Quantum-Safe Encryption Using Postquantum Preshared Keys

This chapter explains how to use Postquantum Preshared Keys (PPK) for quantum-safe encryption of IKEv2 and OTNsec data, through the implementation of RFC 8784 and the Cisco Secure Key Integration Protocol (SKIP).

Quantum-Safe Encryption Using Postquantum Preshared Keys

Quantum-Safe Encryption Using Postquantum Preshared Keys

Table 1: Feature History

Feature Name	Release Information	Description
SKIP Protocol Support for Quantum Safe IKEv2 Encryption	Cisco IOS XR Release 24.1.1	Traditionally, the IKEv2 encryption was vulnerable to quantum attacks. Now, IKEv2 encryption complies with RFC 8784, which specifies using postquantum preshared keys (PPK) to make it resilient to quantum attacks. You can generate both manual and dynamic PPKs. The dynamic PPKs are generated using the Cisco Secure Key Integration Protocol (SKIP). The IKEv2 encryption is configured through CLI or by the Cisco-IOS-XR-um-ikev2-cfg Yang model. CLI: • The **ppk manual/dynamic** keyword is introduced in the **keyring** command. • The **keyring ppk** keyword is introduced in the **ikev2 profile** command. • The **sks profile** command is introduced.

Quantum computers have raised concerns about the security of cryptographic algorithms used extensively today. AN example of a cryptosystem that could be vulnerable to quantum computers is the Internet Key Exchange Protocol Version 2 (IKEv2). Any VPN communications could be decrypted in the future when a quantum computer becomes available. To address this issue, IKEv2 can be extended that uses preshared keys making it resistant to quantum computers.

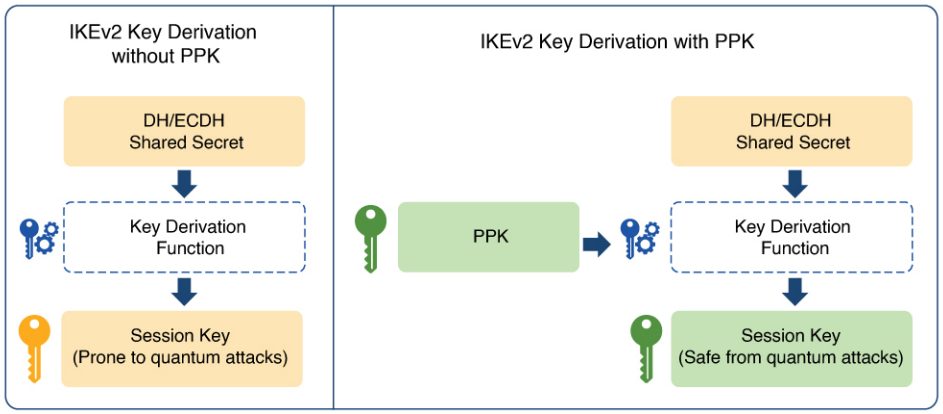
Postquantum Preshared Keys

Session keys that are derived from preshared keys are safe to quantum attacks if the preshared keys are endowed with sufficient entropy. Therefore, the resulting system is deemed secure against classical attackers of today, and against future quantum attackers.

RFC 8784 (Mixing Preshared Keys in IKEv2 for Postquantum Security) outlines an enhancement to the IKEv2 protocol that renders it quantum-computer-resistant through the incorporation of preshared keys, referred to as PPKs. This RFC establishes the specifications for enabling PPK capability negotiation, PPK ID transmission,

the integration of PPK as a supplementary factor in session key derivation, and the potential fallback to sessions not dependent on PPKs.

Figure 1: IKEv2 Key Derivation - With and Without PPK



DH: Diffie-Hellman
ECDH: Elliptic-curve Diffie-Hellman
PPK: Postquantum Preshared Key

Dynamic Postquantum Preshared Keys and SKIP

The Cisco Secure Key Integration Protocol (SKIP) is an HTTPS-driven protocol designed to enable encryption devices like routers to import PPKs from an external key source. These externally imported PPKs, referred to as dynamic PPKs, provide advantages such as automated provisioning and updates, and improved PPK entropy. Encryption devices must have the SKIP client and the external key source must have the SKIP server.

To be SKIP-compliant, an external key source must follow the Cisco SKIP protocol and use an out-of-band synchronization mechanism. This ensures that the same PPK is provided to both the initiator and responder encryption devices. The external key source can be in the form of a Quantum Key Distribution (QKD) device, software, or cloud-based key source or service.

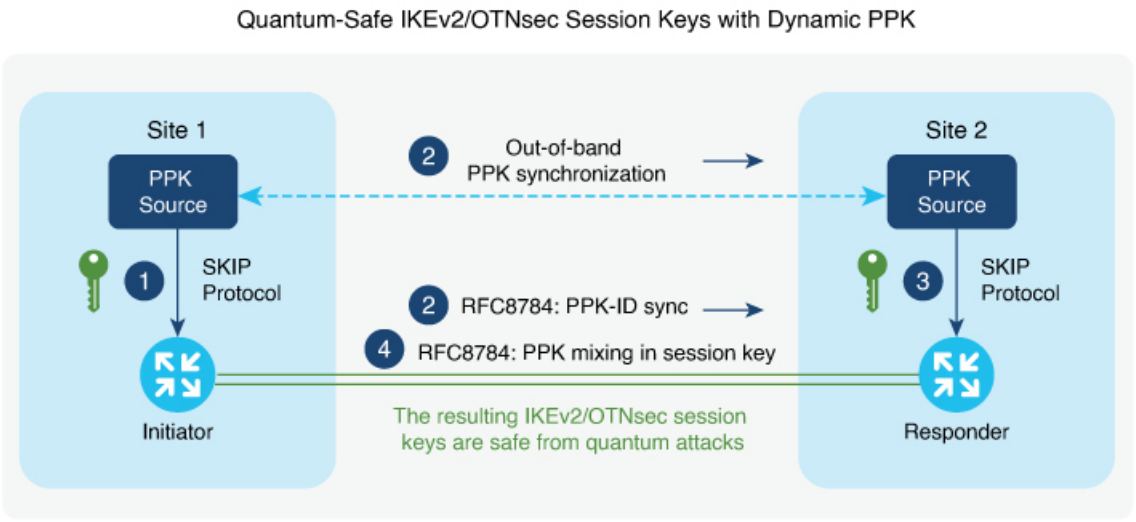
The external key source must meet the following expectations to be SKIP-compliant:

- Must implement the SKIP protocol or API, as specified in the Cisco SKIP specification.
- Must provide the same PPK to the encryption device pair—initiator and responder—using an out-of-band synchronization mechanism.

Note Key source vendors, such as QKD vendors, must contact their Cisco representative to implement the Cisco SKIP protocol.

The following figure shows quantum-safe IKEv2 and OTNsec session keys using dynamic PPK.

Figure 2: Quantum-Safe IKEv2 and OTNsec Session Keys with Dynamic PPK



The IKEv2 initiator and responder are connected to their respective local key sources and are configured with the SKIP client that specifies the IP address and port of the key source. The PPK sources are also configured with the SKIP parameters, which include the local key source identity and a list of identities of the peer key sources.

The high-level operation of Cisco SKIP protocol is as follows:

1. The IKEv2 initiator places a request for a PPK from its key source. The key source replies with a PPK and the corresponding PPK ID.
2. The initiator-side key source synchronizes the PPK to the responder-side key source using an out-of-band mechanism that is specific to the type of key source. The IKEv2 initiator communicates the PPK ID to the IKEv2 responder over IKEv2 using the RFC 8784 extensions.
3. The IKEv2 responder requests from its key source, the PPK corresponding to the PPK ID received from the IKEv2 initiator. The key source replies with the PPK corresponding to the PPK ID.
4. The IKEv2 initiator and responder mix the PPK in the key derivation, as specified in RFC 8784. The resulting IKEv2 and OTNsec session keys are quantum-safe.

Configure Dynamic PPK in IKEv2

Cisco Secure Key Import Protocol (SKIP) is a protocol that allows an encryption device to securely import keys from an external PPK source. The externally imported PPKs are known as dynamic PPKs. To use SKIP, the encryption devices must implement the SKIP client, and the PPK source must implement the SKIP server. SKIP allows the use of QKD devices or Cisco Session Key Service (SKS) servers as the source of PPKs.

Configuring Dynamic PPK using SKS SKIP

Use the following commands to configure the dynamic PPK for one or more peers or groups of peers, in the IKEv2 keyring.

configure terminal

keyring *dynamic*

peer *name*

ppk dynamic *sks-profile-name* **[required]**

pre-shared-key *key-string*

address {*ipv4-address mask*}

ikev2 profile *name*

match identity remote address {*ipv4-address mask*}

keyring ppk *keyring-name*

keyring *keyring-name*

sks profile *profile-name* **type remote**

kme server ipv4 *ip-address* **port** *port-number*

exit

exit

Example :

```
RP/0/RP0/CPU0:ios#configure terminal
RP/0/RP0/CPU0:ios(config)#keyring dynamic
RP/0/RP0/CPU0:ios(config-ikev2-keyring)#peer peer1
RP/0/RP0/CPU0:ios(config-ikev2-keyring-peer)#ppk dynamic qkd required
RP/0/RP0/CPU0:ios(config-ikev2-keyring)#pre-shared-key cisco123!cisco123
RP/0/RP0/CPU0:ios(config-ikev2-keyring-peer)#address 10.0.0.1 255.0.0.0
RP/0/1/CPU0:ios(config)#ikev2 profile test
RP/0/1/CPU0:ios(config-ikev2-profile-test)#keyring dynamic
RP/0/1/CPU0:ios(config-ikev2-profile-test)#keyring ppk dynamic
RP/0/1/CPU0:ios(config-ikev2-profile-name)#match address 10.0.0.1 255.255.255.0


RP/0/1/CPU0:ios(config)#sks profile qkd type remote
RP/0/1/CPU0:ios(config-sks-profile)#kme server ipv4 192.0.2.34 port 10001
RP/0/RP0/CPU0:ios(config-ikev2-keyring-peer)#exit
RP/0/RP0/CPU0:ios(config)#exit
```

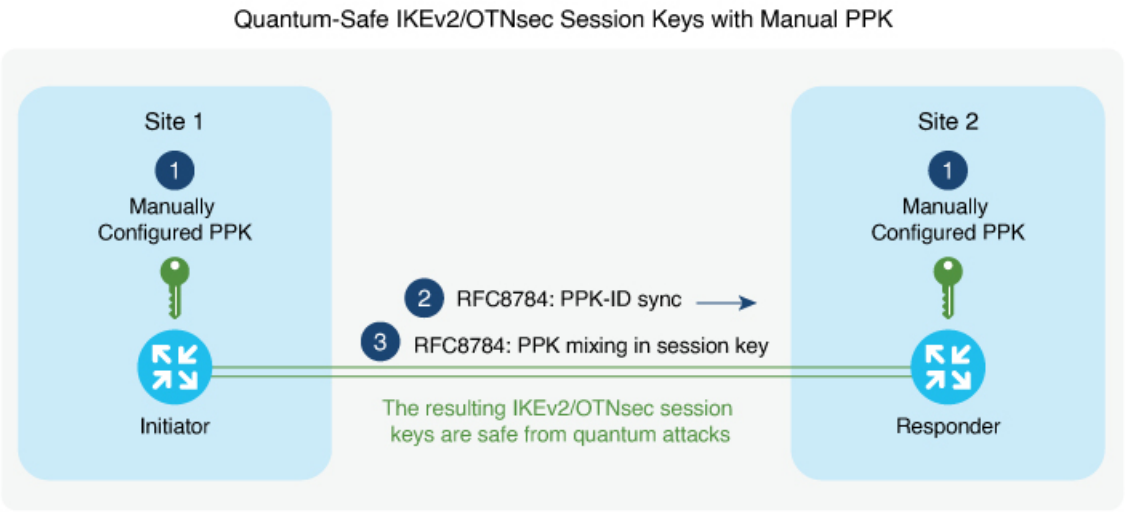
Manual Postquantum Preshared Keys

You can also use another easier way known as manual PPKs. When using the manual PPKs, you can provision the same PPKs on both the IKEv2 and OTNsec initiator and responder by manually configuring the PPKs on both sides.

Ensure that a manual PPK is of sufficient size, entropy, and is frequently rotated by the administrator.

In the following figure, you can see the session keys of quantum-safe IKEv2 and OTNsec, which are obtained through a manual PPK.

Figure 3: Quantum-Safe IKEv2 and OTNsec Session Keys with Manual PPK



Configure Manual PPK in IKEv2

Use the following commands to configure the manual PPK for one or more peers or groups of peers, in the IKEv2 keyring.

configure terminal

keyring *keyring-name*

peer *name*

ppk manual id *ppk-id* **key [clear | password]** *password* **[required]**

pre-shared-key *key-string*

address {*ipv4-address mask* }

ikev2 profile *name*

match identity remote address {*ipv4-address mask*}

keyring ppk *keyring-name*

keyring *keyring-name*

exit

exit

Example :

```
RP/0/RP0/CPU0:ios#configure terminal
RP/0/RP0/CPU0:ios(config)#keyring manual
RP/0/RP0/CPU0:ios(config-ikev2-keyring)#peer peer1
RP/0/RP0/CPU0:ios(config-ikev2-keyring-peer)#ppk manual id cisco123 key password
060506324F41584B56 required
RP/0/RP0/CPU0:ios(config-ikev2-keyring-peer)#pre-shared-key cisco123cisco123
RP/0/RP0/CPU0:ios(config-ikev2-keyring-peer)#address 10.0.0.1 255.0.0.0
RP/0/RP0/CPU0:ios(config-ikev2-keyring-peer)#exit
RP/0/RP0/CPU0:ios(config)#exit
```

```
RP/0/1/CPU0:ios(config)#ikev2 profile test
RP/0/1/CPU0:ios(config-ikev2-profile-test)#keyring manual
RP/0/1/CPU0:ios(config-ikev2-profile-test)#keyring ppk manual
RP/0/1/CPU0:ios(config-ikev2-profile-test)#match address 10.0.0.1 255.255.255.0
RP/0/RP0/CPU0:ios(config-ikev2-profile-test)#exit
RP/0/RP0/CPU0:ios(config)#exit
```

Note When using the `password6` keyword for PPK and preshared key, you must use an encrypted key. You can use the encrypted form of the `clear` PPK and preshared key that you previously configured (retrieve the encrypted form using the **show running-config keyring** command), as long as the primary key used to enable the type 6 password remains the same.

Verify the PPK Configuration

This section describes the commands to verify the configured PPK details.

View the Current IKEv2 Security Associations

Use the **show ikev2 sa detail** command to display information about the current IKEv2 security associations. The `Quantum resistance` parameter in the output of the commnd indicates that manual PPK-based quantum-safe encryption is enabled.

Note Both manual and dynamic PPK options can be used for viewing IKEv2 details.

The following is a sample output from the **show ikev2 sa detail** command:

```
RP/0/1/CPU0:ios#show ikev2 sa detail

IKE SA ID                           : 866
------------------------------------------------------------------------------
 Local                              : 192.0.2.34/500
 Remote                             : 192.0.2.40/500
 Status(Description)                : READY (Negotiation done)
 Role                               : Initiator
 Fvrf                               : Default
 Encryption/Keysize                 : AES-CBC/256
 PRF/Hash/DH Group                  : SHA512/SHA512/19
 Authentication(Sign/Verify)        : PSK/PSK
 Life/Active Time(sec)              : 86400/21
 Session ID                         : 5
 Local SPI                          : C18D2946B0C4259C
 Remote SPI                         : 5D1BD398AEB3A1E1
 Local ID                           : 192.0.2.34
 Remote ID                          : 192.0.2.40
 Quantum resistance                 : Enabled with manual PPK
```

View IKEv2 Session Statistics

Use the **show ikev2 statistics** command to display the statistics and counters related to IKEv2 sessions.

The following is a sample output from the **show ikev2 statistics** command:

```
RP/0/1/CPU0:ios#show ikev2 statistics
Thu Jun  8 13:30:06.360 IST

.............................

NO_NAT                        :        2               0               0               0


PPK COUNTERS
=============================================================================================

PPK ERRORS
---------------------------------------------------------------------------------------------
PPK_ID_MISMATCH               :        0
PPK_RETRIEVE_FAIL             :        0
PPK_AUTH_FAIL                 :        0
```

View IKEv2 Session Summary

Use the **show ikev2 summary** command to display the IKEv2 session summary of NCS 1014.

The following is a sample output from the **show ikev2 summary** command:

```
RP/0/1/CPU0:ios#show ikev2 summary
Thu Jun  8 12:54:30.969 IST

IKEv2 SA Summary
-------------------------------------------------
Total SA (Active/Negotiating)         : 2 (2/0)
Total Outgoing SA (Active/Negotiating): 2 (2/0)
Total Incoming SA (Active/Negotiating): 0 (0/0)
Total QR SA (Dynamic/Manual)          : 2 (1/1)
```

View IKEv2 Profile Details

Use the **show ikev2 profile** command to display all the IKEv2 profile details.

The following is a sample output from the **show ikev2 profile** command:

```
RP/0/1/CPU0:ios#show ikev2 profile
Tue Jun  6 18:00:20.277 IST

Profile Name                          : p4
=============================================================================
Keyring                               : k4
Fvrf                                  : Default
Lifetime(Sec)                         : 86400
DPD Interval(Sec)                     : 4
DPD Retry Interval(Sec)               : 2
Match ANY                             : NO
Total Match remote peers              : 1
   Addr/Prefix                        : 198.51.100.19/255.255.255.0
Number of Trustpoints                 : 0
Local auth method                     : PSK
Number of remote auth methods         : 1
   Auth Method                        : PSK
PPK Keyring                           : Not Configured

Profile Name                          : ppk_d
=============================================================================
```

```
Keyring                                 : Not Configured
Fvrf                                    : Default
Lifetime(Sec)                           : 86400
DPD Interval(Sec)                       : 4
DPD Retry Interval(Sec)                 : 2
Match ANY                               : NO
Total Match remote peers                : 0
Number of Trustpoints                   : 0
Local auth method                       : NULL
Number of remote auth methods           : 0
PPK Keyring                             : ppk_d

Profile Name                            : ppk_m
================================================================================
Keyring                                 : Not Configured
Fvrf                                    : Default
Lifetime(Sec)                           : 86400
DPD Interval(Sec)                       : 4
DPD Retry Interval(Sec)                 : 2
Match ANY                               : NO
Total Match remote peers                : 0
Number of Trustpoints                   : 0
Local auth method                       : NULL
Number of remote auth methods           : 0
PPK Keyring                             : ppk_m
```

View Keyring Details

Use the **show keyring** command to display the configured keyring details on NCS 1014.

The following is a sample output from the **show keyring** command:

```
RP/0/1/CPU0:ios#show keyring
Tue Jun  6 18:00:28.272 IST

Keyring Name                            : k4
================================================================================
Total Peers                             : 1
--------------------------------------------------------------------------------
   Peer Name                            : init
   IP Address                           : 198.51.100.19
   Subnet Mask                          : 255.255.255.0
   Local PSK                            : Configured
   Remote PSK                           : Configured
   PPK Mode                             : Not Configured
   PPK Mandatory                        : Not Configured

Keyring Name                            : ppk_m
================================================================================
Total Peers                             : 1
--------------------------------------------------------------------------------
   Peer Name                            : init
   IP Address                           : Not Configured
   Subnet Mask                          : Not Configured
   Local PSK                            : Not Configured
   Remote PSK                           : Not Configured
   PPK Mode                             : Manual
   PPK Mandatory                        : No


Keyring Name                            : ppk_m_req
================================================================================
Total Peers                             : 1
```

```
--------------------------------------------------------------------------------
   Peer Name                          : init
   IP Address                         : Not Configured
   Subnet Mask                        : Not Configured
   Local PSK                          : Not Configured
   Remote PSK                         : Not Configured
   PPK Mode                           : Manual
   PPK Mandatory                      : Yes


Keyring Name                          : ppk_d
================================================================================
Total Peers                           : 1
--------------------------------------------------------------------------------
   Peer Name                          : init
   IP Address                         : Not Configured
   Subnet Mask                        : Not Configured
   Local PSK                          : Not Configured
   Remote PSK                         : Not Configured
   PPK Mode                           : Dynamic
   PPK Mandatory                      : No


Keyring Name                          : ppk_d_req
================================================================================
Total Peers                           : 1
--------------------------------------------------------------------------------
   Peer Name                          : init
   IP Address                         : Not Configured
   Subnet Mask                        : Not Configured
   Local PSK                          : Not Configured
   Remote PSK                         : Not Configured
   PPK Mode                           : Dynamic
   PPK Mandatory                      : Yes
```

View IKEv2 Session Detail

Use the **show ikev2 session detail** command to display information about the current IKEv2 session.

The following is a sample output from the **show ikev2 session detail** command:

```
RP/0/1/CPU0:ios#show ikev2 session detail
Fri Feb  2 11:21:09.131 IST
Session ID                             : 3
================================================================================
 Status                                : UP-ACTIVE
 IKE Count                             : 1
 Child Count                           : 1
 IKE SA ID                             : 11625
--------------------------------------------------------------------------------
  Local                                : 192.0.2.3/500
  Remote                               : 192.0.2.1/500
  Status(Description)                  : READY (Negotiation done)
  Role                                 : Initiator
  Fvrf                                 : Default
  Encryption/Keysize                   : AES-CBC/256
  PRF/Hash/DH Group                    : SHA512/SHA512/19
  Authentication(Sign/Verify)          : PSK/PSK
  Life/Active Time(sec)                : 200/115
  Session ID                           : 3
  Local SPI                            : E8F0716FF44EA1C3
  Remote SPI                           : B1046E13B805178E
```

```
 Local ID                              : 192.0.2.3
 Remote ID                             : 192.0.2.1
 Quantum resistance                    : Enabled with manual PPK

Child SA
------------------------------------------------------------------------------
  Local Selector                       : 0.0.0.0/0 - 255.255.255.255/65535
  Remote Selector                      : 0.0.0.0/0 - 255.255.255.255/65535
  ESP SPI IN/OUT                       : 0xf5e2a1c2 / 0x12bb94fd
  Encryption                           : AES-CBC
  Keysize                              : 256
  ESP HMAC                             : SHA384
```