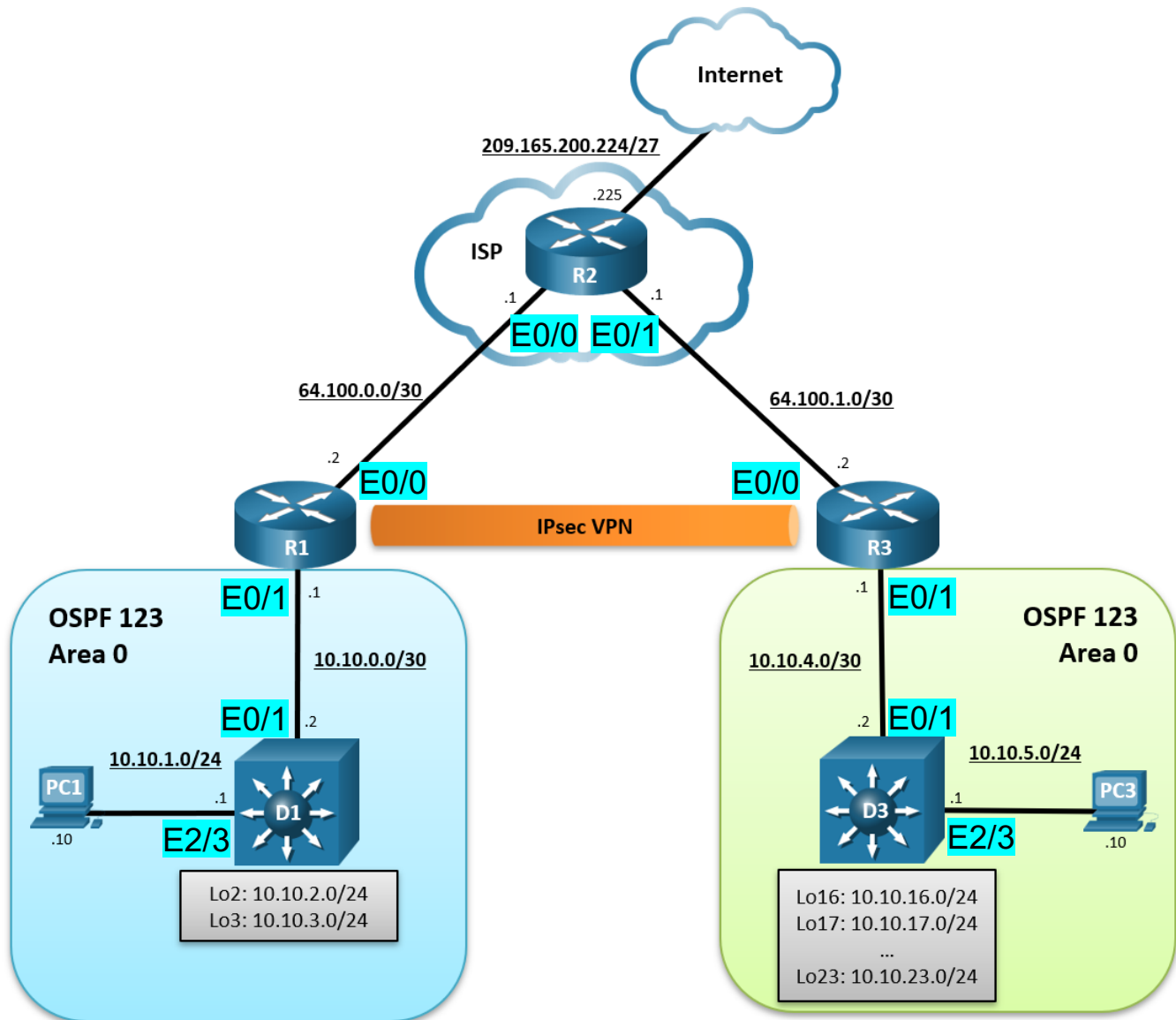


Lab - Implement IPsec Site-to-Site VPNs

Topology



Addressing Table

Device	Interface	IPv4 Address	Default Gateway
R1	E0/0	64.100.0.2/30	N/A
	E0/1	10.10.0.1/29	
R2	E0/0	64.100.0.1/30	N/A

	E0/1	64.100.1.1/30	
	Lo0	209.165.200.225	
R3	E0/0	64.100.1.2/30	N/A
	E0/1	10.10.4.1/30	
D1	E0/1	10.10.0.2/29	N/A
	E2/3	10.10.1.1/24	
	Lo2	10.10.2.1/24	
	Lo3	10.10.3.1/24	
D3	E0/1	10.10.0.3/29	N/A
	E2/3	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.

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-timeout 0 0
exit
banner motd # This is R1, Implement IPsec Site-to-Site VPNs #
interface Ethernet0/0
  description Connection to R2
```

```
ip add 64.100.0.2 255.255.255.252
no shut
exit
interface Ethernet0/1
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 Ethernet0/0
description Connection to R1
ip add 64.100.0.1 255.255.255.252
no shut
exit
interface Ethernet0/1
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 Ethernet0/0
  description Connection to R2
  ip add 64.100.1.2 255.255.255.252
  no shut
  exit
interface Ethernet0/1
  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 Ethernet0/1
  description Connection to R1
  no switchport
  ip address 10.10.0.2 255.255.255.252
  no shut
  exit
interface Ethernet2/3
  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
```

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 Ethernet0/1
description Connection to R3
no switchport
ip address 10.10.4.2 255.255.255.252
no shut
exit
interface Ethernet2/3
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
```

- 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
```

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
```

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
```

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, Ethernet0/1
```

```
O      10.10.2.0/24 [110/2] via 10.10.0.2, 00:29:03, Ethernet0/1
```

```
O      10.10.3.0/24 [110/2] via 10.10.0.2, 00:29:03, Ethernet0/1
```

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 it 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:
- o Encryption: **aes 256**
 - o Hash: **sha256**
 - o Authentication method: **pre-share key**
 - o Diffie-Hellman group: **14**
 - o 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?

- 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?

- 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?

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 e0/0
R1(config-if)# crypto map S2S-CMAP
R1(config-if)# end
*Jan 29 15:45:20.117: %CRYPTO-6-ISA_KMP_ON_OFF: ISAKMP is ON

R3(config)# interface e0/0
R3(config-if)# crypto map S2S-CMAP
R3(config-if)# end
*Jan 29 15:43:29.524: %CRYPTO-6-ISA_KMP_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:
  Ethernet0/0

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:
  Ethernet0/0

```

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

Step 2: Display ISAKMP and IPsec security associations.

- The **show crypto isakmp sa** 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

```

- 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 Ethernet0/0/0
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?

- c. Next, we will generate some "uninteresting" test traffic and observe the results. From R1, **ping** the R3 E0/0 interface IP address (i.e., 64.100.1.2) and then ping the R3 E0/1 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.

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 e0/1
```

```
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?

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

How many packets have been transformed between R1 and R3?

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

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

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

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)
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.