacs+
aaa authorization configuration ACS group tacacs+
```

3. Enable authorization on the PKI trustpoint CA for the user certificate.

```
crypto pki trustpoint CA2
  authorization list ACS
```

Troubleshooting

Commonly Used show Commands

Verify the status of the SSH server.

show ip ssh

```
Router#sh ip ssh
SSH Enabled - version 2.0
Authentication methods:publickey
Authentication Publickey Algorithms:x509v3-ssh-rsa
Hostkey Algorithms:x509v3-ssh-rsa,ssh-rsa
Encryption Algorithms:aes128-ctr,aes192-ctr,aes256-ctr,aes128-cbc,3des-
cbc,aes192-cbc,aes256-cbc
MAC Algorithms:hmac-sha1,hmac-sha1-96
Authentication timeout: 60 secs; Authentication retries: 2
Minimum expected Diffie Hellman key size : 1024 bits
IOS Keys in SECSH format(ssh-rsa, base64 encoded): SSH-RSA
ssh-rsa
```

Verify that the certificate for the root CA (CA2) is properly installed.

show crypto pki certificates

```
Router#show crypto pki certificates
CA Certificate
  Status: Available
  Certificate Serial Number (hex): 05
  Certificate Usage: Signature
  Issuer:
    cn=DoD Root CA 2
```

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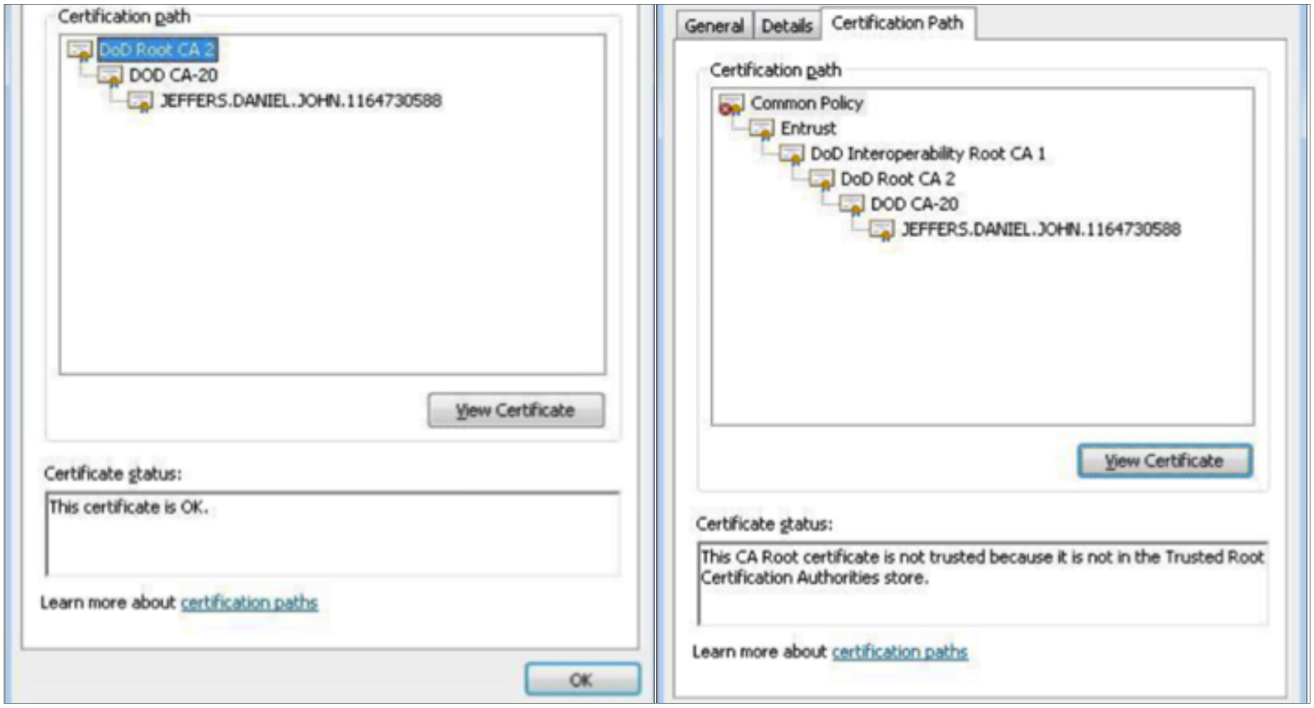
```
        ou=PKI
        ou=DoD
        o=U.S. Government
        c=US
    Subject:
        cn=DoD Root CA 2
        ou=PKI
        ou=DoD
        o=U.S. Government
        c=US
    Validity Date:
        start date: 10:00:10 EST Dec 13 2004
        end date: 10:00:10 EST Dec 5 2029
        Associated Trustpoints: CA2
```

Commonly Encountered Problems

IOS SSH server failed to validate the user certificate without the intermediate CA

The issue is that the workstation has an improperly configured certificate chain. When the PKI CA certificates are not properly installed in the correct locations on the workstation, Microsoft CryptoAPI (CAPI) will attempt to build a path to a known issuer (such as Common Policy) and will automatically install cross-certificates obtained during path processing into the user trust store. This will cause the wrong certificate chain to be sent to the Cisco IOS SSH server and will result in the failed certificate validation. Figure 2 shows examples of correct and incorrect certificate chains.

Figure 2. Correct and Incorrect Certificate Chains



Correctly Installed DoD Certificate Chain

Certification path

- DoD Root CA 2
  - DOD CA-20
    - JEFFERS.DANIEL.JOHN.1164730588

Certificate status:

This certificate is OK.

Learn more about certification paths

Improperly Configured Certificate Chain

Certification path

- Common Policy
  - Entrust
    - DoD Interoperability Root CA 1
      - DoD Root CA 2
        - DOD CA-20
          - JEFFERS.DANIEL.JOHN.1164730588

Certificate status:

This CA Root certificate is not trusted because it is not in the Trusted Root Certification Authorities store.

Learn more about certification paths

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Commonly Used debug Commands

debug crypto pki callbacks

debug crypto pki messages

debug crypto pki transactions

debug crypto pki validation

debug ip ssh detail

debug ip ssh packet

debug tacacs authentication

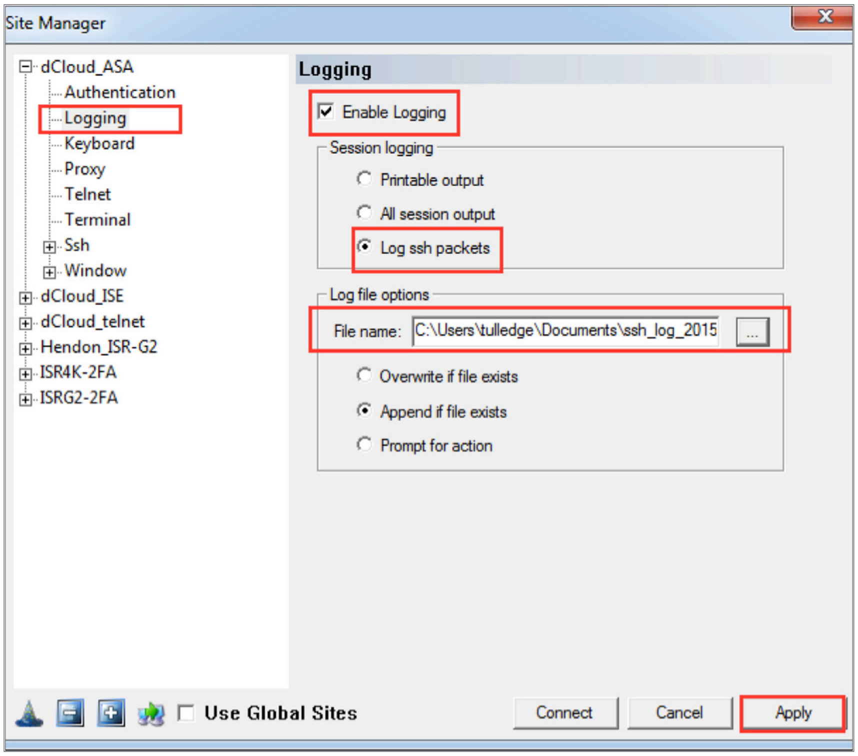
debug tacacs authorization

debug tacacs events

debug tacacs packet

Using Pragma Fortress Client Logging

1. The Pragma client has an SSH logging capability that allows you to see the SSH packet interchange with a server in the clear. Click Logging to enable.
2. Check Enable Logging.
3. Click Log ssh packets, and set the log filename.
4. Click Apply.



Logging

☑ Enable Logging

Session logging

○ Printable output
○ All session output
● Log ssh packets

Log file options

File name: C:\Users\tulledge\Documents\ssh_log_2015

○ Overwrite if file exists
● Append if file exists
○ Prompt for action

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Example Configuration

```
service timestamps debug datetime msec localtime show-timezone
service timestamps log datetime msec localtime show-timezone
!
aaa new-model
!
aaa group server tacacs+ ACS
  server name ACS
!
aaa authorization config-commands
aaa authorization exec ACS group tacacs+
aaa authorization commands 0 ACS group tacacs+ if-authenticated
aaa authorization commands 1 ACS group tacacs+ if-authenticated
aaa authorization commands 15 ACS group tacacs+ if-authenticated
aaa authorization network ACS group tacacs+
aaa authorization configuration ACS group tacacs+
!
clock timezone EST -5 0
clock summer-time EDT recurring
!
crypto pki trustpoint CA2
  enrollment terminal
  revocation-check none
  authorization list ACS
  authorization username subjectname commonname
!
crypto pki certificate chain CA2
  certificate ca 05
!
ip ssh time-out 60
ip ssh authentication-retries 2
ip ssh rsa keypair-name SSH-RSA
ip ssh version 2
ip ssh server certificate profile
  user
   trustpoint verify CA2
ip ssh server algorithm hostkey ssh-rsa
ip ssh server algorithm authentication publickey
ip ssh server algorithm publickey x509v3-ssh-rsa
!
tacacs server ACS
  address ipv4 172.25.180.117
  key cisco123
!
line vty 0 4
  login
  transport input ssh
!
ntp server 192.5.41.40
```

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About Pragma Systems

Pragma Systems Inc. is a leading provider of enterprise-class remote access and secure file transfer software for Microsoft Windows platforms and is a Microsoft Gold Certified Partner. Pragma is an industry leader of SSH, SFTP, SCP, and Telnet technologies. Pragma's SSH product line has FIPS 140-2 (certificate #1500), U.S. DoD UCAPL, and U.S. Army TIC lab certifications. Pragma offers its services to build secure infrastructure, data centers, mobile, cloud, and IT delivery solutions for government and corporate enterprises. Pragma's software solution is deployed in the majority of Fortune 500 companies in the United States and in over 4500 companies worldwide in 70 countries, with millions of licensed nodes. To learn more, visit www.pragmasys.com.

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