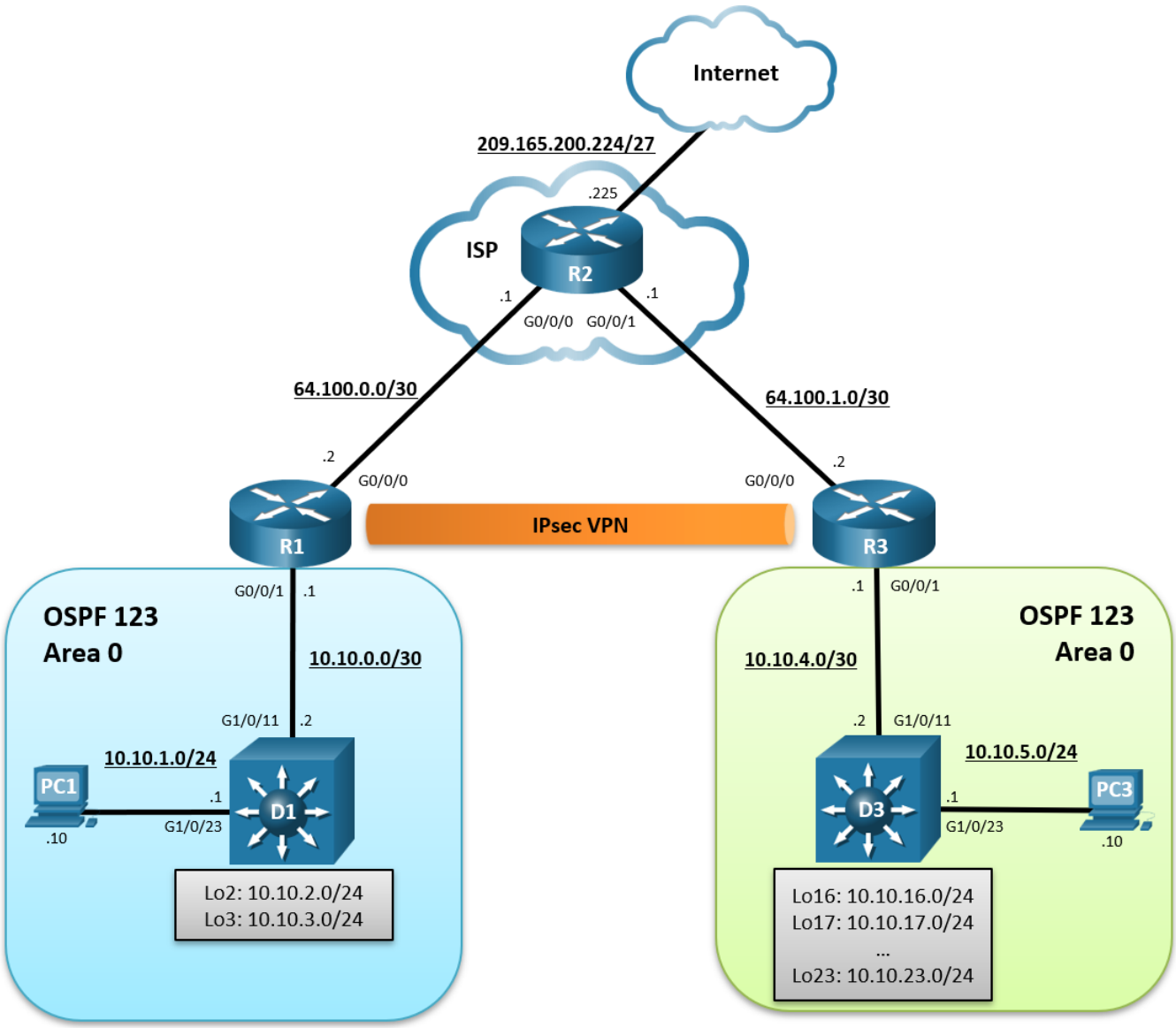
Lab - Implement IPsec Site-to-Site VPNs (Instructor Version)

Instructor Note: Red font color or gray highlights indicate text that appears in the instructor copy only.

Answers: 16.1.3 Lab - Implement IPsec Site-to-Site

Topology



Addressing Table

Device	Interface	IPv4 Address	Default Gateway
R1	G0/0/0	64.100.0.2/30	N/A
	G0/0/1	10.10.0.1/29	
R2	G0/0/0	64.100.0.1/30	N/A
	G0/0/1	64.100.1.1/30	
	Lo0	209.165.200.225	
R3	G0/0/0	64.100.1.2/30	N/A
	G0/0/1	10.10.4.1/30	
D1	G1/0/11	10.10.0.2/29	N/A
	G1/0/23	10.10.1.1/24	
	Lo2	10.10.2.1/24	
	Lo3	10.10.3.1/24	
D3	G1/0/11	10.10.0.3/29	N/A
	G1/0/23	10.10.5.1/24	
	Lo16	10.10.16.1/24	
	Lo17	10.10.17.1/24	
	Lo18	10.10.18.1/24	
	Lo19	10.10.19.1/24	
	Lo20	10.10.20.1/24	
	Lo21	10.10.21.1/24	
	Lo22	10.10.22.1/24	
	Lo23	10.10.23.1/24	
PC1	NIC	10.10.1.10/24	10.10.1.1
PC3	NIC	10.10.5.10/24	10.10.5.1

Objectives

Part 1: Build the Network, Configure Basic Device Settings and Static Routing

Part 2: Configure a Site-to-Site VPN using Crypto Maps Between R1 and R3

Part 3: Verify a Site-to-Site VPN Between R1 and R3

Background / Scenario

VPNs provide a secure method of transmitting data over a public network, such as the internet. VPN connections help reduce the costs associated with leased lines. Site-to-site VPNs typically provide a secure (IPsec or other) tunnel between a branch office and a central office. Another common implementation of VPN

technology is remote access to a corporate office from a telecommuter location, such as a small office or home office.

In this lab, you will establish a site-to-site IPsec VPN tunnel between R1 to R3 via R2. R2 is the ISP router, and it will have no knowledge of the VPN. IPsec provides secure transmission of sensitive information over unprotected networks, such as the internet. IPsec works at the network layer and protects and authenticates IP packets between participating IPsec devices (peers), such as Cisco routers.

Note: This lab is an exercise in developing, deploying, and verifying how VPNs operate and does not reflect networking best practices.

Note: The routers used with this CCNP hands-on lab are three Cisco 4221 and the two Layer 3 switches are Catalyst 3650 switches. Other routers and Layer 3 switches and Cisco IOS versions can be used. Depending on the model and Cisco IOS version, the commands available and the output produced might vary from what is shown in the labs.

Note: Ensure that the routers and switches have been erased and have no startup configurations. If you are unsure contact your instructor.

Instructor Note: Refer to the Instructor Lab Manual for the procedures to initialize and reload devices.

Required Resources

- 3 Routers (Cisco 4221 with Cisco IOS XE Release 16.9.4 universal image or comparable)
- 2 Switches (Cisco 4221 with Cisco IOS XE Release 16.9.4 universal image or comparable)
- 2 PCs (Choice of operating system with a terminal emulation program installed)
- Console cables to configure the Cisco IOS devices via the console ports
- Ethernet cables as shown in the topology

Instructions

Part 1: Build the Network, Configure Basic Device Settings and Static Routing

In Part 1, you will set up the network topology, configure basic settings, interface addressing, and single-area OSPFv2 on the routers.

Step 1: Cable the network as shown in the topology.

Attach the devices as shown in the topology diagram, and cable as necessary.

Step 2: Configure basic settings for the routers.

a. Console into each router and switch, enter global configuration mode, and apply the basic settings, and interface addressing. A command list for each device is provided for your reference.

Routing is enabled as follows:

- R2 has a static route to the networks connected to R1 (i.e., 10.10.0.0/22) and two static routes to the networks connected to R3 (i.e., 10.10.4.0/22, 10.10.16.0/21).
- R1 and R3 each have a default static route to R2.
- OSPFv2 routing is enabled between R1 and D1, and R1 is propagating the default route to D1.
- OSPFv2 routing is enabled between R3 and D3, and R3 is propagating the default route to D3.
- A command list for each router is listed below to perform initial configuration.

Router R1

```
hostname R1
```

```
no ip domain lookup
line con 0
 logging sync
 exec-time 0 0
 exit
banner motd # This is R1, Implement IPsec Site-to-Site VPNs #
interface g0/0/0
 description Connection to R2
 ip add 64.100.0.2 255.255.255.252
 no shut
 exit
interface GigabitEthernet0/0/1
 description Connection to D1
 ip address 10.10.0.1 255.255.255.252
 no shut
 exit
router ospf 123
 router-id 1.1.1.1
 auto-cost reference-bandwidth 1000
 network 10.10.0.0 0.0.0.3 area 0
 default-information originate
exit
ip route 0.0.0.0 0.0.0.0 64.100.0.1
```

Router R2

```
hostname R2
no ip domain lookup
line con 0
logging sync
exec-time 0 0
exit
banner motd # This is R2, Implement IPsec Site-to-Site VPNs #
interface g0/0/0
 description Connection to R1
 ip add 64.100.0.1 255.255.255.252
 no shut
 exit
interface GigabitEthernet0/0/1
 description Connection to R3
 ip address 64.100.1.1 255.255.255.252
 no shut
 exit
int lo0
description Internet simulated address
ip add 209.165.200.225 255.255.255.224
exit
```

```
ip route 0.0.0.0 0.0.0.0 Loopback0
ip route 10.10.0.0 255.255.252.0 64.100.0.2
ip route 10.10.4.0 255.255.252.0 64.100.1.2
ip route 10.10.16.0 255.255.248.0 64.100.1.2
```

Router R3

```
hostname R3
no ip domain lookup
line con 0
logging sync
exec-time 0 0
exit
banner motd # This is R3, Implement IPsec Site-to-Site VPNs #
interface g0/0/0
 description Connection to R2
 ip add 64.100.1.2 255.255.255.252
 no shut
 exit
interface GigabitEthernet0/0/1
 description Connection to D3
 ip address 10.10.4.1 255.255.255.252
 no shut
 exit
ip route 0.0.0.0 0.0.0.0 64.100.1.1
router ospf 123
 router-id 3.3.3.1
 auto-cost reference-bandwidth 1000
 network 10.10.4.0 0.0.0.3 area 0
 default-information originate
exit
```

Switch D1

```
hostname D1
no ip domain lookup
line con 0
exec-timeout 0 0
logging synchronous
exit
banner motd # This is D1, Implement IPsec Site-to-Site VPNs #
interface G1/0/11
 description Connection to R1
 no switchport
 ip address 10.10.0.2 255.255.255.252
 no shut
 exit
interface G1/0/23
```

```
 description Connection to PC1
 no switchport
 ip address 10.10.1.1 255.255.255.0
 no shut
 exit
int Lo2
 description Loopback to simulate an OSPF network
 ip add 10.10.2.1 255.255.255.0
 ip ospf network point-to-point
exit
int Lo3
 description Loopback to simulate an OSPF network
 ip add 10.10.3.1 255.255.255.0
 ip ospf network point-to-point
exit
ip routing
router ospf 123
 router-id 1.1.1.2
 auto-cost reference-bandwidth 1000
 network 10.10.0.0 0.0.3.255 area 0
exit
int range G1/0/1 - 10, G1/0/12 - 22, G1/0/24
 shut
exit
```

Switch D3

```
hostname D3
no ip domain lookup
line con 0
logging sync
exec-time 0 0
exit
banner motd # This is D3, Implement IPsec Site-to-Site VPNs #
interface G1/0/11
 description Connection to R3
 no switchport
 ip address 10.10.4.2 255.255.255.252
 no shut
 exit
interface G1/0/23
 description Connection to PC3
 no switchport
 ip address 10.10.5.1 255.255.255.0
 no shut
 exit
int Lo16
```

```
 description Loopback to simulate an OSPF network
 ip add  10.10.16.1 255.255.255.0
 ip ospf network point-to-point
exit
int Lo17
description Loopback to simulate an OSPF network
ip add 10.10.17.1 255.255.255.0
ip ospf network point-to-point
exit
int Lo18
description Loopback to simulate an OSPF network
ip add 10.10.18.1 255.255.255.0
ip ospf network point-to-point
exit
int Lo19
description Loopback to simulate an OSPF network
ip add 10.10.19.1 255.255.255.0
ip ospf network point-to-point
exit
int Lo20
description Loopback to simulate an OSPF network
ip add 10.10.20.1 255.255.255.0
ip ospf network point-to-point
exit
int Lo21
description Loopback to simulate an OSPF network
ip add 10.10.21.1 255.255.255.0
ip ospf network point-to-point
exit
int Lo22
 description Loopback to simulate an OSPF network
 ip add 10.10.22.1 255.255.255.0
 ip ospf network point-to-point
 exit
int Lo23
 description Loopback to simulate an OSPF network
 ip add 10.10.23.1 255.255.255.0
 ip ospf network point-to-point
 exit
ip routing
router ospf 123
 router-id 3.3.3.2
 auto-cost reference-bandwidth 1000
 network 10.10.4.0 0.0.1.255 area 0
 network 10.10.16.0 0.0.7.255 area 0
```

```
exit
int range G1/0/1 - 10, G1/0/12 - 22, G1/0/24
 shut
exit
```

b. Save the running configuration to startup-config.

Step 3: Configure PC1 and PC3 with IP addressing.

Configure the two PCs with the IP addresses listed in the Address Table. Also configure their respective default gateways.

Step 4: On PC1, verify end-to-end connectivity.

a. From PC1, **ping** PC3 (i.e., 10.10.5.10).

```
PC1> ping 10.10.5.10

Pinging 10.10.5.10 with 32 bytes of data:
Reply from 10.10.5.10: bytes=32 time=1ms TTL=123
Reply from 10.10.5.10: bytes=32 time=1ms TTL=123
Reply from 10.10.5.10: bytes=32 time=1ms TTL=123
Reply from 10.10.5.10: bytes=32 time=1ms TTL=123

Ping statistics for 10.10.5.10:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 1ms, Maximum = 1ms, Average = 1ms
```

The pings should be successful. If the pings are unsuccessful, troubleshoot the basic device configurations before continuing.

b. From PC1, **ping** the first loopback on D3 (i.e., 10.10.16.1).

```
PC1> ping 10.10.16.1

Pinging 10.10.16.1 with 32 bytes of data:
Reply from 10.10.16.1: bytes=32 time=2ms TTL=250
Reply from 10.10.16.1: bytes=32 time=2ms TTL=250
Reply from 10.10.16.1: bytes=32 time=2ms TTL=250
Reply from 10.10.16.1: bytes=32 time=2ms TTL=250

Ping statistics for 10.10.16.1:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 2ms, Maximum = 2ms, Average = 2ms
```

The pings should be successful. If the pings are unsuccessful, troubleshoot the basic device configurations before continuing.

c. Finally, from PC1, **ping** the default gateway loopback on R2 (i.e., 209.165.200.225).

```
PC1> ping 209.165.200.225

Pinging 209.165.200.225 with 32 bytes of data:
Reply from 209.165.200.225: bytes=32 time=1ms TTL=253
```

```
Reply from 209.165.200.225: bytes=32 time=1ms TTL=253
Reply from 209.165.200.225: bytes=32 time=1ms TTL=253
Reply from 209.165.200.225: bytes=32 time=1ms TTL=253

Ping statistics for 209.165.200.225:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 1ms, Maximum = 1ms, Average = 1ms
```

The pings should be successful. If the pings are unsuccessful, troubleshoot the basic device configurations before continuing.

Step 5: Verify the routing table of R1.

a. Verify the OSPF routing table of R1.

```
R1# show ip route ospf | begin Gateway
Gateway of last resort is 64.100.0.1 to network 0.0.0.0

      10.0.0.0/8 is variably subnetted, 5 subnets, 3 masks
O        10.10.1.0/24 [110/11] via 10.10.0.2, 00:29:03, GigabitEthernet0/0/1
O        10.10.2.0/24 [110/2] via 10.10.0.2, 00:29:03, GigabitEthernet0/0/1
O        10.10.3.0/24 [110/2] via 10.10.0.2, 00:29:03, GigabitEthernet0/0/1
```

The routing table confirms that R1 has knowledge of the networks connected to D1. Notice however, that R1 has no knowledge of the routes connected to the R3 OSPF domain. The reason why PC1 can still reach PC3 is because R1 has a default static route to R2. R1 forwarded the traffic to R2 because it did not know where the 10.10.5.0 network was. R2 has a static route to this network and therefore forwarded it to R3.

Part 2: Configure a Site-to-Site VPN using Crypto Maps Between R1 and R3

In Part 2 of this lab, you will configure an IPsec VPN tunnel between R1 and R3 that passes through R2. You will configure R1 and R3 using the Cisco IOS CLI. You will then review and test the resulting configuration.

IPsec is an open framework that allows for the exchange of security protocols as new technologies, and encryption algorithms as they are developed.

There are two central configuration elements in the implementation of an IPsec VPN:

- Implement Internet Key Exchange (IKE) parameters
- Implement IPsec parameters

Step 1: On R1 and R3, implement Internet Key Exchange (IKE) parameters.

In this step, you will enable IKE policies on R1 and R3. IKE Phase 1 defines the key exchange method used to exchange and validate IKE policies between peers. In IKE Phase 2, the peers exchange and match IPsec policies for the authentication and encryption of data traffic.

IKE must be enabled for IPsec to function. IKE is enabled, by default, on IOS images with cryptographic feature sets. However, if is disabled, you can enable it with the **crypto isakmp enable** command. This command can also be used to verify that the router IOS supports IKE and that it is enabled.

Note: If the command produces an error and cannot be executed, then the device must be upgraded to an IOS image that includes the Cisco cryptographic services.

a. When a VPN is negotiated, the router will attempt to connect to the other device using the defined ISAKMP policies. To allow IKE Phase 1 negotiation, you must create an ISAKMP policy that defines the

authentication, encryption algorithms, and the hash function used to send control traffic between the two VPN endpoints. When an ISAKMP security association has been accepted by the IKE peers, IKE Phase 1 has been completed.

There are multiple ISAKMP policies available by default. On R1, view the ISAKMP policies available using the **show crypto isakmp policy** global config command.

```
R1# show crypto isakmp policy

Default IKE policy
Protection suite of priority 65507
        encryption algorithm:   AES - Advanced Encryption Standard (128 bit keys).
        hash algorithm:         Secure Hash Standard
        authentication method:  Rivest-Shamir-Adleman Signature
        Diffie-Hellman group:   #5 (1536 bit)
        lifetime:               86400 seconds, no volume limit
Protection suite of priority 65508
        encryption algorithm:   AES - Advanced Encryption Standard (128 bit keys).
        hash algorithm:         Secure Hash Standard
        authentication method:  Pre-Shared Key
        Diffie-Hellman group:   #5 (1536 bit)
        lifetime:               86400 seconds, no volume limit

<Output omitted>

Protection suite of priority 65514
        encryption algorithm:   Three key triple DES
        hash algorithm:         Message Digest 5
        authentication method:  Pre-Shared Key
        Diffie-Hellman group:   #2 (1024 bit)
        lifetime:               86400 seconds, no volume limit
```

These are default policies that are available if no custom ISAKMP policy is configured. The policies are listed in order of priority with policy 65507 providing the most secure settings and policy 65514 offering the least secure.

Default policies may not provide the required settings for your VPNs. And although default policies exist, it is recommended that you define specific custom policies.

b. To create a custom ISAKMP policy, enter ISAKMP configuration mode using the **crypto isakmp policy** *number* global configuration mode command. The policy number uniquely identifies the IKE policy and assigns a priority to the policy, where 1 is the highest priority.

On R1, create ISAKMP policy number 10 as shown.

```
R1(config)# crypto isakmp policy 10
```

c. View the various IKE parameters available using Cisco IOS help by typing a question mark (**?**).

```
R1(config-isakmp)# ?
ISAKMP commands:
  authentication  Set authentication method for protection suite
  default         Set a command to its defaults
  encryption      Set encryption algorithm for protection suite
  exit            Exit from ISAKMP protection suite configuration mode
  group           Set the Diffie-Hellman group
```

```
hash            Set hash algorithm for protection suite
lifetime        Set lifetime for ISAKMP security association
no              Negate a command or set its defaults
```

As shown in the table below, several parameters can be configured in ISAKMP policy configuration mode.

Parameter	Options	Default	Recommended
authentication	pre-share | rsa-encr | rsa-sig	rsa-sig	(varies)
encryption	des | 3des | aes | aes [128 | 192 | 256]	des	aes (or higher)
group	1 | 2 | 5 | 14 | 15 | 16 | 19 | 20 | 24	1	14 (or higher)
hash	md5 | sha | sha256 | sha384 | sha512	sha	sha256 (or higher)
lifetime	60-86400 (in seconds)	86400 (24 hours)	(shorter timeframes are more secure)

Note: The last column lists the minimum recommended options.

d. Entering the ISAKMP policy configuration mode automatically assigns default parameters to the policy. To view these defaults, use the **do show crypto isakmp policy** command.

```
R1(config-isakmp)# do show crypto isakmp policy

Global IKE policy
Protection suite of priority 10
        encryption algorithm:   DES - Data Encryption Standard (56 bit keys).
        hash algorithm:         Secure Hash Standard
        authentication method:  Rivest-Shamir-Adleman Signature
        Diffie-Hellman group:   #1 (768 bit)
        lifetime:               86400 seconds, no volume limit
```

The output highlights the default parameters automatically assigned to the new policy. For security reason, most of these should be updated to the recommended minimum listed in the table.

Your choice of an encryption algorithm determines how confidential the control channel between the endpoints is. The hash algorithm controls data integrity, ensuring that the data received from a peer has not been tampered with in transit. The authentication type ensures that the packet was sent and signed by the remote peer. The Diffie-Hellman group is used to create a secret key shared by the peers that has not been sent across the network.

e. In this lab, we will use the following parameters for the ISAKMP policy 10 on R1 and R3:

- Encryption: **aes 256**
- Hash: sha256
- Authentication method: **pre-share key**
- Diffie-Hellman group: **14**
- Lifetime: **3600** seconds (60 minutes / 1 hour)

Note: Older versions of Cisco IOS do not support AES 256 encryption and SHA as a hash algorithm. Substitute whatever encryption and hashing algorithm your router supports. Ensure that the same changes are made on R3 in order to be in sync.

```
R1(config-isakmp)# encryption aes 256
R1(config-isakmp)# hash sha256
```

```
R1(config-isakmp)# authentication pre-share
R1(config-isakmp)# group 14
R1(config-isakmp)# lifetime 3600
R1(config-isakmp)# exit
```

f. Configure the same policy on R3.

```
R3(config)# crypto isakmp policy 10
R3(config-isakmp)# encryption aes 256
R3(config-isakmp)# hash sha256
R3(config-isakmp)# authentication pre-share
R3(config-isakmp)# group 14
R3(config-isakmp)# lifetime 3600
```

g. Verify the IKE policy with the show crypto isakmp policy command on R1 and R3.

```
R1(config)# do show crypto isakmp policy

Global IKE policy
Protection suite of priority 10
        encryption algorithm:   AES - Advanced Encryption Standard (256 bit keys).
        hash algorithm:         Secure Hash Standard 2 (256 bit)
        authentication method:  Pre-Shared Key
        Diffie-Hellman group:   #14 (2048 bit)
        lifetime:               3600 seconds, no volume limit
```

```
R3(config)# do show crypto isakmp policy

Global IKE policy
Protection suite of priority 10
        encryption algorithm:   AES - Advanced Encryption Standard (256 bit keys).
        hash algorithm:         Secure Hash Standard 2 (256 bit)
        authentication method:  Pre-Shared Key
        Diffie-Hellman group:   #14 (2048 bit)
        lifetime:               3600 seconds, no volume limit
```

The policies must match. Troubleshoot and verify that the configurations were done correctly on both routers.

Step 2: On R1 and R3, configure the pre-shared keys.

Because pre-shared keys are used as the authentication method in the IKE policy, a key must be configured on each router that points to the other VPN endpoint. These keys must match for authentication to be successful.

Use the **crypto isakmp key** *key-string* **address** *ip-address* global configuration mode command to enter a pre-shared key. Use the global IP address of the remote peer, which is the outside interface of the remote peer router.

Note: The *ip-address* parameter can be assigned **0.0.0.0 0.0.0.0** to allow a match against any peer.

Which IP addresses should you use to configure the IKE peers, given the topology diagram and IP addressing table?

The IP addresses should be as follows: R1 G0/0/0 IP address 64.100.0.2 and R3 G0/0/0 IP address 64.100.1.2. These are the addresses that are used to send normal traffic between R1 and R3.

a. Each IP address that is used to configure the IKE peers is also referred to as the IP address of the remote VPN endpoint. Configure the pre-shared key of **cisco123** on R1. This command points to the remote peer R3 G0/0/0 IP address.

Note: Production networks should use longer and more complex keys.

```
R1(config)# crypto isakmp key cisco123 address 64.100.1.2
```

b. Configure the pre-shared key **cisco123** on router R3. The command for R3 points to the R1 G0/0/0 IP address.

```
R3(config)# crypto isakmp key cisco123 address 64.100.0.2
```

Step 3: On R1 and R3, configure the IPsec transform set and lifetime.

The IPsec transform set is another crypto configuration parameter that routers negotiate to form a security association. To create an IPsec transform set, use the **crypto ipsec transform-set** *transform-set-name transform1* [*transform2* [*transform3*]] command.

a. On R1 and R3, create a transform set with the name **S2S-VPN** and use ? to see which parameters are available.

```
R1(config)# crypto ipsec transform-set S2S-VPN ?
  ah-md5-hmac      AH-HMAC-MD5 transform
  ah-sha-hmac      AH-HMAC-SHA transform
  ah-sha256-hmac   AH-HMAC-SHA256 transform
  ah-sha384-hmac   AH-HMAC-SHA384 transform
  ah-sha512-hmac   AH-HMAC-SHA512 transform
  esp-192-aes      ESP transform using AES cipher (192 bits)
  esp-256-aes      ESP transform using AES cipher (256 bits)
  esp-3des         ESP transform using 3DES(EDE) cipher (168 bits)
  esp-aes          ESP transform using AES cipher
  esp-des          ESP transform using DES cipher (56 bits)
  esp-gcm          ESP transform using GCM cipher
  esp-gmac         ESP transform using GMAC cipher
  esp-md5-hmac     ESP transform using HMAC-MD5 auth
  esp-null         ESP transform w/o cipher
  esp-seal         ESP transform using SEAL cipher (160 bits)
  esp-sha-hmac     ESP transform using HMAC-SHA auth
  esp-sha256-hmac  ESP transform using HMAC-SHA256 auth
  esp-sha384-hmac  ESP transform using HMAC-SHA384 auth
  esp-sha512-hmac  ESP transform using HMAC-SHA512 auth

R1(config)# crypto ipsec transform-set S2S-VPN
```

b. On R1 and R3, use the AES 256 cipher with ESP and the SHA 256 hash function.

```
R1(config)# crypto ipsec transform-set S2S-VPN esp-aes 256 esp-sha256-hmac
R1(cfg-crypto-trans)# exit

R3(config)# crypto ipsec transform-set S2S-VPN esp-aes 256 esp-sha256-hmac
R3(cfg-crypto-trans)# exit
```

What is the function of the IPsec transform set?

The IPsec transform set specifies the cryptographic algorithms and functions (transforms) that a router employs on the actual data packets sent through the IPsec tunnel. These algorithms include the encryption, encapsulation, authentication, and data integrity services that IPsec can apply.

c. You can also change the IPsec security association lifetime from the default of 3600 seconds. On R1 and R3, set the IPsec security association lifetime to 30 minutes, or 1800 seconds.

```
R1(config)# crypto ipsec security-association lifetime seconds 1800

R3(config)# crypto ipsec security-association lifetime seconds 1800
```

Step 4: On R1 and R3, define interesting traffic.

It is necessary to define interesting traffic that will tell the router to enable an IPsec VPN with the other VPN peer. Do this by using an extended access list to tell the router which traffic to encrypt. A packet that is permitted by an access list used for defining IPsec traffic is encrypted if the IPsec session is configured correctly. A packet that is denied by one of these access lists is not dropped but is instead forwarded to its destination unencrypted. Also, like any other access list, there is an implicit deny at the end, which means the default action is to not encrypt traffic. If there is no IPsec security association correctly configured, no traffic is encrypted and traffic is forwarded unencrypted.

In this scenario, from the perspective of R1, the traffic you want to encrypt is traffic going from the R1 LANs to the R3 Ethernet LANs or vice versa from the perspective of R3. These access lists are used outbound on the VPN endpoint interfaces and must mirror each other.

a. On R1, identify interesting IPsec VPN traffic using a named extended ACL called **S2S-VPN-ACL**.

```
R1(config)# ip access-list extended S2S-VPN-ACL
R1(config-ext-nacl)# remark ACL identifies interesting traffic going to R3
R1(config-ext-nacl)# permit ip 10.10.0.0 0.0.3.255 10.10.4.0 0.0.3.255
R1(config-ext-nacl)# permit ip 10.10.0.0 0.0.3.255 10.10.16.0 0.0.7.255
R1(config-ext-nacl)# exit
```

The ACL identifies traffic from the R1 networks going to the R3 networks as interesting.

b. Configure the IPsec VPN interesting traffic named extended ACL on R1.

```
R3(config)# ip access extended S2S-VPN-ACL
R3(config-ext-nacl)# remark ACL identifies interesting traffic going to R1
R3(config-ext-nacl)# permit ip 10.10.4.0 0.0.3.255 10.10.0.0 0.0.3.255
R3(config-ext-nacl)# permit ip 10.10.16.0 0.0.7.255 10.10.0.0 0.0.3.255
R3(config-ext-nacl)# exit
```

The ACL identifies traffic from the R3 networks going to the R1 networks as interesting.

Does IPsec evaluate whether the access lists are mirrored as a requirement to negotiate its security association?

Yes. IPsec does evaluate whether access lists are mirrored. IPsec does not form a security association if the peers do not have mirrored access lists to select interesting traffic.

Step 5: On R1 and R3, create and apply a crypto map.

A crypto map associates traffic that matches an access list to a peer and various IKE and IPsec settings. After the crypto map is created, it can be applied to one or more interfaces. The interfaces that it is applied to should be the ones facing the IPsec peer.

To create a crypto map, use **crypto map** *name sequence-number type* command in global configuration mode to enter crypto map configuration mode for that sequence number. Multiple crypto map statements can belong to the same crypto map and are evaluated in ascending numerical order.

a. Create the crypto map on R1, name it **S2S-CMAP**, use **10** as the sequence number, and set the type as **ipsec-isakmp**, which means IKE is used to establish IPsec security associations.

```
R1(config)# crypto map S2S-CMAP 10 ipsec-isakmp
% NOTE: This new crypto map will remain disabled until a peer
        and a valid access list have been configured.
```

Notice that a message is displayed after the command is issued.

b. Use the **match address** ACL command to specify which access list defines which traffic to encrypt.

```
R1(config-crypto-map)# match address S2S-VPN-ACL
```

c. To view the list of possible **set** commands that you can do with a crypto map, use the help function.

```
R1(config-crypto-map)# set ?
  identity              Identity restriction.
  ikev2-profile         Specify ikev2 Profile
  ip                    Interface Internet Protocol config commands
  isakmp-profile        Specify isakmp Profile
  nat                   Set NAT translation
  peer                  Allowed Encryption/Decryption peer.
  pfs                   Specify pfs settings
  reverse-route         Reverse Route Injection.
  security-association  Security association parameters
  transform-set         Specify list of transform sets in priority order
```

d. Setting a peer IP or hostname is required. Set it to R3's remote VPN endpoint interface using the following command:

```
R1(config-crypto-map)# set peer 64.100.1.2
```

e. Use the **set transform-set** *name* command to hard code the transform set to be used with this peer. Set the perfect forwarding secrecy type using the **set pfs** *type* command, and modify the default IPsec security association lifetime with the **set security-association lifetime seconds** *seconds* command.

```
R1(config-crypto-map)# set pfs group14
R1(config-crypto-map)# set transform S2S-VPN
R1(config-crypto-map)# set security-association lifetime seconds 900
R1(config-crypto-map)# exit
```

f. Create a mirrored matching crypto map on R3.

```
R3(config)# crypto map S2S-CMAP 10 ipsec-isakmp
% NOTE: This new crypto map will remain disabled until a peer
        and a valid access list have been configured.
R3(config-crypto-map)# match address S2S-VPN-ACL
R3(config-crypto-map)# set peer 64.100.0.2
```

```
R3(config-crypto-map)# set pfs group14
R3(config-crypto-map)# set transform S2S-VPN
R3(config-crypto-map)# set security-association lifetime seconds 900
R3(config-crypto-map)# exit
```

g. Apply the crypto map to interfaces.

Note: The SAs are not established until the crypto map has been activated by interesting traffic. The router generates a notification that crypto is now on.

Apply the crypto maps to the appropriate interfaces on R1 and R3.

```
R1(config)# interface g0/0/0
R1(config-if)# crypto map S2S-CMAP
R1(config-if)# end
*Jan 29 15:45:20.117: %CRYPTO-6-ISAKMP_ON_OFF: ISAKMP is ON

R3(config)# interface g0/0/0
R3(config-if)# crypto map S2S-CMAP
R3(config-if)# end
*Jan 29 15:43:29.524: %CRYPTO-6-ISAKMP_ON_OFF: ISAKMP is ON
```

Part 3: Verify a Site-to-Site VPN Between R1 and R3

After a VPN is configured, it must be tested to see if it performs as expected.

Step 1: Verify the Site-to-Site IPsec VPN Configuration.

Previously, you used the **show crypto isakmp policy** command to display the configured ISAKMP policies on the router.

a. Use the **show crypto ipsec transform-set** [*transform-set-name*] command to display the configured IPsec policies in the form of the transform sets.

```
R1# show crypto ipsec transform-set S2S-VPN
{ esp-256-aes esp-sha256-hmac  }
   will negotiate = { Tunnel,  },
```

The S2S-VPN transform set settings are highlighted in the output.

b. On R1 and R3, use the **show crypto map** command to display the crypto maps applied to the router.

```
R1# show crypto map
Crypto Map IPv4 "S2S-CMAP" 10 ipsec-isakmp
        Peer = 64.100.1.2
        Extended IP access list S2S-VPN-ACL
            access-list S2S-VPN-ACL permit ip 10.10.0.0 0.0.3.255 10.10.4.0 0.0.3.255
            access-list S2S-VPN-ACL permit ip 10.10.0.0 0.0.3.255 10.10.16.0 0.0.7.255
        Current peer: 64.100.1.2
        Security association lifetime: 4608000 kilobytes/900 seconds
        Responder-Only (Y/N): N
        PFS (Y/N): Y
        DH group:  group14
        Mixed-mode : Disabled
        Transform sets={
                S2S-VPN:  { esp-256-aes esp-sha256-hmac  } ,
```

```
        }
        Interfaces using crypto map S2S-CMAP:
                GigabitEthernet0/0/0

R3# show crypto map
Crypto Map IPv4 "S2S-CMAP" 10 ipsec-isakmp
        Peer = 64.100.0.2
        Extended IP access list S2S-VPN-ACL
            access-list S2S-VPN-ACL permit ip 10.10.4.0 0.0.3.255 10.10.0.0 0.0.3.255
            access-list S2S-VPN-ACL permit ip 10.10.16.0 0.0.7.255 10.10.0.0 0.0.3.255
        Current peer: 64.100.0.2
        Security association lifetime: 4608000 kilobytes/900 seconds
        Responder-Only (Y/N): N
        PFS (Y/N): Y
        DH group:  group14
        Mixed-mode : Disabled
        Transform sets={
                S2S-VPN:  { esp-256-aes esp-sha256-hmac  } ,
        }
        Interfaces using crypto map S2S-CMAP:
                GigabitEthernet0/0/0
```

Note: The output of these **show** commands does not change when the VPN tunnel is enabled.

Step 2: Display ISAKMP and IPsec security associations.

a. The **show crypto isakmp as** command reveals that no IKE SAs exist yet. When interesting traffic is sent, this command output will change.

```
R1# show crypto isakmp sa
IPv4 Crypto ISAKMP SA
dst             src             state          conn-id status

IPv6 Crypto ISAKMP SA
```

b. The **show crypto ipsec sa** command displays packet statistics information for each of the ACE statements in the VPN ACL. The first portion of the output displays the packet statistics for traffic from the R1 10.10.0.0/22 networks to the R3 10.10.4.0/22 networks. The bottom portion displays the statistics for traffic from the R1 10.10.0.0/22 networks to the R3 10.10.16.0/21 networks.

```
R1# show crypto ipsec sa

interface: GigabitEthernet0/0/0
    Crypto map tag: S2S-CMAP, local addr 64.100.0.2

   protected vrf: (none)
   local  ident (addr/mask/prot/port): (10.10.0.0/255.255.252.0/0/0)
   remote ident (addr/mask/prot/port): (10.10.4.0/255.255.252.0/0/0)
   current_peer 64.100.1.2 port 500
     PERMIT, flags={origin_is_acl,}
    #pkts encaps: 0, #pkts encrypt: 0, #pkts digest: 0
    #pkts decaps: 0, #pkts decrypt: 0, #pkts verify: 0
    #pkts compressed: 0, #pkts decompressed: 0
```

```
      #pkts not compressed: 0, #pkts compr. failed: 0
      #pkts not decompressed: 0, #pkts decompress failed: 0
      #send errors 0, #recv errors 0

       local crypto endpt.: 64.100.0.2, remote crypto endpt.: 64.100.1.2
       plaintext mtu 1438, path mtu 1500, ip mtu 1500, ip mtu idb GigabitEthernet0/0/0
       current outbound spi: 0x0(0)
       PFS (Y/N): N, DH group: none

       inbound esp sas:

       inbound ah sas:

       inbound pcp sas:

       outbound esp sas:

       outbound ah sas:

       outbound pcp sas:

    protected vrf: (none)
    local  ident (addr/mask/prot/port): (10.10.0.0/255.255.252.0/0/0)
    remote ident (addr/mask/prot/port): (10.10.16.0/255.255.248.0/0/0)
    current_peer 64.100.1.2 port 500
      PERMIT, flags={origin_is_acl,}
     #pkts encaps: 0, #pkts encrypt: 0, #pkts digest: 0
     #pkts decaps: 0, #pkts decrypt: 0, #pkts verify: 0
     #pkts compressed: 0, #pkts decompressed: 0
     #pkts not compressed: 0, #pkts compr. failed: 0
     #pkts not decompressed: 0, #pkts decompress failed: 0
     #send errors 0, #recv errors 0

      local crypto endpt.: 64.100.0.2, remote crypto endpt.: 64.100.1.2
<Output omitted>
```

Note: The output lists the current status for each ACE in the S2S-VPN-ACL.

Why haven't any SAs been negotiated?

IPsec has not begun to negotiate a SA over which it will encrypt traffic because no interesting traffic has been identified.

c. Next, we will generate some "uninteresting" test traffic and observe the results. From R1, **ping** the R3 G0/0/0 interface IP address (i.e., 64.100.1.2) and then ping the R3 G0/0/1 interface IP address (i.e., 10.10.4.1). These pings should be successful.

d. Issue the **show crypto isakmp sa** command again.

   Was an SA created for these pings? Explain.

No, there are no SAs created. The S2S-VPN-ACL associated with the crypto map for R1 defines interesting traffic as IP packets from R1 LANs to the R3 LANs. The main reason why the SA were not created is because the source of both pings was the R1 G0/0/0 address of 64.100.0.2 which does not match the VPN ACL. Therefore, these pings were not "interesting" traffic.

Step 3: Generate some interesting test traffic and observe the results.

A VPN is initiated when interesting traffic is generated. Typically, inside users connecting to the remote network can initiate a VPN connection.

a. From PC1, **ping** PC3 to generate interesting traffic.

```
PC1> ping 10.10.5.10

Pinging 10.10.5.10 with 32 bytes of data:
Request timed out.
Reply from 10.10.5.10: bytes=32 time=1ms TTL=64
Reply from 10.10.5.10: bytes=32 time=1ms TTL=64
Reply from 10.10.5.10: bytes=32 time=1ms TTL=64

Ping statistics for 10.10.5.10:
    Packets: Sent = 4, Received = 3, Lost = 1 (25% loss),
Approximate round trip times in milli-seconds:
    Minimum = 1ms, Maximum = 1ms, Average = 1ms
```

Notice how the first ping reply timed out. The reason is because, the first echo request triggered the S2S-VPN-ACL which made R1 negotiate and establish the IPsec VPN tunnel with R3.

b. An alternate method to initiate interesting traffic would be to use an extended ping on R1. An extended ping allows you to control the source address of the packets.

```
R1# ping 10.10.16.1 source g0/0/1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.10.16.1, timeout is 2 seconds:
Packet sent with a source address of 10.10.0.1
.!!!!
Success rate is 80 percent (4/5), round-trip min/avg/max = 2/3/4 ms
```

Like the previous ping, the first echo reply timed out. The reason was to establish an SA for the 10.10.16.0/23 networks.

c. Re-issue the **show crypto isakmp sa** command.

```
R1# show crypto isakmp sa
IPv4 Crypto ISAKMP SA
dst             src             state          conn-id status
64.100.1.2      64.100.0.2      QM_IDLE           1001 ACTIVE

IPv6 Crypto ISAKMP SA
```

The SA displays that the tunnel is active.

Why was an SA created between R1 and R3 this time?

The source of the pings was from the R1 networks to the R3 network. This is interesting traffic based on the ACL S2S-VPN-ACL statements. An SA is established and packets travel through the tunnel as encrypted traffic.

c. Verify the IPsec traffic statistics using the **show crypto ipsec sa** command.

How many packets have been transformed between R1 and R3?

Answers may vary. Seven: Three of the five packets from the R1 to R3 pings, four packets from the PC-A to R3 pings, and one packet for each echo request. The number of packets may vary depending on how many pings have been issued and from where.

```
R1# show crypto ipsec sa
interface: GigabitEthernet0/0/0
    Crypto map tag: S2S-CMAP, local addr 64.100.0.2

   protected vrf: (none)
   local  ident (addr/mask/prot/port): (10.10.0.0/255.255.252.0/0/0)
   remote ident (addr/mask/prot/port): (10.10.4.0/255.255.252.0/0/0)
   current_peer 64.100.1.2 port 500
     PERMIT, flags={origin_is_acl,}
    #pkts encaps: 3, #pkts encrypt: 3, #pkts digest: 3
    #pkts decaps: 3, #pkts decrypt: 3, #pkts verify: 3
    #pkts compressed: 0, #pkts decompressed: 0
    #pkts not compressed: 0, #pkts compr. failed: 0
    #pkts not decompressed: 0, #pkts decompress failed: 0
    #send errors 0, #recv errors 0

     local crypto endpt.: 64.100.0.2, remote crypto endpt.: 64.100.1.2
     plaintext mtu 1438, path mtu 1500, ip mtu 1500, ip mtu idb GigabitEthernet0/0/0
     current outbound spi: 0xD225EBA7(3525700519)
     PFS (Y/N): Y, DH group: group14

     inbound esp sas:
      spi: 0xB2682427(2993169447)
        transform: esp-256-aes esp-sha256-hmac ,
        in use settings ={Tunnel, }
        conn id: 2007, flow_id: ESG:7, sibling_flags FFFFFFFF80004048, crypto map:
S2S-CMAP
        sa timing: remaining key lifetime (k/sec): (4608000/590)
        IV size: 16 bytes
        replay detection support: Y
        Status: ACTIVE(ACTIVE)

     inbound ah sas:

     inbound pcp sas:

     outbound esp sas:
      spi: 0xD225EBA7(3525700519)
```

```
        transform: esp-256-aes esp-sha256-hmac ,
        in use settings ={Tunnel, }
        conn id: 2008, flow_id: ESG:8, sibling_flags FFFFFFFF80004048, crypto map:
S2S-CMAP
        sa timing: remaining key lifetime (k/sec): (4608000/590)
        IV size: 16 bytes
        replay detection support: Y
        Status: ACTIVE(ACTIVE)

     outbound ah sas:

     outbound pcp sas:

   protected vrf: (none)
   local  ident (addr/mask/prot/port): (10.10.0.0/255.255.252.0/0/0)
   remote ident (addr/mask/prot/port): (10.10.16.0/255.255.248.0/0/0)
   current_peer 64.100.1.2 port 500
     PERMIT, flags={origin_is_acl,}
    #pkts encaps: 4, #pkts encrypt: 4, #pkts digest: 4
    #pkts decaps: 4, #pkts decrypt: 4, #pkts verify: 4
    #pkts compressed: 0, #pkts decompressed: 0
    #pkts not compressed: 0, #pkts compr. failed: 0
    #pkts not decompressed: 0, #pkts decompress failed: 0
    #send errors 0, #recv errors 0
<Output omitted>
```

d. The previous example used pings to generate interesting traffic.

What other types of traffic would result in an SA forming and tunnel establishment?

Any traffic (e.g., FTP, HTTP, Telnet, and others) initiated from an R1 network with a destination address to the R3 networks would be interesting traffic.

Are routing protocols able to traverse an IPsec site-to-site VPN?

Not by default. GRE would need to be configured with IPsec to support routing protocols between sites.

Router Interface Summary Table

Router Model	Ethernet Interface #1	Ethernet Interface #2	Serial Interface #1	Serial Interface #2
1800	Fast Ethernet 0/0 (F0/0)	Fast Ethernet 0/1 (F0/1)	Serial 0/0/0 (S0/0/0)	Serial 0/0/1 (S0/0/1)
1900	Gigabit Ethernet 0/0 (G0/0)	Gigabit Ethernet 0/1 (G0/1)	Serial 0/0/0 (S0/0/0)	Serial 0/0/1 (S0/0/1)
2801	Fast Ethernet 0/0 (F0/0)	Fast Ethernet 0/1 (F0/1)	Serial 0/1/0 (S0/1/0)	Serial 0/1/1 (S0/1/1)

Router Model	Ethernet Interface #1	Ethernet Interface #2	Serial Interface #1	Serial Interface #2
2811	Fast Ethernet 0/0 (F0/0)	Fast Ethernet 0/1 (F0/1)	Serial 0/0/0 (S0/0/0)	Serial 0/0/1 (S0/0/1)
2900	Gigabit Ethernet 0/0 (G0/0)	Gigabit Ethernet 0/1 (G0/1)	Serial 0/0/0 (S0/0/0)	Serial 0/0/1 (S0/0/1)
4221	Gigabit Ethernet 0/0/0 (G0/0/0)	Gigabit Ethernet 0/0/1 (G0/0/1)	Serial 0/1/0 (S0/1/0)	Serial 0/1/1 (S0/1/1)
4300	Gigabit Ethernet 0/0/0 (G0/0/0)	Gigabit Ethernet 0/0/1 (G0/0/1)	Serial 0/1/0 (S0/1/0)	Serial 0/1/1 (S0/1/1)

Note: To find out how the router is configured, look at the interfaces to identify the type of router and how many interfaces the router has. There is no way to effectively list all the combinations of configurations for each router class. This table includes identifiers for the possible combinations of Ethernet and Serial interfaces in the device. The table does not include any other type of interface, even though a specific router may contain one. An example of this might be an ISDN BRI interface. The string in parenthesis is the legal abbreviation that can be used in Cisco IOS commands to represent the interface.

Device Configs – Final

Router R1

```
R1# show running-config
Building configuration...

Current configuration : 2141 bytes
!
version 16.9
service timestamps debug datetime msec
service timestamps log datetime msec
platform qfp utilization monitor load 80
no platform punt-keepalive disable-kernel-core
!
hostname R1
!
boot-start-marker
boot-end-marker
!
no aaa new-model
!
no ip domain lookup
!
login on-success log
!
subscriber templating
!
multilink bundle-name authenticated
!
spanning-tree extend system-id
```

```
!
redundancy
 mode none
!
crypto isakmp policy 10
 encr aes 256
 hash sha256
 authentication pre-share
 group 14
 lifetime 3600
crypto isakmp key cisco123 address 64.100.1.2
!
crypto ipsec security-association lifetime seconds 1800
!
crypto ipsec transform-set S2S-VPN esp-aes 256 esp-sha256-hmac
 mode tunnel
!
crypto map S2S-CMAP 10 ipsec-isakmp
 set peer 64.100.1.2
 set security-association lifetime seconds 900
 set transform-set S2S-VPN
 set pfs group14
 match address S2S-VPN-ACL
!
interface GigabitEthernet0/0/0
 description Connection to R2
 ip address 64.100.0.2 255.255.255.252
 negotiation auto
 crypto map S2S-CMAP
!
interface GigabitEthernet0/0/1
 description Connection to D1
 ip address 10.10.0.1 255.255.255.252
 negotiation auto
!
interface Serial0/1/0
 no ip address
!
interface Serial0/1/1
 no ip address
!
router ospf 123
 router-id 1.1.1.1
 auto-cost reference-bandwidth 1000
 network 10.10.0.0 0.0.0.3 area 0
 default-information originate
!
ip forward-protocol nd
no ip http server
ip http secure-server
```

```
ip route 0.0.0.0 0.0.0.0 64.100.0.1
!
ip access-list extended S2S-VPN-ACL
 remark ACL identifies interesting traffic going to R3
 permit ip 10.10.0.0 0.0.3.255 10.10.4.0 0.0.3.255
 permit ip 10.10.0.0 0.0.3.255 10.10.16.0 0.0.7.255
!
control-plane
!
banner motd ^C This is R1, Implement IPsec Site-to-Site VPNs ^C
!
line con 0
 exec-timeout 0 0
 logging synchronous
 transport input none
 stopbits 1
line aux 0
 stopbits 1
line vty 0 4
 login
!
end
```

Router R2

```
R2# show running-config
Building configuration...

Current configuration : 1478 bytes
!
version 16.9
service timestamps debug datetime msec
service timestamps log datetime msec
platform qfp utilization monitor load 80
no platform punt-keepalive disable-kernel-core
!
hostname R2
!
boot-start-marker
boot-end-marker
!
no aaa new-model
!
no ip domain lookup
!
login on-success log
!
subscriber templating
!
multilink bundle-name authenticated
```

```
!
spanning-tree extend system-id
!
redundancy
 mode none
!
interface Loopback0
 description Internet simulated address
 ip address 209.165.200.225 255.255.255.224
!
interface GigabitEthernet0/0/0
 description Connection to R1
 ip address 64.100.0.1 255.255.255.252
 negotiation auto
!
interface GigabitEthernet0/0/1
 description Connection to R3
 ip address 64.100.1.1 255.255.255.252
 negotiation auto
!
ip forward-protocol nd
no ip http server
ip http secure-server
ip route 0.0.0.0 0.0.0.0 Loopback0
ip route 10.10.0.0 255.255.252.0 64.100.0.2
ip route 10.10.4.0 255.255.252.0 64.100.1.2
ip route 10.10.16.0 255.255.248.0 64.100.1.2
!
control-plane
!
banner motd ^C This is R2, Implement IPsec Site-to-Site VPNs ^C
!
line con 0
 exec-timeout 0 0
 logging synchronous
 transport input none
 stopbits 1
line aux 0
 stopbits 1
line vty 0 4
 login
!
end
```

Router R3

```
R3# show running-config
Current configuration : 2141 bytes
!
version 16.9
```

```
service timestamps debug datetime msec
service timestamps log datetime msec
platform qfp utilization monitor load 80
no platform punt-keepalive disable-kernel-core
!
hostname R3
!
boot-start-marker
boot-end-marker
!
no aaa new-model
!
no ip domain lookup
!
login on-success log
!
subscriber templating
!
multilink bundle-name authenticated
!
spanning-tree extend system-id
!
redundancy
 mode none
!
crypto isakmp policy 10
 encr aes 256
 hash sha256
 authentication pre-share
 group 14
 lifetime 3600
crypto isakmp key cisco123 address 64.100.0.2
!
crypto ipsec security-association lifetime seconds 1800
!
crypto ipsec transform-set S2S-VPN esp-aes 256 esp-sha256-hmac
 mode tunnel
!
crypto map S2S-CMAP 10 ipsec-isakmp
 set peer 64.100.0.2
 set security-association lifetime seconds 900
 set transform-set S2S-VPN
 set pfs group14
 match address S2S-VPN-ACL
!
interface GigabitEthernet0/0/0
 description Connection to R2
 ip address 64.100.1.2 255.255.255.252
 negotiation auto
 crypto map S2S-CMAP
```

```
!
interface GigabitEthernet0/0/1
 description Connection to D3
 ip address 10.10.4.1 255.255.255.252
 negotiation auto
!
interface Serial0/1/0
 no ip address
!
interface Serial0/1/1
 no ip address
!
router ospf 123
 router-id 3.3.3.1
 auto-cost reference-bandwidth 1000
 network 10.10.4.0 0.0.0.3 area 0
 default-information originate
!
ip forward-protocol nd
no ip http server
ip http secure-server
ip route 0.0.0.0 0.0.0.0 64.100.1.1
!
ip access-list extended S2S-VPN-ACL
 remark ACL identifies interesting traffic going to R1
 permit ip 10.10.4.0 0.0.3.255 10.10.0.0 0.0.3.255
 permit ip 10.10.16.0 0.0.7.255 10.10.0.0 0.0.3.255
!
control-plane
!
banner motd ^C This is R3, Implement IPsec Site-to-Site VPNs ^C
!
line con 0
 exec-timeout 0 0
 logging synchronous
 transport input none
 stopbits 1
line aux 0
 stopbits 1
line vty 0 4
 login
!
end
```

Layer 3 Switch D1

```
D1# show running-config
Building configuration...

Current configuration : 7031 bytes
```

```
!
version 16.9
no service pad
service timestamps debug datetime msec
service timestamps log datetime msec
! Call-home is enabled by Smart-Licensing.
service call-home
no platform punt-keepalive disable-kernel-core
!
hostname D1
!
vrf definition Mgmt-vrf
 !
 address-family ipv4
 exit-address-family
 !
 address-family ipv6
 exit-address-family
!
no aaa new-model
switch 1 provision ws-c3650-24ps
!
ip routing
!
no ip domain lookup
!
login on-success log
!
crypto pki trustpoint SLA-TrustPoint
 enrollment pkcs12
 revocation-check crl
!
license boot level ipservicesk9
!
diagnostic bootup level minimal
!
spanning-tree mode rapid-pvst
spanning-tree extend system-id
!
redundancy
 mode sso
!
transceiver type all
 monitoring
!
class-map match-any system-cpp-police-topology-control
  description Topology control
class-map match-any system-cpp-police-sw-forward
  description Sw forwarding, L2 LVX data, LOGGING
class-map match-any system-cpp-default
```

```
  description Inter FED, EWLC control, EWLC data
class-map match-any system-cpp-police-sys-data
  description Learning cache ovfl, High Rate App, Exception, EGR Exception,
NFLSAMPLED DATA, RPF Failed
class-map match-any system-cpp-police-punt-webauth
  description Punt Webauth
class-map match-any system-cpp-police-l2lvx-control
  description L2 LVX control packets
class-map match-any system-cpp-police-forus
  description Forus Address resolution and Forus traffic
class-map match-any system-cpp-police-multicast-end-station
  description MCAST END STATION
class-map match-any system-cpp-police-multicast
  description Transit Traffic and MCAST Data
class-map match-any system-cpp-police-l2-control
  description L2 control
class-map match-any system-cpp-police-dot1x-auth
  description DOT1X Auth
class-map match-any system-cpp-police-data
  description ICMP redirect, ICMP_GEN and BROADCAST
class-map match-any system-cpp-police-stackwise-virt-control
  description Stackwise Virtual
class-map match-any non-client-nrt-class
class-map match-any system-cpp-police-routing-control
  description Routing control and Low Latency
class-map match-any system-cpp-police-protocol-snooping
  description Protocol snooping
class-map match-any system-cpp-police-dhcp-snooping
  description DHCP snooping
class-map match-any system-cpp-police-system-critical
  description System Critical and Gold Pkt
!
policy-map system-cpp-policy
!
interface Loopback2
 description Loopback to simulate an OSPF network
 ip address 10.10.2.1 255.255.255.0
 ip ospf network point-to-point
!
interface Loopback3
 description Loopback to simulate an OSPF network
 ip address 10.10.3.1 255.255.255.0
 ip ospf network point-to-point
!
interface GigabitEthernet0/0
 vrf forwarding Mgmt-vrf
 no ip address
 negotiation auto
!
interface GigabitEthernet1/0/1
```

```
 shutdown
!
interface GigabitEthernet1/0/2
 shutdown
!
interface GigabitEthernet1/0/3
 shutdown
!
interface GigabitEthernet1/0/4
 shutdown
!
interface GigabitEthernet1/0/5
 shutdown
!
interface GigabitEthernet1/0/6
 shutdown
!
interface GigabitEthernet1/0/7
 shutdown
!
interface GigabitEthernet1/0/8
 shutdown
!
interface GigabitEthernet1/0/9
 shutdown
!
interface GigabitEthernet1/0/10
 shutdown
!
interface GigabitEthernet1/0/11
 description Connection to R1
 no switchport
 ip address 10.10.0.2 255.255.255.252
!
interface GigabitEthernet1/0/12
 shutdown
!
interface GigabitEthernet1/0/13
 shutdown
!
interface GigabitEthernet1/0/14
 shutdown
!
interface GigabitEthernet1/0/15
 shutdown
!
interface GigabitEthernet1/0/16
 shutdown
!
interface GigabitEthernet1/0/17
```

```
 shutdown
!
interface GigabitEthernet1/0/18
 shutdown
!
interface GigabitEthernet1/0/19
 shutdown
!
interface GigabitEthernet1/0/20
 shutdown
!
interface GigabitEthernet1/0/21
 shutdown
!
interface GigabitEthernet1/0/22
 shutdown
!
interface GigabitEthernet1/0/23
 description Connection to PC1
 no switchport
 ip address 10.10.1.1 255.255.255.0
!
interface GigabitEthernet1/0/24
 shutdown
!
interface GigabitEthernet1/1/1
!
interface GigabitEthernet1/1/2
!
interface GigabitEthernet1/1/3
!
interface GigabitEthernet1/1/4
!
interface Vlan1
 no ip address
!
router ospf 123
 router-id 1.1.1.2
 auto-cost reference-bandwidth 1000
 network 10.10.0.0 0.0.3.255 area 0
!
ip forward-protocol nd
ip http server
ip http secure-server
!
control-plane
 service-policy input system-cpp-policy
!
banner motd ^C This is D1, Implement IPsec Site-to-Site VPNs ^C
!
```

```
line con 0
 exec-timeout 0 0
 logging synchronous
 stopbits 1
line aux 0
 stopbits 1
line vty 0 4
 login
line vty 5 15
 login
!
end
```

Layer 3 Switch D3

```
D3# show running-config
Building configuration...

Current configuration : 7924 bytes
!
version 16.9
no service pad
service timestamps debug datetime msec
service timestamps log datetime msec
! Call-home is enabled by Smart-Licensing.
service call-home
no platform punt-keepalive disable-kernel-core
!
hostname D3
!
vrf definition Mgmt-vrf
 !
 address-family ipv4
 exit-address-family
 !
 address-family ipv6
 exit-address-family
!
no aaa new-model
switch 1 provision ws-c3650-24ps
!
ip routing
!
no ip domain lookup
!
login on-success log
!
license boot level ipservicesk9
!
diagnostic bootup level minimal
```

```
!
spanning-tree mode rapid-pvst
spanning-tree extend system-id
!
redundancy
 mode sso
!
transceiver type all
 monitoring
!
class-map match-any system-cpp-police-topology-control
  description Topology control
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  description Sw forwarding, L2 LVX data, LOGGING
class-map match-any system-cpp-default
  description Inter FED, EWLC control, EWLC data
class-map match-any system-cpp-police-sys-data
  description Learning cache ovfl, High Rate App, Exception, EGR Exception,
NFLSAMPLED DATA, RPF Failed
class-map match-any system-cpp-police-punt-webauth
  description Punt Webauth
class-map match-any system-cpp-police-l2lvx-control
  description L2 LVX control packets
class-map match-any system-cpp-police-forus
  description Forus Address resolution and Forus traffic
class-map match-any system-cpp-police-multicast-end-station
  description MCAST END STATION
class-map match-any system-cpp-police-multicast
  description Transit Traffic and MCAST Data
class-map match-any system-cpp-police-l2-control
  description L2 control
class-map match-any system-cpp-police-dot1x-auth
  description DOT1X Auth
class-map match-any system-cpp-police-data
  description ICMP redirect, ICMP_GEN and BROADCAST
class-map match-any system-cpp-police-stackwise-virt-control
  description Stackwise Virtual
class-map match-any non-client-nrt-class
class-map match-any system-cpp-police-routing-control
  description Routing control and Low Latency
class-map match-any system-cpp-police-protocol-snooping
  description Protocol snooping
class-map match-any system-cpp-police-dhcp-snooping
  description DHCP snooping
class-map match-any system-cpp-police-system-critical
  description System Critical and Gold Pkt
!
policy-map system-cpp-policy
!
interface Loopback16
```

```
 description Loopback to simulate an OSPF network
 ip address 10.10.16.1 255.255.255.0
 ip ospf network point-to-point
!
interface Loopback17
 description Loopback to simulate an OSPF network
 ip address 10.10.17.1 255.255.255.0
 ip ospf network point-to-point
!
interface Loopback18
 description Loopback to simulate an OSPF network
 ip address 10.10.18.1 255.255.255.0
 ip ospf network point-to-point
!
interface Loopback19
 description Loopback to simulate an OSPF network
 ip address 10.10.19.1 255.255.255.0
 ip ospf network point-to-point
!
interface Loopback20
 description Loopback to simulate an OSPF network
 ip address 10.10.20.1 255.255.255.0
 ip ospf network point-to-point
!
interface Loopback21
 description Loopback to simulate an OSPF network
 ip address 10.10.21.1 255.255.255.0
 ip ospf network point-to-point
!
interface Loopback22
 description Loopback to simulate an OSPF network
 ip address 10.10.22.1 255.255.255.0
 ip ospf network point-to-point
!
interface Loopback23
 description Loopback to simulate an OSPF network
 ip address 10.10.23.1 255.255.255.0
 ip ospf network point-to-point
!
interface GigabitEthernet0/0
 vrf forwarding Mgmt-vrf
 no ip address
 negotiation auto
!
interface GigabitEthernet1/0/1
 shutdown
!
interface GigabitEthernet1/0/2
 shutdown
!
```

```
interface GigabitEthernet1/0/3
 shutdown
!
interface GigabitEthernet1/0/4
 shutdown
!
interface GigabitEthernet1/0/5
 shutdown
!
interface GigabitEthernet1/0/6
 shutdown
!
interface GigabitEthernet1/0/7
 shutdown
!
interface GigabitEthernet1/0/8
 shutdown
!
interface GigabitEthernet1/0/9
 shutdown
!
interface GigabitEthernet1/0/10
 shutdown
!
interface GigabitEthernet1/0/11
 description Connection to R3
 no switchport
 ip address 10.10.4.2 255.255.255.252
!
interface GigabitEthernet1/0/12
 shutdown
!
interface GigabitEthernet1/0/13
 shutdown
!
interface GigabitEthernet1/0/14
 shutdown
!
interface GigabitEthernet1/0/15
 shutdown
!
interface GigabitEthernet1/0/16
 shutdown
!
interface GigabitEthernet1/0/17
 shutdown
!
interface GigabitEthernet1/0/18
 shutdown
!
```

```
interface GigabitEthernet1/0/19
 shutdown
!
interface GigabitEthernet1/0/20
 shutdown
!
interface GigabitEthernet1/0/21
 shutdown
!
interface GigabitEthernet1/0/22
 shutdown
!
interface GigabitEthernet1/0/23
 description Connection to PC3
 no switchport
 ip address 10.10.5.1 255.255.255.0
!
interface GigabitEthernet1/0/24
 shutdown
!
interface GigabitEthernet1/1/1
!
interface GigabitEthernet1/1/2
!
interface GigabitEthernet1/1/3
!
interface GigabitEthernet1/1/4
!
interface Vlan1
 no ip address
!
router ospf 123
 router-id 3.3.3.2
 auto-cost reference-bandwidth 1000
 network 10.10.4.0 0.0.1.255 area 0
 network 10.10.16.0 0.0.7.255 area 0
!
ip forward-protocol nd
ip http server
ip http secure-server
!
control-plane
 service-policy input system-cpp-policy
!
banner motd ^C This is D3, Implement IPsec Site-to-Site VPNs ^C
!
line con 0
 exec-timeout 0 0
 logging synchronous
 stopbits 1
```

```
line aux 0
 stopbits 1
line vty 0 4
 login
line vty 5 15
 login
!
end
```