The Notebook
of
CCNA

Huy Bui

THE PUBLISHER

Contents

0.1 List of Codes

Chapter 1

Introduction

1.1 Securing network

1.1.1 Terminologies

An attack vector is a path or other means by which an attacker can gain access to a server, host, or network. Attack vectors can originate from outside (external threat) or inside (internal threat) the corporate network. Internal threats have the potential to cause greater damage than external threats because employees have direct access to infrastructure devices as well as the knowledge of the corporate network.

White hat hackers perform *ethical* network penetration test to discover network vulnerabilities. **Grey hat hackers** do unethical things, but not for personal gain or to cause damage (e.g. disclose vulnerability publicly). **Black hat hackers** violate computer and network security for personal gain and malicious purposes. The following list displays modern hacking terms and a brief description of each.

Security Artichoke is the analogy used to describe what a hacker must do to launch an attack in a Borderless network. They remove certain *artichoke leafs*, and each *leaf* of the network may reveal some sensitive data. And leaf after leaf, it all leads the hacker to more data.

Cryptography is the study and practice of hiding information. It ensures three components of information security: Confidentiality, Integrity, and Availability.

A **Security Policy** is a formal statement of the rules by which people that are given access to the technology and information assets of an organization, must abide.

1.1.2 Network topology

SOHO network: Attackers may want to use someone's Internet connection for free or illegal activity, or view financial transactions. Home networks and SOHOs are typically protected using a consumer *grade router*, such as a *Linksys home wireless router*.

WAN network: Main site and Regional site are protected by an ASA (stateful firewall and VPN). Branch site is secured using hardened ISR and VPN connection to the main site. The SOHO and Mobile users connect to the main site using Cisco Anyconnect VPN client.

Data center network: Data center networks are interconnected to corporate sites using VPN and ASA devices along with *integrated data center switches*, such as a high-speed Nexus switches. Data center physical security can be divided into two areas: Outside perimeter security and Inside perimeter security.

Cloud and virtual network: This kind of network uses virtual machines (VM) to provide services to their clients. VMs are also prone to specific targeted attacks as shown in the following list. The **Cisco Secure Data Center** is a solution to secure Cloud and virtual network. The core components of this solution provide: Secure Segmentation, Threat Defense, and Visibility.

- **Hyperjacking:** An attacker could hijack a VM hypervisor and use it as a starting point to attack other devices.
- **Instant on activation:** A VM that has not been used for a long period of time can introduce security vulnerabilities when activated.
- **Antivirus storm:** Multiple VMs attempt to download antivirus file at the same time

Borderless Network: To accommodate the BYOD trend, Cisco developed the Borderless Network. To support this network, Cisco devices support Mobile Device Management (MDM) features. MDM features secure, monitor, and manage mobile devices, including corporate-owned devices and employee-owned devices.

1.2 Network threats

1.2.1 Malware

A **virus** is malicious code that is attached to executable files which are often legitimate programs. A virus is triggered by an event. When activated, the virus can infect all the files it has not yet infected, but does not automatically propagate itself to other systems. Viruses are *spread* by USB memory drives, CDs, DVDs, network shares, and email. Email viruses are now the most common type of virus.

A **Trojan horse** is malware that carries out malicious operations under the guise of a desired function. A Trojan horse comes with malicious code hidden inside of it. This malicious code exploits the *privileges* of the user that *runs* it. Trojans are often found attached to online games.

Worms run by themselves, replicate and then spread very quickly (self-propagation) to slow down networks. They does not require user participation. After a host is infected, the worm is able to over the network. Most worm attacks consist of three components:

- **Enabling vulnerability:** A worm installs itself using an exploit mechanism, such as an email attachment, an executable file, or a Trojan horse.
- **Propagation mechanism:** After gaining access to a device, the worm replicates itself and locates new targets.
- **Payload:** Any malicious code that results in some action is a payload. Most often this is used to create a backdoor to the infected host or create a DoS attack.

Note! Worms never really stop on the Internet. After they are released, they continue to propagate until all possible sources of infection are properly patched.

Some other examples of modern malware:

- Ransomware – deny access to the infected computer system, then demand a paid ransom for the restriction to be removed.
- Spyware – gather information about a user and send the information to another entity
- Adware – display annoying pop-up advertising pertinent to websites visited
- Scareware – include scam software which uses social engineering to shock or induce anxiety by creating the perception of a threat
- Phishing – attempt to convince people to divulge sensitive information, e.g. receiving an email from their bank asking users to divulge their account and PIN numbers.
- Rootkits – installed on a compromised system, then hide its intrusion and maintain privileged access to the hacker.

1.2.2 Common network attacks

The method used in this course classifies attacks in three major categories: Reconnaissance, Access, and DoS Attacks.

Reconnaissance attacks gather information about a network and scan for access. Some examples of reconnaissance attacks: information query, ping sweep[1], port scan, Vulnerability Scanners, Exploitation tools.

Access attacks exploit network vulnerabilities to gain access or control to sensitive information. There are five common types of access attacks: Password attack, Trust exploitation, Port redirection, Man-in-the-middle, Buffer overflow, IP spoofing, MAC spoofing, DHCP Spoofing.

- Password attack – a dictionary is used for repeated login attempts
- Trust exploitation – uses granted privileges to access unauthorized material
- Port redirection – uses a compromised internal host to pass traffic through a firewall
- Man-in-the-middle – an unauthorized device positioned between two legitimate devices in order to redirect or capture traffic
- Buffer overflow – too much data sent to a buffer memory

Denial-of-Service (DoS) attacks prevent users from accessing a system. They are popular and simple to conduct. There are two major sources of DoS attacks:

- *Maliciously Formatted Packets* is forwarded to a host and the receiver is unable to handle an unexpected condition, which leads to slow or crashed system.
- *Overwhelming Quantity of Traffic* causes the system to crash or become extremely slow.

A Distributed DoS Attack (DDoS) is similar in intent to a DoS attack, except that a DDoS attack increases in magnitude because it originates from multiple, coordinated sources. As an example, a DDoS attack could proceed as follows:

1. A hacker builds a network of infected machines. A network of infected hosts is called a *botnet*. The compromised computers are called *zombie computers*, and they are controlled by *handler systems*.
2. The zombie computers continue to scan and infect more targets to create more zombies.
3. When ready, the hacker instructs the handler systems to make the botnet of zombies carry out the DDoS attack.

1.3 Mitigating Threats

1.3.1 Mitigating common network attacks

Malware: The primary means of mitigating virus and Trojan horse attacks is antivirus software. Antivirus software are host-based product that prevents hosts from getting infected and spreading malicious code. However, they do not prevent viruses from entering the network.

Worms: They are more network-based than viruses. The response to a worm attack can be broken down into four phases:

1. **Containment:** limit the spread of worm infection
2. **Inoculation:** run parallel to or subsequent to the Containment phase; all uninfected systems are patched with the appropriate vendor patch.
3. **Quarantine:** identify the infected machines
4. **Treatment:** disinfect the infected systems

[1] a network scanning technique that indicates the live hosts in a range of IP addresses

Reconnaissance: *Encryption* is an effective solution for sniffer attacks. Using *IPS* and *firewall* can limit the impact of *port scanning*. *Ping sweeps* can be stopped if *ICMP* echo and echo-reply are turned off on edge routers.

Access attacks: The network should be designed using the principle of minimum trust. This means that systems should not use one another unnecessarily. Other options are valid network security access protections (encrypted or hashed authentication protocols) but do not relate to the principle of minimum trust.

DoS attacks: One of the first signs of a DoS attack is a large number of user complaints about unavailable resources. To minimize the number of attacks, a network utilization software and anti-spoofing technologies (port security, DHCP snooping, IP source guard, ARP inspection, and ACL) should be running at all times.

1.3.2 Cisco SecureX architecture

The Cisco SecureX architecture is designed to provide effective security for any user, using any device, from any location, and at any time. This architecture includes the five major components: Scanning Engines, Delivery Mechanisms, Security Intelligence Operations (SIO), Policy Management Consoles, and Next-Generation Endpoints. The most important component of SecureX is SIO, which detects and blocks malicious traffic.

The SecureX is a huge and complex computing model. Therefore, a **context-aware scanning element** is used to scale SecureX. It is a device that examines packets as well as external information to understand the full context of the situation. To be accurate, this context-aware device defines security policies based on five parameters: person ID, application, device type, location, and access time.

Security Intelligence Operations (SIO) is a Cloud-based service that connects global threat information, reputation-based services, and sophisticated analysis, to SecureX network security devices.

1.3.3 Cisco Network Foundation Protection Framework

The Cisco Network Foundation Protection (NFP) framework provides comprehensive guidelines for protecting the network infrastructure. NFP logically divides routers and switches into three functional areas: Control plane, Management plane, and Data plane.

- **Control plane** is responsible for routing functions. Its security is implemented by Routing protocol authentication, CoPP, and AutoSecure. CoPP (Control Plane Policing) prevents unnecessary traffic from overwhelming the route processor. **AutoSecure** can lock down the management plane functions and the forwarding plane services and functions of a router.

- **Management plane** is responsible for network security and management. Its security is implemented by password policy, RBAC[2], authorization, access reporting.

- **Data plane** (Forwarding plane) is responsible for forwarding data. Its security can be implemented using *ACLs*, *antispoofing mechanisms*, and *Layer 2 security* features.

[2]Role-based access control restricts user access based on the role of the user. In Cisco IOS, the role-based CLI access feature implements RBAC for router management access.

Chapter 2

Securing the network infrastructure

2.1 Securing device access

2.1.1 Edge router

There are many approaches to secure the edge router:

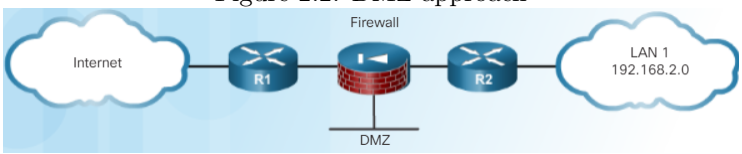
- **Single router approach:** a single router connects internal LAN to the Internet. All security policies are configured on this device. This is commonly deployed in small networks such as branch and small office, SOHO sites. The required security features can be supported by ISRs.
- **Defense-in-depth approach:** there are three primary layers of defense: the edge router, the firewall, and an internal router that connects to the protected LAN (Figure 2.1). By default, the firewall denies the initiation of connections from the outside (untrusted) networks.
- **DMZ approach:** A variation of the defense-in-depth approach is the DMZ approach (Figure 2.2). The firewall is set up to permit the required connections, such as HTTP, from the outside networks to the public servers in the DMZ. The firewall serves as the primary protection for all devices in the DMZ.

Three areas of router security must be maintained:

- **Physical security:** Place the router and physical devices that connect to it in a secure locked and dedicated room
- **Operating system security:** Configure the router with the maximum amount of memory possible, Use the latest, stable version of the operating system, Keep a secure copy of router operating system images and router configuration files
- **Router Hardening:** Secure administrative control, Disable unnecessary ports, interfaces and services

Figure 2.1: Defense-in-depth approach

Figure 2.2: DMZ approach



2.1.2 Administrative access

Type of management access: When logging and managing information, the information flow between management hosts and the managed devices can take two paths: In-band (SSH, SNMP, etc.) and Out-of-band (console port). Out-of-band management is appropriate for large enterprise networks, because it remains unaffected by the downed link. In-band management is recommended in smaller networks as a means of achieving a more cost-effective security deployment.

Strong password: To create a strong password, use a blank space in the password (only password-leading spaces are ignored) or create a phrase made of many words. This is called a *passphrase*. A passphrase is often easier to remember than a complex password and more difficult to guess.

Secret Password Algorithms: All passwords in Cisco IOS uses an MD5 hash by default. However, MD5 hashes are no longer considered secure. Therefore, it is now recommended that you configure all passwords using either type 8 `sha256` or type 9 `scrypt` passwords.

Listing 1: Secret password type 9

```
enable algorithm-type scrypt secret cisco12345
username Huy algorithm-type scrypt secret cisco12345
```

2.1.3 Virtual logins

The following Cisco IOS login enhancements commands increase the security of virtual login connections.

Listing 2: Login security commands

```
login block-for 15 attempts 5 within 60
login quite-mode access-class PERMIT-ADMIN
login delay 10
login on-access log
login on-failure log
```

The `login block-for` command can defend against DoS attacks by disabling logins for 60 seconds if more than 5 login failures occur in 15 seconds or less. Specifically, this command operates in two modes: **Normal** mode and **Quite** mode. When quiet mode is enabled, all login attempts, including valid administrative access, are not permitted. However, this behavior can be overridden using the `login quiet-mode` command with an ACL that identifies the permitted hosts.

The `login delay` command specifies a number of seconds the user must wait between unsuccessful login attempts. The `login on-success` and `login on-failure` commands generate syslog messages for successful and unsuccessful login attempts. The `security auth failure rate` command can be configured to generate a log message when the login failure rate is exceeded.

Use the `show login` command to verify the login block-for command settings and current mode. The `show login failures` command displays additional information regarding the failed attempts, such as the IP address from which the failed login attempts originated.

These login enhancements do *not* apply to console connections. When dealing with console connections, it is assumed that only authorized personnel have physical access to the devices.

Note! These login enhancements can only be enabled if the local database is used for authentication for local and remote access. If the lines are configured for password authentication only, then the enhanced login features are not enabled.

2.1.4 Configuring SSH

There are four requirements the router must meet before configuring SSH:

- Runs a Cisco IOS release that supports SSH
- Uses a unique hostname
- Contains the correct domain name of the network
- Configured for local authentication or AAA services

The five steps needed to configure a Cisco router to support SSH with local authentication:

1. Configure the IP domain name of the network
2. Create RSA key to encrypt the SSH traffic (Once RSA keys are generated, SSH is automatically enabled)
3. Ensure that there is a valid local database username entry.
4. Enable vty inbound SSH sessions using the line vty commands
5. Verify SSH and display the generated keys

Listing 3: Configuring SSH

```
ip domain-name cisco.com

crypto key zeroize rsa
crypto key generate rsa general-keys modulus 1024

ip ssh version 2
username Huy algorithm-type scrypt secret cisco12345

line vty 0 4
  login local
  transport input ssh

ip ssh time-out 90
ip ssh authentication-retries 2

sh crypto key mypubkey rsa
sh ssh
```

If there are existing key pairs, it is recommended that they are removed using the `crypto key zeroize rsa` command. To verify the status of the client connections, use the `sh ssh` command. The default SSH timeouts and authentication parameters can be altered using `ip ssh time-out` and `ip ssh authentication-retries` commands.

2.2 Administrative roles

Cisco IOS software has two methods of providing infrastructure access: privilege level and role-based CLI. Both methods help determine who should be allowed to connect to the device and what that person should be able to do with it. Role-based CLI access provides more granularity and control.

2.2.1 Privilege levels

There are 16 privilege levels (0 – 15) that can be applied to user accounts. Levels 0, 1, and 15 have predefined settings. This leaves levels 2 through 14 available for custom levels of access. Below is the detailed settings of level 1 and 15:

- **Level 1:** User EXEC mode – The lowest user privileges and allows only user-level commands available at the `router>` prompt.
- **Level 15:** Privileged EXEC mode – the user has full access to view and change the configuration, including viewing the running the configuration.

The first command shown below configures privilege level 5, so that any level-5 user has access to all the commands available for the level 1 to 4 and the `ping` command. Remember that not all commands are available for privilege level 5. For example, level-5 users cannot reload the router. To enable access to the reload command, use the command `privilege exec level 5 reload` . The second command assigns a privilege level to a specific EXEC mode password. The last assigns privilege level `5` to user `SUPPORT`.

Listing 4: Privilege level configuration

```
privilege exec level 5 ping
enable algorithm-type scrypt secret level 5 cisco5
username SUPPORT privilege 5 algorithm-type scrypt secret cisco5
```

The use of privilege levels has its limitations:

- No access control to specific interfaces, ports, logical interfaces, and slots on a router.
- Commands available at lower privilege levels are always executable at higher levels.
- Commands specifically set at a higher privilege level are not available for lower privileged users.
- Assigning a command with multiple keywords allows access to all commands that use those keywords. For example, allowing access to show ip route allows the user access to all show and show ip commands.

2.2.2 Role-based CLI

Role-based CLI enhances the security of the device by defining the set of CLI commands accessible by a specific user. Users only see the CLI commands applicable to the ports and CLI to which they have access. Therefore, the router appears to be less complex, and commands are easier to identify when using the help feature on the device. Role-based CLI provides three types of views that dictate which commands are available:

- **Root view:** Only a root view user can configure a new view and add or remove commands from the existing views.
- **CLI view:** A specific set of commands can be bundled into a CLI view. A view does not inherit commands from any other view. Additionally, the same commands can be used in multiple views.
- **Superview:** A superview consists of one or more CLI views. Users who are logged into a superview can access all the commands that are configured for any of the CLI views that are part of the superview. Deleting a superview does not delete the associated CLI views, and those views remain available to be assigned to another superview.

Note! Commands cannot be configured for a superview. An administrator must add commands to the CLI view and add that CLI view to the superview.

Listing 5: CLI View configuration

```
aaa new-model
parser view SUPPORT
  secret cisco
  commands exec include show
end

enable view SUPPORT
```

In the above example, the `commands exec include` command assigns all `show` commands to the EXEC mode of the view. To access existing views, enter the `enable view view-name` command in user mode and enter the password that was assigned to the custom view. Use the question mark (?) command to verify that the commands available in the view are correct.

Note! AAA must be enabled before configuring any views.

Listing 6: Superview configuration

```
parser view JR-ADMIN superview
  secret cisco2
  view SHOWVIEW
  view VERIFYVIEW
  view REBOOTVIEW
end
```

You must be in root view to configure a superview. To confirm that root view is being used, use either the `enable view` or `enable view root` command. In the above example, more than one CLI view are assigned to the current superview using `view` command. To access the superview, use the `enable view` command followed by the name of the superview, and provide the password. Use the question mark (?) command to verify that the commands available in the view are correct.

From the root view, use the `show parser view all` command to see a summary of all views. Notice how the asterisk identifies superviews.

2.3 IOS image and Configuration files

2.3.1 Backup and restore

The **Cisco IOS resilient configuration** feature maintains a secure working copy of the router IOS image file and a copy of the running configuration file. These secure files cannot be removed by the user and are referred to as the primary bootset.

To secure the IOS image and enable Cisco IOS image resilience, use the `secure boot-image` command. Once enabled, this feature can only be disabled through a console session. This command functions properly only when the system is configured to run an image from a flash drive with an ATA interface. Additionally, the running image must be loaded from secured storage. Images that are loaded from a remote location, such as a TFTP server, cannot be secured.

To take a snapshot of the router running configuration and securely archive it in persistent storage, use the `secure boot-config` global configuration mode command.Use the `show secure bootset` command to verify the existence of the archive.

Restore a primary bootset from a secure archive after the router has been tampered with:

1. Reload the router using the reload command. If necessary, issue the break sequence to enter ROMmon mode.
2. From ROMmon mode, enter the dir command to list the contents of the device that contains the secure bootset file.
3. Boot the router with the secure bootset image using the boot command followed by the flash memory location (e.g. flash0), a colon, and the filename found in Step 2.
4. Enter global configuration mode and restore the secure configuration to a filename of your choice.
5. Exit global configuration mode and issue the copy command to copy the rescued configuration file to the running configuration.

Listing 7: Restore a primary bootset

```
Router# reload

rommon 1 > dir flash0:
rommon 2 > boot flash0:c1900-universalk9-mz.SPA.154-3.M2.bin

Router> enable
Router# conf t
Router(config)# secure boot-config restore flash0:rescue-cfg
Router(config)# end
Router# copy flash0:rescue-cfg running-config
```

2.3.2 Secure Copy Protocol(SCP)

The Cisco IOS Resilient feature provides a secure and authenticated method for copying router configuration or router image files to a remote location, that is **Secure Copy Protocol (SCP) feature**. SCP relies on SSH and requires that AAA authentication. The following commands configure the router for server-side SCP with local AAA:

Listing 8: Configure SCP with local AAA

```
ip domain-name cisco.com
crypto key generate rsa general-keys modulus 1024
username Huy algorithm-type scrypt secret cisco12345

aaa new-model
aaa authentication login default local
aaa authorization exec default local

ip scp server enable
```

With the above configuration, R1 is now an SCP server and will use SSH connections to accept secure copy transfers from authenticated and authorized users. For example, you want to transfer a backup file from R2 to R1. On R2, use the `copy flash0:R2backup.cfg scp:` command.

2.3.3 Password recovery

An attacker could gain control of that device through the password recovery procedure. An administrator can mitigate this potential security breach by using the `no service password-recovery` global configuration mode command. This command disables all access to ROMmon mode.

To recover a device with password-recovery disabled, initiate the break sequence within **5** seconds after the image decompresses during the boot. You are prompted to confirm the break key action. After the action is confirmed, the startup configuration is completely erased, the router boots with the factory default configuration, and therefore, the password recovery procedure is enabled. If you do not confirm the break action, the router boots normally with the no service password-recovery command enabled.

2.4 Syslog

2.4.1 Introduction

The syslog protocol allows networking devices to send their system messages across the network to syslog servers. The syslog server serves as an event message collector. Syslog messages are sent using **UDP** port **514**.

Syslog operations include gathering information, selecting which type of information to capture, and redirecting the captured information to a storage location. The logging service stores messages in a logging buffer that is time-limited, and cannot retain the information when a router is rebooted. Syslog does not authenticate or encrypt messages.

Syslog messages sent to an internal buffer (RAM) are only viewable through the CLI of the device (console line, terminal line). Alternatively, syslog messages can be sent to an external syslog server. To view syslog messages, a syslog server must be installed on a workstation. One advantage of viewing syslog messages on a syslog server is the ability to perform granular searches through the data. Also, a network administrator can quickly delete unimportant syslog messages from the database.

2.4.2 Severity level and Facility

Cisco devices produce syslog messages as a result of network events. Every syslog message contains a **severity level** and a **facility**. The security level can be shown as a number. The smaller the number, the more critical syslog alarms (Table 2.1).

Table 2.1: Syslog Severity level

Severity level	Name	Explanation
0	Emergency	A ”panic” condition, System unusable
1	Alert	Should be corrected immediately, e.g. loss of backup ISP connection
2	Critical	Critical condition
3	Error	Error condition, Non-urgent failures
4	Warning	NOT an error, but indication that an error will occur if action is not taken, e.g. file system 85% full
5	Notification	Normal but significant condition
6	Informational	Not affect functionality, harvested for reporting, measuring throughput,
7	Debugging	Debugging message

Level 0 – 4 are error messages. Level 5 notifies system messages such as interface up or down transitions and system restart messages. Level 6 generates messages , for example, when the device is booting. By default, Cisco routers and switches send log messages up to level 6 of severity (levels 0 through 6) to the console.

2.4.3 Message format

By default, the format of syslog messages on the Cisco IOS Software is as follows:

```
seq no: timestamp: %facility-severity-MNEMONIC: description
00:00:46: %LINK-3-UPDOWN: Interface Port-channel1, changed state to up
```

The fields contained in the syslog message above are explained in Table 2.2.

Table 2.2: Syslog message format

Field	Example	Explanation
`seq no`	–	Will be shown only if the service `sequence-numbers` is configured
`timestamp`	`00:00:46`	Date and time of the message, which appears only if the service `timestamps` is configured
`facility`	`LINK`	The facility to which the message refers
`severity`	`3`	A number from 0 to 7 that indicates the severity of the message
`MNEMONIC`	`UPDOWN`	Briefly and Uniquely describe the message
`description`	`Interface ...`	Report the event in detail

2.4.4 Configuration

By default, log messages do not include a timestamp. The `show logging` command displays the default logging service settings.

Listing 9: Logging service

```
service timestamps log datetime msec
logging 192.168.1.3
logging trap 4
logging source-interface g0/0
```

Above is an example showing logging service configuration. The first command enable timestamp to log messages. R1 is configured to send log messages of levels 4 and lower to the syslog server at 192.168.1.3. The source interface is set as the g0/0 interface.

2.5 SNMP

2.5.1 Introduction

Simple Network Management Protocol (SNMP) was developed to allow administrators to manage nodes such as servers, workstations, routers, switches, and security appliances, on an IP network. The SNMP system consists of three elements:

- **SNMP manager**: a part of a network management system (NMS), run SNMP management software.
- **SNMP agents** (managed node): responsible for providing access to the MIB which resides on each SNMP client device.
- **MIB** (Management Information Base): store data about the device and operational statistics

Table 2.3: SNMP requests

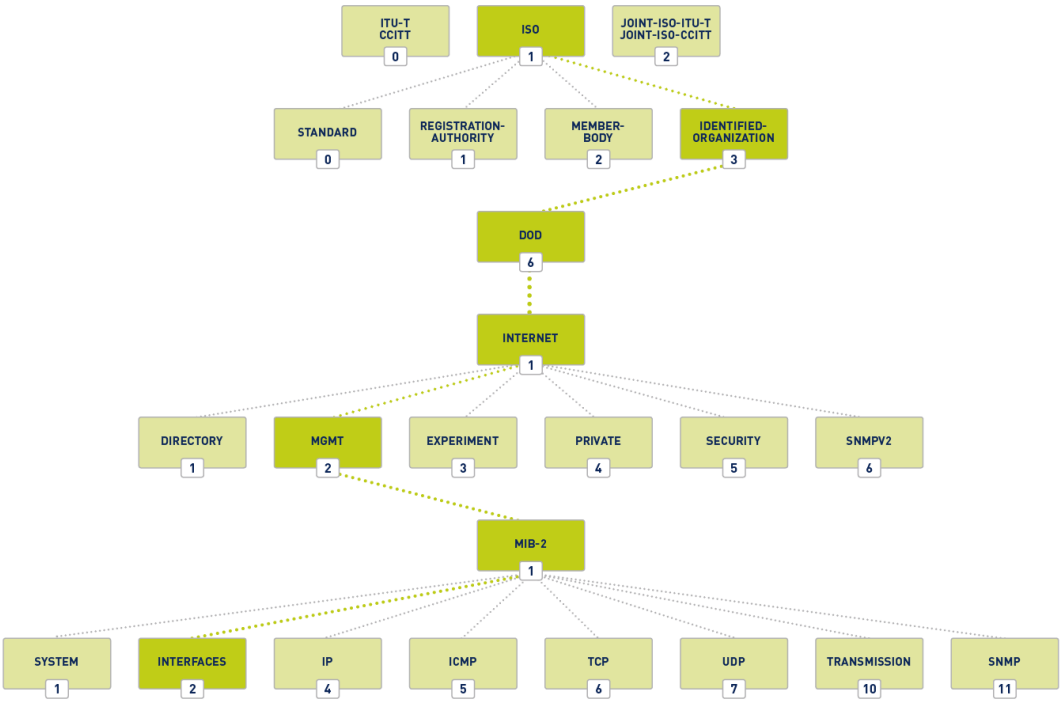
Operation	Description
`get-request`	Retrieves a value from a specific variable
`get-next-request`	Retrieves a value from a variable within a table
`get-bulk-request`	Retrieve large block of data such as multiple rows in a table
`get-response`	Replies to a `get-request`, `get-next-request`, and `set-request`
`set-request`	Stores a value in a specific variable

Polls vs Traps: An NMS periodically *polls* the SNMP agents, which provide information to monitor traffic loads and to verify device configurations. Disadvantages: A delay between the time that an event occurs and the time that it is noticed (via polling) by the NMS; A trade-off between polling frequency and bandwidth usage. SNMP *agent traps* are used to mitigate these disadvantages. SNMP agents send traps to inform the NMS immediately of certain events.

Community string: SNMPv1 and SNMPv2c use community strings as plaintext password to control access to the MIB. There are two types of community strings: Read-only (**ro**) and Read-write (**rw**).

Object ID: MIB saves data in variables and organizes them hierarchically. Formally, the MIB defines each variable as an Object ID (OID). OIDs uniquely identify managed objects in the MIB hierarchy (figure 2.3). For example, OIDs belonging to Cisco, are numbered as follows: .iso (1).org (3).dod (6).internet (1).private (4).enterprises (1).cisco (9). Therefore the OID is 1.3.6.1.4.1.9.

Figure 2.3: OID tree



SNMPv2 configuration

Listing 10: SNMPv2 configuration

```
snmp-server community batonaug ro SNMP_ACL

snmp-server enable traps
snmp-server host 192.168.1.3 version 2c batonaug

show snmp
```

The first command configures the community string, access level (read-only `ro` , read-write `rw`), and restrict SNMP access using ACL.The next two command enable traps and specify the recipient of the SNMP trap. By default, SNMP does not have any traps set. Without this command, SNMP managers must poll for all relevant information.

2.5.2 SNMPv3 configuration

SNMPv3 provides three security features: Message integrity and authentication, Encryption, Access control. The following commands show an example of basic SNMPv3 configuration:

Listing 11: SNMPv3 configuration

```
snmp-server view SNMP-RO iso included
snmp-server group ADMIN v3 priv read SNMP-RO access PERMIT-ADMIN
snmp-server user BOB ADMIN v3 auth sha cisco12345 priv aes 128 cisco54321
```

In the above example, the first command creates an SNMP view `SNMP-RO` and include the entire `iso` tree from the MIB. The next command creates an SNMP group `ADMIN` , the set to version 3 with authentication and encryption required. This command also gives read-only access to the view `SNMP-RO` to the group specified by the ACL called `PERMIT-ADMIN` .

2.6 NTP

2.6.1 System clock

The software clock on a router or switch starts when the system boots and is the primary source of time for the system. It is important to synchronize the time across all devices on the network because all aspects of managing, securing, troubleshooting, and planning networks require accurate time-stamping. Typically, the date and time settings on a router or switch can be set using one of two methods:

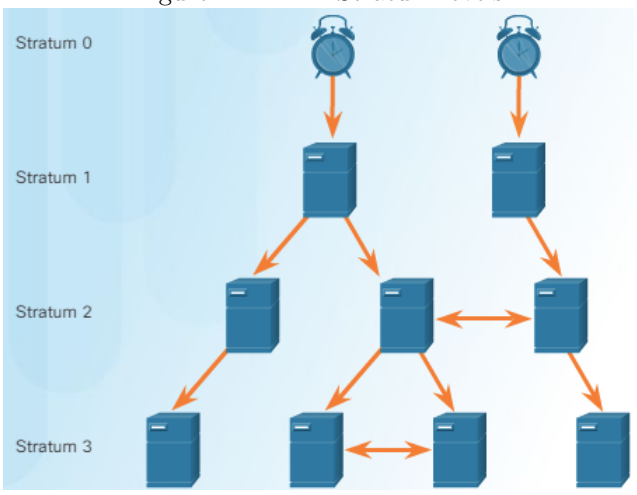
- Manually configure the date and time. For example, `clock set 20:36:00 aug 30 2016`
- Configure the NTP

2.6.2 Operation

NTP allows routers on the network to synchronize their time settings with an NTP server. It uses **UDP** port **123**.

NTP networks use a hierarchical system of time sources. Each level in this hierarchical system is called a **stratum**. The stratum level is defined as the number of hop counts from the authoritative time source (Figure 2.4). Smaller stratum numbers indicate that the server is closer to the authorized time source than larger stratum numbers. The max hop count is 15. Stratum 16, the lowest stratum level, indicates that a device is unsynchronized.

Figure 2.4: NTP Stratum levels



Stratum 0 is an NTP network that gets the time from authoritative time sources (represented by the clock in the figure 2.4). Stratum 1 are directly connected to the authoritative time sources. They act as the primary network time standard. The stratum 2 servers are connected to stratum 1 devices through network connections. Stratum 2 devices, such as NTP clients, synchronize their time using the NTP packets from stratum 1 servers. They can also act as servers for stratum 3 devices.

2.6.3 Configuration

The first command identifies NTP server. The second command periodically updates the hardware clock with the time learned from NTP. The following commands configure NTP authentication on R1 using key 1 and password NTPpa55. To verify the system clock, use `show clock` command. To see if the device is synchronized with the NTP server, use `sh ip ntp ass` and `sh ntp status` .

Listing 12: NTP authentication

```
ntp server 192.168.1.5
ntp update-calendar

ntp authenticate
ntp trusted-key 1
ntp authentication-key 1 md5 NTPpa55

sh ntp status
sh ip ntp ass
sh clock
```

2.7 Cisco AutoSecure

AutoSecure makes recommendations for fixing security vulnerabilities and then modifies the security configuration of the router. It can lock down the functions of data and management plane. During AutoSecure setup, the following steps occur:

1. The AutoSecure command is entered
2. The wizard gathers info about the outside interfaces
3. Disable unnecessary services

4. Prompt for a security banner
5. Prompt for passwords and login features
6. Secure interface
7. Secure data plane

Use the `auto secure` command to enable the Cisco AutoSecure feature setup. In interactive mode, the router prompts with options to enable and disable services and other security features. This is the *default* mode, but it can also be configured using the `auto secure full` command.

The non-interactive mode is configured with the `auto secure no-interact` command. This will automatically execute the Cisco AutoSecure feature with the recommended Cisco default settings.

When the AutoSecure command is initiated, a CLI wizard steps the administrator through the configuration of the device. User input is required. AutoSecure should be used when a router is initially being configured. It is not recommended on production routers.

2.8 Control plane security

2.8.1 Routing protocol authentication

Routing Protocol Authentications mitigate against attacks like redirection of traffic to an insecure link, and redirection of traffic to discard it. OSPF supports routing protocol authentication using either MD5 or SHA.

OSPF MD5 authentication

Listing 13: OSPF MD5 interface authentication

```
interface s0/0/0
  ip ospf message-digest-key 1 md5 cisco12345
  ip ospf authentication message-digest
```

Listing 14: OSPF MD5 area authentication

```
router ospf 100
  area 50 authentication message-digest

interface s0/0/0
  ip ospf message-digest-key 1 md5 cisco12345
end
```

Note! The interface setting overrides the global setting. OSPF adjacency is lost until MD5 authentication is matched between two routers.

OSPF SHA authentication

MD5 is now considered vulnerable to attacks. Therefore, the administrator should use SHA authentication. OSPF SHA authentication includes two major steps:

1. Specify an authentication key chain
2. Assign the authentication key to the desired interfaces

Listing 15: OSPF SHA authentication

```
key chain HUY
  key 1
  key-string cisco12345
  cryptographic-algorithm hmac-sha-256

interface s0/0/0
  ip ospf authentication key-chain HUY
```

2.8.2 Control plane policing

Routers must be able to distinguish between data plane, control plane, and management plane packets to treat each packet appropriately:

- **Data plane packets:** always have a transit destination IP address and can be handled by normal destination IP address-based forwarding processes.
- **Control plane packets:** used for routing protocol (OSPF, EIGRP, BGP, etc.); sent to the router or network device
- **Management plane packets:** used for management and reporting protocol (SSH, SNMP, NTP, etc.)

The vast majority of packets handled by network devices are data plane packets. They are handled by CEF. This forwarding method uses the control plane to pre-populate the FIB table. Subsequent packets that flow between same source and destination are forwarded by the data plane based on the information contained in the FIB.

Chapter 3

AAA model

3.1 Introduction

AAA network security services provide the primary framework to set up access control on a network device. AAA is a way to control who is permitted to access a network (authenticate), what they can do while they are there (authorize), and to audit what actions they performed while accessing the network (accounting).

Authentication: Cisco provides two common methods of implementing AAA authentication: Local AAA Authentication and Server-Based AAA Authentication. **Local AAA Authentication** uses a local database for authentication. This method stores usernames and passwords locally in the Cisco router. With **Server-Based AAA Authentication**, the central AAA server contains the usernames and password for all users.

Authorization is typically implemented using a AAA server-based solution. Authorization uses a created set of attributes that describes the user's access to the network. These attributes are compared to the information contained within the AAA database, and a determination of restrictions. Authorization is implemented immediately and automatically after the user is authenticated.

Accounting is implemented using a AAA server-based solution. This service reports usage statistics back to the ACS server.

3.2 Local AAA authentication

3.2.1 Configuration

Before enabling AAA, at least a local database entry must be configured. To enable AAA, the `aaa new-model` global configuration command must *first* be configured. No other AAA commands are available until this command is entered.

Create the default login authentication list by issuing the `authentication login default method1[method2][method3]` command. The following commands configure the list to first use RADIUS (`group radius`) for the authentication service, and then none. The keyword `none` means that if no RADIUS server can be reached and authentication cannot be performed, the router globally allows access without authentication. This is a safeguard measure in case the router starts up without connectivity to an active RADIUS server.

The `aaa authentication login default` command allows the HUY users to log into the router vty terminal lines. The `default` keyword means that the authentication method applies to all lines (vty, console, aux). However, if you want AAA authentication only applied to vty line, replace `default` by the name of the method list, for example `SSH-LOGIN` .

Listing 16: Default server-based AAA authentication

```
username HUY algorithm-type scrypt secret cisco12345

aaa new-model
aaa authentication login default group radius none

aaa local authentication attempts max-fail 3
```

Listing 17: Custom server-based AAA authentication

```
username HUY algorithm-type scrypt secret cisco12345

aaa new-model
aaa authentication login SSH-LOGIN group radius none

line vty 0 4
login authentication SSH-LOGIN

aaa local authentication attempts max-fail 3
```

Below is the syntax of `aaa authentication login` command. This command lists authentication methods (four methods at the maximum) in the order of execution. In other words, the next listed authentication method is executed only when there is no response or an error from the previous method occurs. The name of this list is specified by the user as `<list-name>` . Table 3.1 shows the command syntax and all available method type keywords.

Table 3.1: AAA login authentication methods

`aaa authentication login default | list-name method1 ... method4`	
Keywords	**Description**
`enable`	Use the enable password
`local`	Use local username database
`local-case`	Use case-sensitive local username database
`none`	Ensure that the authentication succeeds even if all methods return an error
`group radius`	Use the lists of all RADIUS servers
`group tacacs+`	Use the lists of all TACACS+ servers
`group <group-name>`	Use a subset of RADIUS or TACACS+ servers

The `aaa local authentication attempts max-fail` command locks the user account if the authentication fails. The locked out user account remains locked until it is manually cleared by an administrator using the `clear aaa local user lockout` privileged EXEC mode command. This command is different from `login delay` command, which introduces a delay between failed login attempts without locking the account.

To display a list of all locked-out users, use the `sh aaa local user lockout` command. To display the history of activities (attributes), use the `sh aaa user` command. This command does not provide information for all users who are logged into a device, but only for those who have been authenticated or authorized using AAA, or whose sessions are being accounted for by the AAA module. The `sh aaa sessions` command can be used to show the unique ID of a session. The `debug aaa authentication` command is instrumental when troubleshooting AAA

problems.

3.3 Server-based AAA authentication

3.3.1 RADIUS vs TACACS+

The Cisco Secure Access Control System (ACS) is a centralized solution that ties together an enterprise's network access policy and identity strategy. Cisco Secure ACS supports both TACACS+ and RADIUS protocols (Table 3.2).

Table 3.2: TACACS+ and RADIUS protocols

TACACS+	**RADIUS**
Separates authentication and authorization	Combines RADIUS authentication and authorization as one process.
Encrypts all communication	Encrypts only the password using MD5
TCP port 49	UDP port 1645 or 1812 for authentication, UDP port 1646 or 1813 for accounting
Multiprotocol support	Supports remote-access technologies, VoIP, 802.1X, and Session Initiation Protocol (SIP)

Note! A next-generation AAA protocol alternative to RADIUS is the DIAMETER AAA protocol.

Microsoft Active Directory (AD) is a directory service for Windows domain networks, and is part of most Windows Server operating systems. The AD domain controller is used to enforce security policies by authenticating and authorizing users when they log into the Windows domain. **Cisco Secure ACS** can be integrated to use the AD service. It supports both TACACS+ and RADIUS. Instead of Cisco Secure ACS, Windows Server can also be configured as a AAA server using RADIUS, known as **NPS (Network Policy Server)**.

3.3.2 Identity Services Engine (ISE)

Cisco Identity Services Engine (ISE) is an identity and access control policy platform that enables enterprises to enforce compliance (including *BYOD*), enhance infrastructure security, and streamline their service operations. The architecture of this engine allows administrator to gather real-time information to make proactive governance decisions by tying identity to various network elements. Cisco ISE combines policy definition, control, and reporting in *one* appliance.

Cisco ISE is the main policy component for **Cisco TrustSec**, which protects end devices from unauthorized access. There are four features in the ISE toolset: AAA, Device profiling, Posture assessment, and Guest assessment.

3.3.3 Configuration

There are three basic steps to configure server-based authentication:

1. Globally enable AAA
2. Specify the Cisco Secure ACS (TACACS+ or RADIUS server) and Configure the encryption key between the server and router.
3. Configure the AAA authentication method list to refer to the TACACS+ or RADIUS server. For redundancy, it is possible to configure more than one server.

The following commands show how to accomplish step 1 and 2:

Listing 18: Create a TACACS+ server

```
aaa new-models

tacacs server Server-T
  address ipv4 192.168.1.101
  single-connection
  key TACACS-Pa55w0rd
```

Listing 19: Create a RAIDUS server

```
aaa new-models

radius server Server-R
  address ipv4 192.168.1.101 auth-port 1812 acct-port 1813
  single-connection
  key RADIUS-Pa55w0rd
```

The `address ipv4` command allows the option to modify IPv4 address of the server, authentication port, and accounting port. The `key` command is used to configure the shared secret key, which must be exactly the same way on both the router and the server.

The `single-connection` command (TACACS+ only) maintains a single TCP connection for the life of the session. Otherwise, by default, a TCP connection is opened and closed for each session. Because RADIUS uses UDP, there is no `single-connection` keyword.

When the AAA servers have been identified as shown in the above commands, the servers must be included in the method list of the `aaa authentication login` command. AAA servers are identified using the `group tacacs+` or `group radius` keywords.

Listing 20: Configure Authentication to Use the AAA Server

```
aaa authentication login default group tacacs+ group radius local-base
```

The above commands configure a method list for the default login to authenticate first using a TACACS+ server, second with a RADIUS server, and finally with a local username database. It is important to realize that R1 will only attempt to authenticate using RADIUS if the TACACS+ server is not reachable. Likewise, R1 would only attempt to authenticate using the local database if the TACACS+ and RADIUS servers are unavailable.

Troubleshoot Server-based AAA authentication using the following commands: `debug radius` , `debug tacacs` , `debug tacacs events` , and `debug aaa authentication` .

3.4 Server-based AAA authorization

When AAA authorization is not enabled, all users are allowed full access. After authentication is started, the default changes to allow no access. This means that the administrator must create a user with full access rights before authorization is enabled.

To configure command authorization, use the `aaa authorization` command. The service type can specify the types of commands or services: `network` – For network services such as PPP, `exec` – For starting an exec

(shell), `commands <level>` – For exec (shell) commands.

Listing 21: AAA Authorization Configuration

```
aaa authorization {network | commands <level> | exec} {default | <list-name>}
  method1 ... method4

aaa authorization exec default group tacacs+
```

3.5 Server-based AAA accounting

To configure AAA accounting, use the `aaa accounting` command.

Listing 22: AAA Authorization Configuration

```
aaa accounting {network | connection | exec} {default | <list-name>}
         {statrt-stop | stop-only | none} [broadcast] method1 ... method4

aaa account exec default start-stop group tacacs+
```

The following three parameters are commonly used aaa accounting keywords:

- `network` - Runs accounting for all network-related service requests, including PPP.
- `exec` - Runs accounting for the EXEC shell session.
- `connection` - Runs accounting on all outbound connections such as SSH and Telnet.

Next, the record type, or trigger, is configured. The trigger specifies what actions cause accounting records to be updated. Possible triggers include:

- `start-stop` - Sends a ”start” accounting notice at the beginning of a process and a ”stop” accounting notice at the end of a process.
- `stop-only` - Sends a ”stop” accounting record for all cases including authentication failures.
- `none` - Disables accounting services on a line or interface.

3.6 802.1X Port-Based Authentication

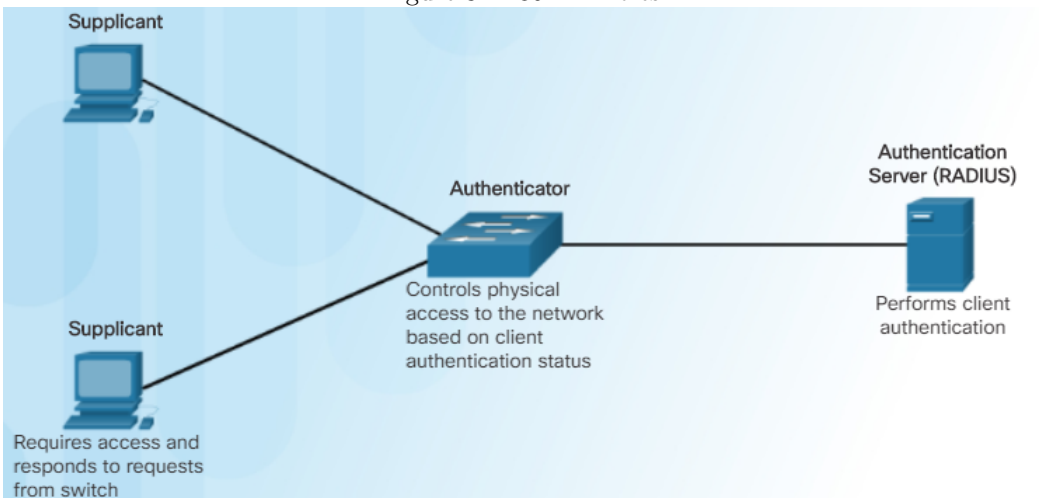
3.6.1 Operation

The IEEE 802.1X standard defines a port-based access control and authentication protocol that restricts unauthorized devices from connecting to a LAN through publicly accessible switch ports. Figure 3.1 shows that with 802.1X port-based authentication roles:

- **Supplicant (Client)** – The device that requests access to LAN. The workstation must be running 802.1X-compliant client software.
- **Authenticator (Switch)** – Controls physical access to the network based on the authentication status of the client. The switch acts as an intermediary (proxy) between the supplicants and the authentication server. It verifies information from the client and relays a response to the client. The switch uses a RADIUS software agent, which is responsible for encapsulating and de-encapsulating the EAP frames and interacting with the authentication server.

- **Authentication server** – Performs the actual authentication of the client. The authentication server validates the identity of the client and notifies the switch. Because the switch acts as the proxy, the authentication service is transparent to the client. The RADIUS security system with EAP extensions is the only supported authentication server.

Figure 3.1: 802.1X roles



If the Supplicant is successfully authenticated (receives an Accept frame from the authentication server), the port state changes to authorized, and all frames from the authenticated client are allowed through the port. If the authentication fails, the port remains in the unauthorized state, but authentication can be retried. If the authentication server cannot be reached, the switch can resend the request. If no response is received from the server after the specified number of attempts, authentication fails, and network access is not granted.

Message exchange Until the workstation is authenticated, 802.1X access control enables only EAPOL (EAP over LAN) traffic through the port to which the workstation is connected. After authentication succeeds, normal traffic can pass through the port. Figure 3.2 shows the complete message exchange between the supplicant, authenticator, and the authentication server. The encapsulation occurs as follows:

- Between the supplicant and the authenticator - EAP data is encapsulated in EAPOL frames.
- Between the authenticator and the authentication server - EAP data is encapsulated using RADIUS.

3.6.2 Port Authorization State

When configured for 802.1X port-based authentication, the port starts in the *unauthorized state*. While in this state, the port disallows all ingress and egress traffic except for 802.1X protocol packets. When a client is successfully authenticated, the port transitions to the *authorized state*, allowing all traffic for the client to flow normally.

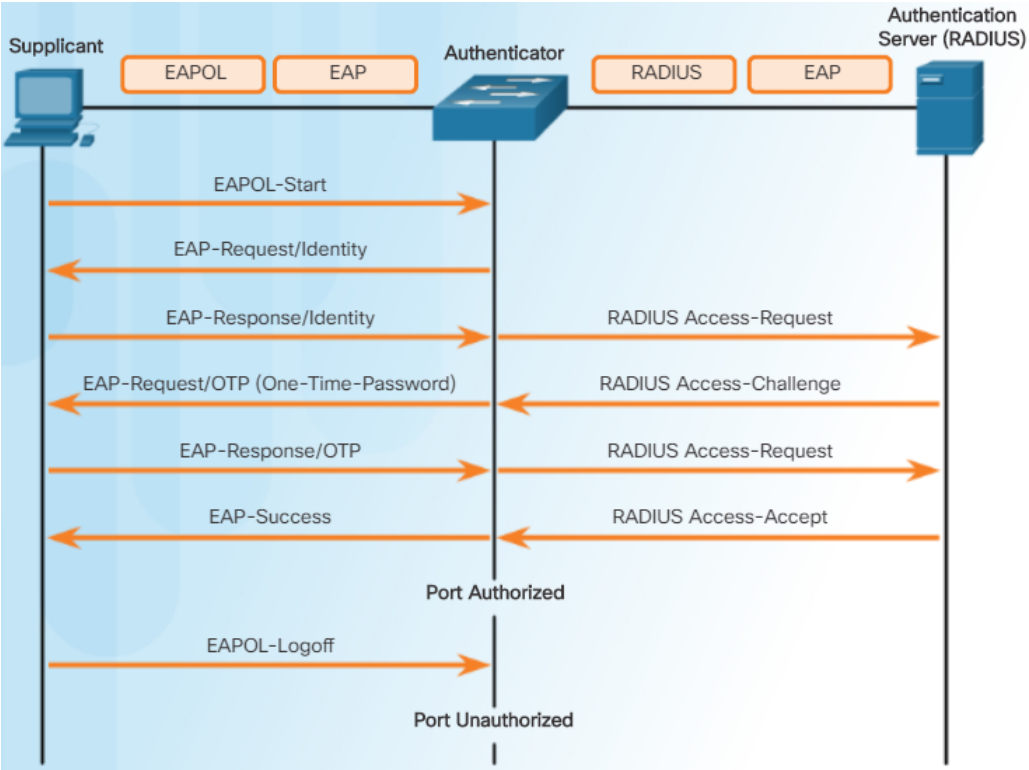
When a client logs out, it sends an EAPOL-logout message, causing the switch port to transition to the unauthorized state. If the link state of a port changes from up to down, or if an EAPOL-logoff frame is received, the port returns to the unauthorized state.

If the supplicant does not support 802.1X, the port remains in the unauthorized state. In contrast, if a switch that is not running the 802.1X protocol, the client begins sending frames as if the port is in the authorized state.

3.6.3 Configuration

The following commands show a scenario where a PC is attached to F0/1 on the switch and the device is getting authenticated via 802.1X with a RADIUS server. Configuring 802.1X requires a few basic steps:

Figure 3.2: 802.1X message exchange



Listing 23: 802.1X configuration

```
aaa new-models

radius server Server-R
  address ipv4 192.168.1.101 auth-port 1812 acct-port 1813
  single-connection
  key RADIUS-Pa55w0rd
  exit

aaa authentication dot1x default group radius
dot1x system-auth-control

interface f0/1
  sw mode access
  authentication port-control auto
  dot1x pae authenticator
  exit
```

1. Enable AAA
2. Configure a RADIUS server
3. Create an 802.1X port-based authentication method list using the `aaa authentication dot1x` command.
4. Globally enable 802.1X port-based authentication using the `dot1x system-auth-control` command.
5. Enable port-based authentication on the interface using the `authentication port-control auto` command.

6. Enable 802.1X authentication on the interface using the `dot1x pae` command. The `authenticator` options sets the Port Access Entity (PAE) type so the interface acts only as an authenticator and will not respond to any messages meant for a supplicant.

The `authentication port-control` command has three options for port state:

- `auto` – Enable 802.1X authentication
- `force-authorized` – Disable 802.1X authentication. This option causes the port to remain authorized and transmit normal traffic. By default, a port is in the force-authorized state.
- `force-unauthorized` – This option causes the port to remain unauthorized and lock all authentication services.

Chapter 4

Firewall

4.1 ACL

ACLs can be used to mitigate IP address spoofing and denial of service (DoS) attacks. Use ACL to block inbound packets from the following addresses:

- All zeros addresses
- Broadcast addresses
- Local host addresses (127.0.0.0/8)
- Reserved private addresses (RFC 1918)
- IP multicast address range (224.0.0.0/4)

Hackers can use ICMP echo packets (pings) to discover network, generate DoS flood attacks, or alter host routing tables. Both ICMP echo and redirect messages should be blocked *inbound* by the router. Several ICMP messages are recommended for proper network operation and should be allowed into the internal network:

- Echo reply – Allows users to ping external hosts.
- Source quench - Requests that the sender decrease the traffic rate of messages.
- Unreachable - Generated for packets that are administratively denied by an ACL.

Several ICMP messages are required for proper network operation and should be allowed to exit the network:

- Echo – Allows users to ping external hosts.
- Parameter problem – Informs the host of packet header problems.
- Packet too big – Enables packet maximum transmission unit (MTU) discovery.
- Source quench – Throttles down traffic when necessary.

As a rule, block all *other* ICMP message types *outbound*.

If SNMP is necessary, exploitation of SNMP vulnerabilities can be mitigated by applying interface ACLs to filter SNMP packets from non-authorized systems. The most effective means of exploitation prevention is to disable the SNMP server on IOS devices for which it is not required.

Note! See also *CCNA notebook* for ACL configuration and IPv6 ACL.

4.2 Firewall

4.2.1 Introduction

All firewalls share some common properties: resistant to attacks, the only transit point between networks because all traffic flows through the firewall, enforce the access control policy. There are many types of firewalls: Packet filtering firewall, Stateful firewall, Application gateway firewall (proxy firewall), etc.

There are two configuration models for Cisco IOS Firewall: Classic Firewall and Zone-based Policy Firewall (ZPF). These models can be enabled concurrently on a router. However, the models cannot be combined on a single interface.

Table 4.1: Packet Filtering Firewall Benefits and Limitations

Advantages	**Disadvantages**
Simple implementation	Susceptible to IP spoofing
Low impact on network performance	Not reliably filter fragmented packets
Initial degree of security at the network layer	Use complex ACLs, which can be difficult to implement and maintain
Almost all the tasks of a high-end firewall at a much lower cost	Stateless: examine each packet individually rather than in the context of the state of a connection.

Stateful firewalls are the most versatile and the most common firewall technologies in use. Unlike a stateless firewall that uses static packet filtering, stateful filtering tracks each connection and confirms that they are valid. Stateful firewalls use a state table to keep track of the actual communication process. Benefits: prevent spoofing and DoS attacks, provide more stringent control over security. Limitations: cannot prevent Application Layer attacks, does not filter UDP and ICMP packets, cannot track connections that use dynamic port negotiation, not support authentication.

Designed with advanced malware protection, the Cisco ASA with FirePOWER services is also called the **Cisco ASA Next-Generation Firewall** because it is an adaptive, threat-focused firewall. It is designed to provide defense across the entire attack continuum, which includes before, during, and after attacks.

4.2.2 DMZ

A demilitarized zone (DMZ) is a firewall design where there is typically one inside interface connected to the private network, one outside interface connected to the public network, and one DMZ interface, as shown in the figure 4.1.

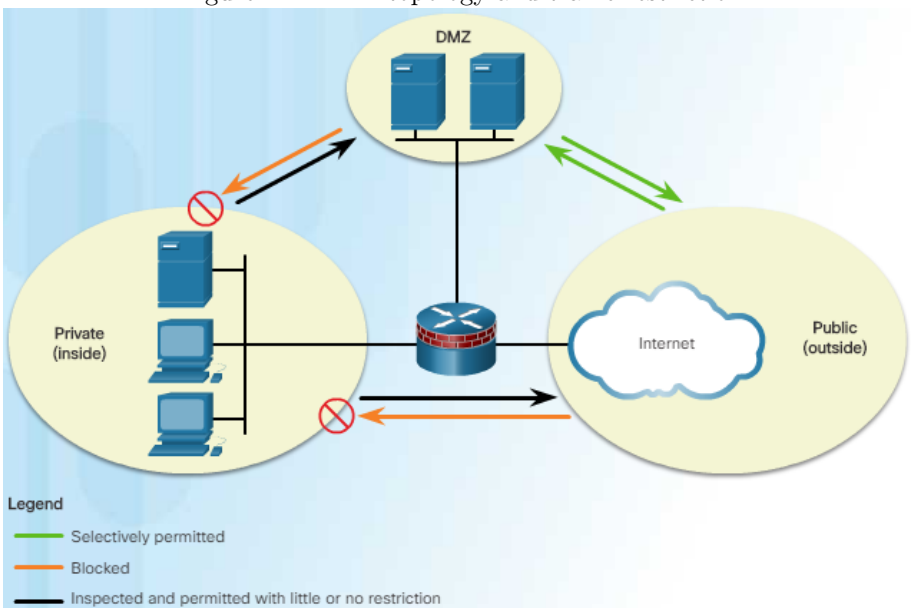
- Private network → DMZ: Inspected
- DMZ → Private network: Blocked
- Public network ↔ DMZ: selectively permitted
- Private network → Public network: Inspected
- Public network → Private network: Blocked

4.2.3 Layered Defense

A layered defense uses different types of firewalls that are combined in layers. Security policies can be enforced between the layers and inside the layers. A traffic from the untrusted network has to go through the following layers and policies:

1. Edge router (packet filtering)

Figure 4.1: DMZ topology and traffic restriction



2. Bastion host (hardened computer located in the DMZ[1]) or Screened firewall

3. Interior screening router

4.3 Classic firewall

4.3.1 Introduction

Classic Firewall (CBAC) is a *stateful* firewall that provides four main functions: traffic filtering, traffic inspection, intrusion detection, and generation of audits and alerts. It can also examine NAT, PAT information, P2P connections. Classic Firewall only provides filtering for those protocols that are specified by an administrator. It can only detects and protects against external attacks that travel through the firewall, but not attacks originating from within the protected network.

Classic Firewall creates *temporary* openings in the ACL to allow returning traffic. These entries are created as inspected traffic leaves the network and are removed when the connection terminates or the idle timeout period for the connection is reached. Figure 4.2 shows how Classic Firewall inspects SSH traffic.

4.3.2 Configuration

Take the topology in figure 4.3 as an example for configuration. Suppose that the administrator wants to allow SSH sessions between the 10.0.0.0 and 172.30.0.0 networks. However, only hosts from the 10.0.0.0 network are allowed to initiate SSH sessions. All other access is denied.

[1]This type of DMZ setup is called a *screened subnet configuration*.

Figure 4.2: Classic Firewall inspects SSH traffic

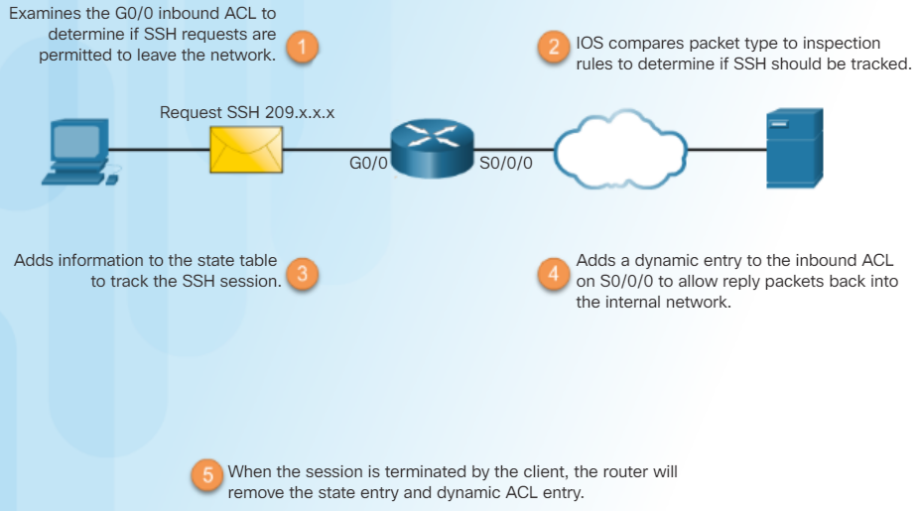
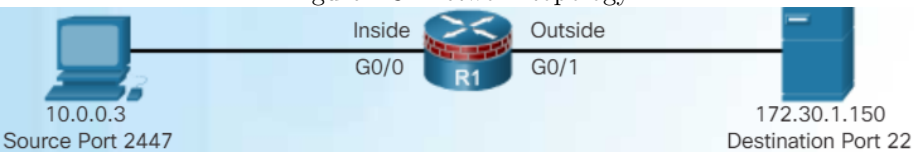


Figure 4.3: Network topology



Listing 24: Classic Firewall configuration

```
ip access-list extended INSIDE
  permit tcp 10.0.0.0 0.0.0.255 any eq 22
ip access-list extended OUTSIDE
  deny ip any any

ip inspect name FWRULE ssh

interface g0/0
  ip access-group INSIDE in
  ip inspect FWRULE in
interface g0/1
  ip access-group OUTSIDE in
```

There are four steps to configure this policy using a Classic Firewall:

1. **Define the internal and external interfaces**: G0/0 is the inside interface and G0/1 is the outside interface.
2. **Configure ACLs for each interface**: The INSIDE ACL allows only SSH traffic from the 10.0.0.0 network; the OUTSIDE ACL will deny inbound traffic from the 172.30.0.0 network.
3. **Define inspection rules**: The inspection rule FWRULE specifies that traffic will be inspected for SSH connections. This inspection rule has no effect until it is applied to an interface.
4. **Apply an inspection rule to an interface**: When the FWRULE is applied to inbound traffic on the G0/0 interface, the Classic Firewall configuration will dynamically add an entry to allow inbound SSH traffic from the 172.30.0.0 network. From now on, the FWRULE inspects SSH traffic between 10.0.0.0 and 172.30.0.0 network.
5. **Verification**: Use `show ip inspect sessions` command to verify inspect sessions.

4.4 Zone-based Policy Firewall (ZPF)

4.4.1 Overview

ZPFs use the concept of zones to provide additional flexibility. A zone is a group of one or more interfaces that have similar functions or features. By default, the traffic between interfaces in the same zone is not subject to any policy and passes freely. However, all zone-to-zone traffic is blocked. In order to permit traffic between zones, a policy allowing or inspecting traffic must be configured.

There are several benefits of a ZPF:

- Not dependent on ACLs.
- The router security posture is to block unless explicitly allowed.
- Policies are easy to read and troubleshoot with the Cisco Common Classification Policy Language (C3PL). C3PL can create traffic policies based on events and affect any given traffic with only one policy, instead of needing multiple ACLs and inspection actions.

4.4.2 Operation

The Cisco IOS ZPF can take three possible actions: Inspect, Drop and Pass. ZPF Rules for Transit Traffic depends on the zone that an interface belongs to:

- Neither intefaces is a zone member: Pass
- Both interfaces are members of the same zone: Pass
- Interfaces belong to different zones: Action defined by policy
- Only one interface is a zone member: Drop

The *self zone* is a special zone which is the router itself and includes all the router interface IP addresses. By default, if the router (self zone) is the source or the destination, then all traffic is permitted. The only exception is if the source and destination are a zone-pair with a specific service-policy. In that case, the policy is applied to all traffic.

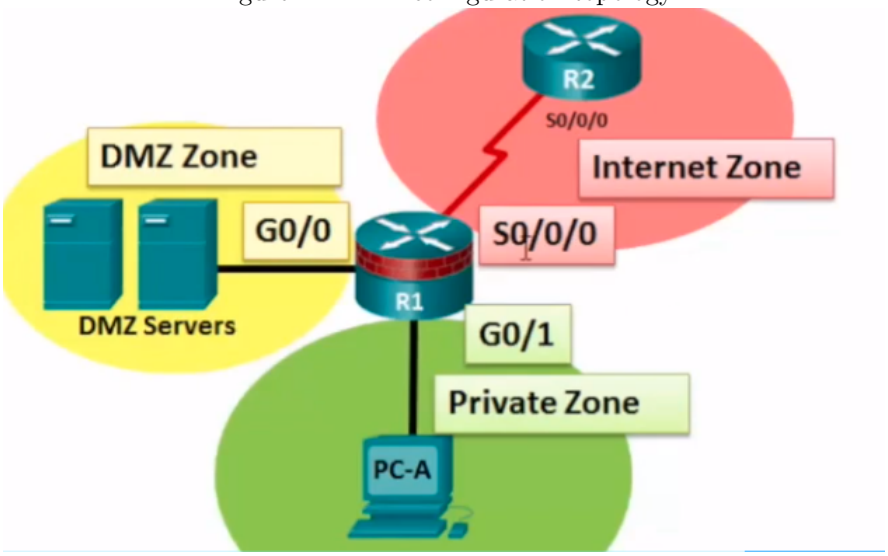
4.4.3 Configuration

There are five steps to configure a ZPF zone:

1. Create the zones and Assign zones to appropriate interfaces
2. Identify traffic with class-map
3. Define an action with policy-map
4. Identify a zone-pair and match it to a policy-map

Take the topology in figure 4.4 as an example.

Figure 4.4: ZPF configuration topology



Listing 25: ZPF configuration

```
zone security PRIVATE
zone security INTERNET
zone security DMZ
int g0/1
  zone-member security PRIVATE
int s0/0/0
  zone-member security INTERNET
int g0/0
  zone-member security DMZ
exit

class-map type inspect match-all PRIVATE-ACL-CLASS
  match access-group 100
class-map type inspect match-any PRIVATE-INTERNET-CLASS
  match protocol http
  match protocol https
  match protocol dns
exit

policy-map type inspect PRIV-TO-PUB-POLICY
  class type inspect PRIVATE-ACL-CLASS
  inspect
  class type inspect PRIVATE-INTERNET-CLASS
  inspect
  class class-default
exit

zone-pair security PRIVATE-2-INTERNET source PRIVATE destination INTERNET
  service-policy type inspect  PRIV-TO-PUB-POLICY
end

show run | begin class-map
show run | begin class-map
show class-map type inspect
show zone security
show zone-pair security
show policy-map type inspect
show policy-map type inspect zone-pair sessions
```

The first step is to create zones and assign them to the appropriate interfaces. Associating a zone to an interface will immediately apply the service-policy that has been associated with the zone. If no service-policy is yet configured for the zone, all transit traffic will be dropped. Use the `zone-member security` command to assign a zone to an interface. In the example, g0/1 is assigned the PRIVATE zone, and s0/0/0 is assigned the INTERNET zone, and g0/0 is assigned to DMZ zone.

The second step is to use a class-map to identify the traffic. A class is a way of identifying a set of packets based on its contents using `match` conditions. Packets must meet one of the match criteria `match-any` or all of the match criteria `match-all` to be considered a member of the class. Table 4.2 shows the syntax for the `class-map` and its sub-commands.

Table 4.2: The syntax of class-map command

`class-map type inspect [match-any | match-all] <class-name>`	
Parameter	**Description**
`match-any`	Packets must meet one of the criteria to be considered a member of the class.
`match-all`	Packets must meet all of the criteria to be considered a member of the class.
`match protocol <protocol-name>`	Configure criteria based on specified protocol.
`match access-group <acl-name>`	Configure criteria based on specified ACL.
`match class-map <class-name>`	Use another class-map as criteria.

The third step is to assign class-maps (PRIVATE-ACL-CLASS and PRIVATE-INTERNET-CLASS) to a policy-map and define what action (Inspect, Drop, or Pass) should be taken for traffic that is a member of a class.

- `inspect` – This action offers state-based traffic control. It tracks UDP or TCP connections and permit the return traffic.
- `drop` – This is the default action for all traffic. Similar to the implicit deny any at the end of every ACL, , there is an explicit `drop` applied to the end of every policy-map.
- `pass` – This action allows *one-direction* traffic between two zones, and does not track the state of connections. A corresponding policy must be applied to allow return traffic to pass in the opposite direction. This action is ideal for secure protocols, such as IPsec.

The fourth step is to identify a zone pair (PRIVATE-2-INTERNET) using `zone-pair security` command, and associate that zone pair to a policy-map (PRIV-TO-PUB-POLICY) using `service-policy type inspect` command.

The service-policy is now active. HTTP, HTTPS, and DNS traffic sourced from the PRIVATE zone and destined for the PUBLIC zone will be inspected. Traffic sourced from the PUBLIC zone and destined for the PRIVATE zone will only be allowed if it is part of sessions originally initiated by PRIVATE zone hosts.

4.4.4 ZPF Configuration Considerations

- The router never filters the traffic between interfaces in the same zone.
- An interface cannot belong to multiple zones. ZPF can coexist with Classic Firewall although they cannot be used on the same interface. Remove the `ip inspect` interface configuration command before applying the `zone-member security` command.

- Traffic can never flow between an interface assigned to a zone and an interface without a zone assignment. Applying the zone-member configuration command always results in a temporary interruption of service until the other zone-member is configured.
- Communication between zones are, by default, dropped. Unless there exits a service-policy configured for the zone-pair.
- The `zone-member` command does not protect the router itself (traffic to and from the router is not affected) unless the zone-pairs are configured using the predefined self zone.

Chapter 5

Intrusion Prevention System (IPS)

5.1 Introduction

Firewalls can only do so much and cannot protect against malware and zero-day attacks. A zero-day attack is a computer attack that tries to exploit software vulnerabilities that are unknown or undisclosed by the software vendor.

Intrusion Detection Systems (IDSs) were implemented to passively monitor the traffic on a network. IDS-enabled device copies the traffic stream and analyzes the copied traffic rather than the actual forwarded packets. **Working offline**, it compares the captured traffic stream with known malicious signatures. Working offline means several things:

- IDS works passively
- IDS device is physically positioned in the network so that traffic must be mirrored in order to reach it
- Network traffic does not pass through the IDS unless it is mirrored

IDS advantage: No impact on the network (delay, jitter) even if there is a sensor failure or overload. **IDS disadvantage:** cannot stop trigger packets, correct tuning required for response action.

Intrusion Prevention System (IPS) was upon IDS technology. However, an IPS device is implemented in **inline mode**. This means that all ingress and egress traffic must flow through it for processing. An IPS does not allow packets to enter the trusted side of the network without first being analyzed. It can detect and immediately address a network problem.

IPS advantage: stop trigger packets, utilize stream normalization[1]. **IPS disadvantage:** some impact on network (delay, jitter), IPS overloading or improper configuration negatively affect the network .

The biggest difference between IDS and IPS is that an IPS responds immediately and does not allow any malicious traffic to pass, whereas no action is taken on malicious packets by the IDS.

IDS and IPS technologies share several characteristics:

- Deployed as sensors
- Use signatures[2] to detect patterns in network traffic
- Can detect atomic signature patterns (single-packet) or composite signature patterns (multi-packet)

[1] a technique used to reconstruct the data stream when the attack occurs over multiple data segments.
[2] A signature is a set of rules that an IDS or IPS uses to detect malicious activity.

5.2 IPS Signatures

5.2.1 Characteristics

Signatures have three distinctive attributes: Type, Trigger (alarm), Action. Signature types are generally categorized as atomic or composite.

An **atomic signature** consists of a single packet, activity, or event that is examined to determine if it matches a configured signature. Because these signatures can be matched on a single event, they do not require an intrusion system to maintain state[3] information. Detecting atomic signatures consumes minimal resources. For example, a LAND attack has an atomic signature because it sends a spoofed TCP SYN packet, therefore, one packet is enough to identify this type of attack.

A **composite signature** is a stateful signature which identifies a sequence of operations distributed across multiple hosts over an arbitrary period of time. The length of time that the signatures must maintain state is known as the event horizon. An IPS uses a configured event horizon to determine how long it will look for a specific attack signature when an initial signature component is detected.

All signatures are contained in a signature file and uploaded to an IPS on a regular basis.

Cisco IOS software relies on **signature micro-engines (SMEs)** to categorize common signatures in groups. Cisco IOS software can then scan for multiple signatures based on group characteristics, instead of one at a time. When IDS or IPS is enabled, an SME is loaded or built on the router. When an SME is built, the router might need to compile the regular expression[4] found in a signature.

Atomic and composite packets are scanned by the SMEs that recognize the protocols contained in the packets. Then, each SME extracts values from the packet and passes portions of the packet to the regular expression engine. The regular expression engine can search for multiple patterns at the same time.

5.2.2 Alarms

The heart of any IPS signature is the signature alarm (signature trigger). Anything that can reliably signal an intrusion or security policy violation can be used as a triggering mechanism. Cisco IDS and IPS sensors can use four types of signature triggers:

- **Pattern-based detection** (signature-based detection) is the simplest triggering mechanism. It compares the network traffic to a database of known attacks, and triggers an alarm or prevents communication if a match is found. The mechanism is only suitable for the suspect packets that are associated with services or ports. However, it cannot deal with protocols and attacks that do not use well-defined ports.
- **Anomaly-based detection** (profile-based detection) defines a profile of what is considered normal for the network. This normal profile can be learned by monitoring activity on the network, or be based on a defined specification, such as an RFC. After defining normal activity, the signature triggers an action if excessive activity occurs beyond a specified threshold that is not included in the normal profile. **Advantage:** new and previously unpublished attacks can be detected. **Disadvantage:** the network must be free of attack traffic during the learning phase, otherwise, the attack activity will be considered normal traffic; Difficult to define normal traffic; Difficult to correlate that alert back to a specific attack
- **Policy-based detection:** (behavior-based detection) is similar to pattern-based detection. However, instead of trying to define specific patterns, the administrator defines behaviors that are suspicious based on historical analysis. The use of behaviors enables a single signature to cover an entire class of activities without having to specify each individual situation.
- Honey pot-based detection uses a dummy server to attract attacks. By staging different types of vulnerabilities in the honey pot server, administrators can analyze incoming types of attacks and malicious traffic patterns. Antivirus and other security vendors tend to use them for research.

[3] State refers to situations in which multiple packets of information are required, but the packets of information are not necessarily received at the same time.

[4] A regular expression is a systematic way to specify a search for a pattern in a series of bytes.

- **Protocol decodes:** This mechanism breaks down a packet into the fields of a protocol, and then search for specific patterns in a specific protocol field. Advantage: enable a more granular inspection of traffic and reduces the number of false positives.

The table shows four types of IPS alarms

Table 5.1: Alarm types

Alarm type	Status	Alarm	Outcome
False positive	normal	•	tune alarm
False negative	dangerous		tune alarm
True positive	dangerous	•	ideal setting
True negative	normal		ideal setting

- A false positive alarm occurs when an intrusion system generates an alarm after processing normal traffic. If this occurs, the administrator must be sure to tune the IPS to change these alarm types to true negatives.
- A false negative is when an intrusion system fails to generate an alarm after processing attack traffic. The goal of the administrator is for these alarm types to generate true positive alarms.
- A true positive alarm is when an intrusion system generates an alarm in response to known attack traffic.
- A true negative describes a situation in which normal network traffic does not generate an alarm.

5.2.3 Actions

Alerts: Should an attacker cause a flood of bogus alerts, examining these alerts can overwhelm the security analysts. IPS solutions incorporate two types of alerts to enable an administrator to efficiently monitor the operation of the network: atomic alerts and summary alerts. **Atomic alerts** are generated every time a signature triggers. A **summary alert** is a single alert that indicates multiple occurrences of the same signature from the same source address or port.

Log activities for later analysis: an IPS can be enabled to log the attacker packets, pair packets, or just the victim packets. **Logging attacker packets** is the action that starts IP logging on the packets that contain attacker's address and sends an alert.**Logging pair packets** is the action that starts IP logging on the packets that contain attacker-victim address pair and sends an alert. **Logging victim packets** is the action that starts IP logging on the packets that contain victim address and sends an alert. Note that the alerts are stored in Event Store.

Deny the Activity: an IPS can be enabled to deny the specific packets, or the attacker packets, or connection. **Denying the attacker packets** is the action that terminates the current and future packets from a particular attacker address for a period of time. There is a sliding timer for each attacker. If attacker A is currently denied, but issues another attack, then the timer for attacker A is reset and this attacker remain denied until the timer expires. **Denying the connection** is the action that terminates packets come from the current TCP flow.

Reset, Block, and Allow Traffic: The **TCP Reset** Signature Action terminates TCP connections by generating a packet for the connection with the TCP RST flag set. Deny packet and deny flow actions do not automatically cause TCP reset actions to occur. **Blocking** is the action that updates ACL on *one* of the infrastructure devices. After a configured period of time, the IPS device removes the ACL. One advantage of the blocking action is that a single IPS device can stop traffic at multiple locations throughout the network, regardless of the location of the IPS device. The **Allow Signature** action define exceptions to configured signatures. Configuring exceptions enables administrators to take a more restrictive approach to security because they can first deny everything and then allow only the activities that are needed.

5.2.4 Manage and monitor

There are four factors to consider when planning a monitor strategy: Management method, Event correlation, Security staff, and Incident response plan. There are three GUI-based IPS device managers available: Cisco Configuration Professional, Cisco IPS Manager Express (IME), and Cisco Security Manager.

Management method: IPS sensors can be managed individually (small network) or centrally (large network). In a larger network, a centralized management system that allows the administrator to configure and manage all IPS devices from a single central system should be deployed.

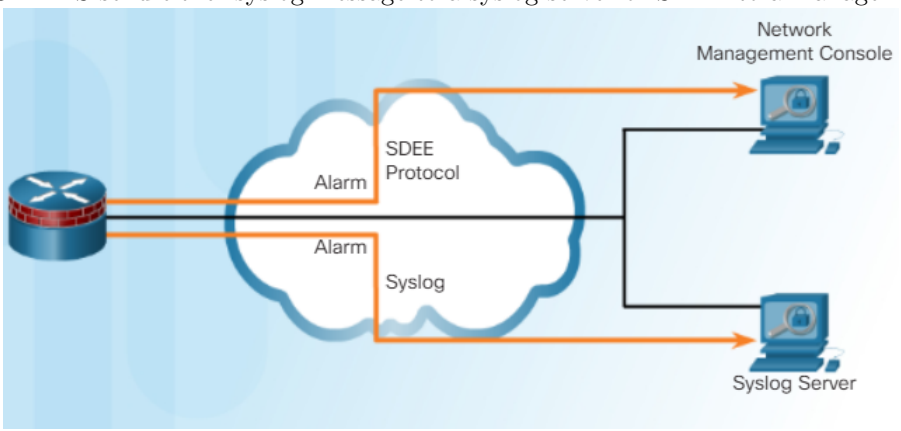
Event correlation: Event correlation refers to the process of correlating attacks and other events that are happening simultaneously at different points across a network. A correlation tool correlates the alerts based on their time-stamps. Therefore, the administrator should enable NTP on all network devices with a common system time. Another factor that facilitates event correlation is deploying a centralized monitoring facility on a network. By monitoring all IPS events at a single location, an administrator greatly improves the accuracy of event correlation.

Security staff: IPS devices tend to generate numerous alerts and other events during network traffic processing. Large enterprises require appropriate security staff to analyze this activity and determine how well the IPS is protecting the network.

Incident response plan: If a system is compromised on a network, a response plan must be in place. The compromised system should be restored to the state it was in before the attack.

SDEE: When an attack signature is detected, the Cisco IOS IPS feature can send either a syslog message or an alarm in Secure Device Event Exchange (SDEE) format, as shown in the figure 5.1. SDEE uses HTTP and XML to provide a standardized approach.Administrators must also enable HTTP or HTTPS on the router when enabling SDEE. The use of HTTPS ensures that data is secured as it traverses the network. The **SDEE buffer** stores up to 200 events by default. The maximum number of events is 1,000.

Figure 5.1: IPS send either syslog message to a syslog server or SDEE to a management app

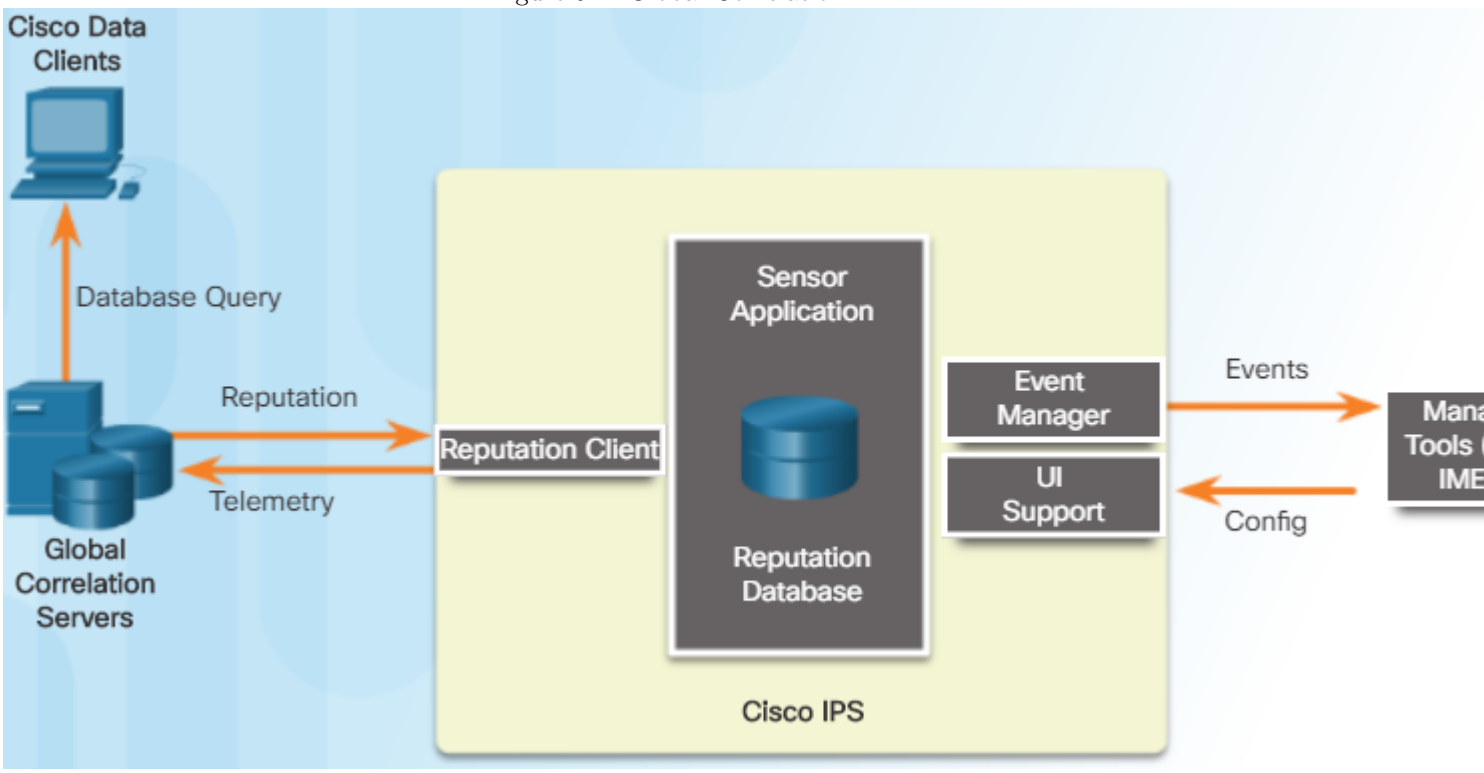


5.2.5 Global correlation

In addition to maintaining signature packs, Cisco IPS includes a security feature called Cisco Global Correlation. With global correlation, Cisco IPS devices receive regular threat updates from a centralized Cisco threat database called the Cisco SensorBase Network.

When participating in global correlation, the Cisco SensorBase Network provides information to the IPS sensor about IP addresses with a reputation, as shown in the figure 5.2. The sensor uses this information to determine which actions to perform when harmful traffic is received from a host with a known reputation. Since the global correlation database changes rapidly, the sensor must periodically download global correlation updates from the

Figure 5.2: Global Correlation



global correlation servers. It is possible to view reputation scores in events and see the reputation score of attackers.

The SensorBase Network is part of a larger, back-end security ecosystem, known as the **Cisco Security Intelligence Operation (SIO)**. The purpose of Cisco SIO is to detect threat activity, research and analyze threats, and provide real-time updates and best practices to keep organizations informed and protected. Cisco SIO consists of three elements:

- *Threat intelligence* from the Cisco SensorBase Network
- *Threat Operations Center*, which is the combination of automated and human processing and analysis
- *Automated and best practices content* that is pushed to network elements in the form of dynamic updates

A **reputation** is based on a commonly held opinion. IP addresses, mail servers, URLs, and other entities can all have a reputation. Many of today's network protection technologies and filtering systems depend on lists to determine if the information is good (whitelist) or bad (blacklist). IPS sensors use reputation filters to deny IP addresses or URLs that are blacklisted before the sensor does further analysis on the traffic.

5.3 Implementation

5.3.1 Configuration

Step 1. Download the IOS IPS files

Prior to configuring IPS, it is necessary to download the IOS IPS signature package files, as shown in Figure 1, and a public crypto key from cisco.com. Only registered customers can download the package files and key.

- `IOS-Sxxx-CLI.pkg` – The latest signature package.
- `realm-cisco.pub.key.txt` – The public crypto key used by IOS IPS.

Step 2. Create an IOS IPS configuration directory in Flash

The second step is to create a directory in flash to store the signature files and configurations. The `mkdir <dir-name>` privileged EXEC command creates the directory in Flash. Other useful commands include `rename <current-name> <new-name>`, which allows the name of the directory to be changed.

Step 3. Configure an IOS IPS Crypto Key

The third step is to configure the crypto key used by IOS IPS. This key is located in the `realm-cisco.pub.key.txt` file that was obtained in Step 1. The crypto key verifies the digital signature for the master signature file `sigdef-default.xml`. The content of the file is signed by a Cisco private key to guarantee its authenticity and integrity.

Open the text file to configure the IOS IPS crypto key. Next, copy the contents of the file, and paste the contents to the router at the global configuration prompt. The text file issues the various commands to generate the RSA key.

If the key is configured incorrectly, an error message is generated as follow

```
%IPS-3-INVALID_DIGITAL_SIGNATURE: Invalid Digital Signature found (key not found)
```

In such case, the key must be removed and then reconfigured. Use the `no crypto key pubkey-chain rsa` and the `no named-key realm-cisco.pub signature` commands. Then repeat the procedure in Step 3 to reconfigure the key. Finally, enter the `show run` command to confirm that the crypto key is configured.

Step 4. Enable IOS IPS

The fourth step is to configure IOS IPS, which is a process that consists of four sub-steps.

1. **Identify the IPS rule name and specify the location:** Create a rule name associated with an optional extended or standard ACL. All traffic that is permitted by the ACL is subject to inspection by the IPS. Next, configure the IPS signature storage location as directory `flash:IPS` (created in step 2).

2. **Enable SDEE and logging event notification:** To use SDEE, the HTTP or HTTPS server must first be enabled with the `ip http server` or `ip https server` command. Enable SDEE event notification by using the `ip ips notify sdee` command. The buffer size can be altered with the `ip sdee events` command. The `clear ip ips sdee` command clears SDEE events or subscriptions.

3. **Enable syslog:** Logging notification is enabled by default. If the logging console is enabled, IPS log messages are displayed on the console. Use the `ip ips notify log` command to enable logging.

4. **Configure the signature category:** All signatures are grouped into categories. The three most common categories are `all`, `basic`, and `advanced`. The signatures that IPS uses to scan traffic can be retired or unretired. **Retiring** a signature means that IPS does not compile that signature into memory for scanning. **Un-retiring** a signature instructs IPS to compile the signature into memory and use it to scan traffic. When IOS IPS is first configured, all signatures in the all category should be retired. Then, selected signatures should be unretired in a less memory-intensive category.

5. **Apply the IPS rule to interfaces**

Note! Do not unretire the `all` category. The `all` signature category contains all signatures in a signature release. The IPS cannot compile and use all the signatures at one time because it will run out of memory.

Note! The order in which the signature categories are configured on the router is also important. IOS IPS processes the category commands in the order listed in the configuration. Some signatures belong to multiple categories. If multiple categories are configured and a signature belongs to more than one of them, IOS IPS uses the signature's properties in the last configured category, for example, retired, unretired, or actions.

Step 5. Loading IOS IPS Signature Package to the Router

The last step is for the administrator to upload the signature package to the router. The most common methods are FTP or TFTP.

Listing 26: Enable IPS

```
ip ips name IOSIPS list ALLOW-HTTP
ip ips config location flash:IPS

ip http server
ip https server

ip ips notify sdee
ip sdee events 500

ip ips notify log
logging 192.168.10.100
logging on

ip ips signature-category
  category all
  retired true
exit
  category ios_ips basic
  retired false
end

conf t

interface g0/0
  ip ips IOSIPS in
interface g0/1
  ip ips IOSIPS in
  ip ips IOSIPS out
end

copy tftp://192.168.1.3/IOS-S416-CLI.pkg idconf
# copy ftp://ftp_user:password@Server_IP_addr/signature_packg  idconf

show ip ips signature count

clear ip ips sdee {events | subscription}
```

5.3.2 Modification

Listing 27: Retire a specific signature

```
ip ips signature-definition
  signature 6130 10
  status
    retired true
end
```

Listing 28: Change actions of a signature

```
ip ips signature-definition
  signature 6130 10
  engine
    event-action produce alert
    event-action deny-packet-inline
    event-action reset-tcp-connection
end
```

Table 5.2: Parameters of event-action command

`deny-attacker-inline`	Terminates the current and future packets from a particular attacker address for a period of time
`deny-connection-inline`	Terminates packets come on this TCP flow.
`deny-packet-inline`	Terminates the packet.
`produce-alert`	Writes event to Event Store as an alert.
`reset-tcp-connection`	Send TCP reset signal and terminate the TCP flow. Only works on TCP signatures that analyze a single connection. Not work for sweeps or floors.

Listing 29: Change actions of a signature category

```
ip ips signature-definition
  category ios_ips basic
    event-action produce alert
    event-action deny-packet-inline
    event-action reset-tcp-connection
end
```

Use the `clear ip ips config` command to disable IPS, remove all IPS configuration entries, and release dynamic resources. The `clear ip ips stat` command resets statistics on packets analyzed, and alarms sent.

Listing 30: IPS verification

```
show running-config
show ip ips
show ip ips all
show ip ips configuration
show ip ips signatures
show ip ips statistics
```

Chapter 6

Securing LAN

6.1 Endpoint security

New security architectures for the borderless network address these challenges by having endpoints use network scanning elements. Protecting endpoints in a borderless network can be accomplished using the following modern security solutions: Antimalware Protection (AMP), Email Security Appliance (ESA), Web Security Appliances (WSA), Network Admission Control (NAC).

6.1.1 Anti-malware protection

Cisco added Sourcefire's Advanced Malware Protection (AMP) technology to protect endpoints and networks more effectively than traditional host-based malware protection. It defeats malware across the extended network before, during, and after an attack.

AMP accesses the collective security intelligence of the Cisco Talos Security Intelligence and Research Group (Talos). Talos detects and correlates threats in real time using the largest threat-detection network in the world.

AMP protects before, during, and after an attack. AMP is available in a variety of formats:

- AMP for Endpoints - integrates with Cisco AMP for Networks to deliver comprehensive protection across extended networks and endpoints.
- AMP for Networks - integrated into dedicated Cisco ASA Firewall and Cisco FirePOWER network security appliances.
- AMP for Content Security – integrated in Cisco Cloud Web Security or Cisco Web and Email Security Appliances to protect against email and web-based advanced malware attacks.

6.2 Layer 2 security

Chapter 7

Virtual Private Networks (VPN) and IPsec

7.1 VPN introduction

A VPN is a private network that is created over a public network, usually the Internet. A VPN is virtual in that it carries information within a private network, but that information is actually transported over a public network. A VPN is private in that the traffic is encrypted to keep the data confidential while it is transported across the public network.

In the simplest sense, a VPN connects two endpoints, such as two remote offices, over a public network to form a logical connection. The logical connections can be made at either Layer 2 or Layer 3. This chapter focuses on Layer 3 VPN technology. Common examples of Layer 3 VPNs are GRE, Multiprotocol Label Switching (MPLS), and IPsec (This course focuses on IPsec VPNs).

Figure 7.1: Remote-access VPN

There are two basic types of VPNs: remote-access and site-to-site. A **remote-access VPN** is created when VPN information is not statically set up, but instead allows for dynamically changing connection information, which can be enabled and disabled when needed (Figure 7.1). A **site-to-site VPN** is created when devices on both sides of the VPN connection are aware of the VPN configuration in advance. The VPN remains static, and internal hosts have no knowledge that a VPN exists (Figure 7.2).

Hairpinning is a situation in which the VPN terminating device at the corporate network is the hub and the remote-access VPN clients are spokes (Figure 7.3). In **Split tunneling**, if traffic is destined for a corporate subnet, it is sent through the VPN tunnel; otherwise, it is sent as unencrypted traffic (untrusted) to the Internet.

Figure 7.2: Site-to-site VPN

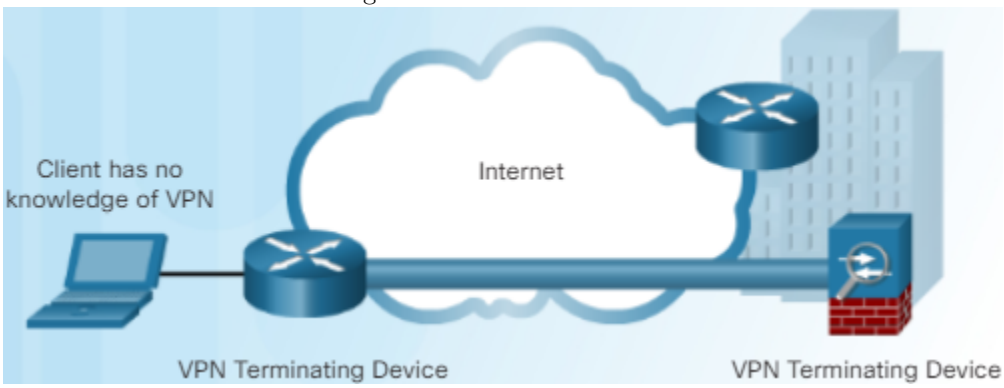


Figure 7.3: Hairspinning

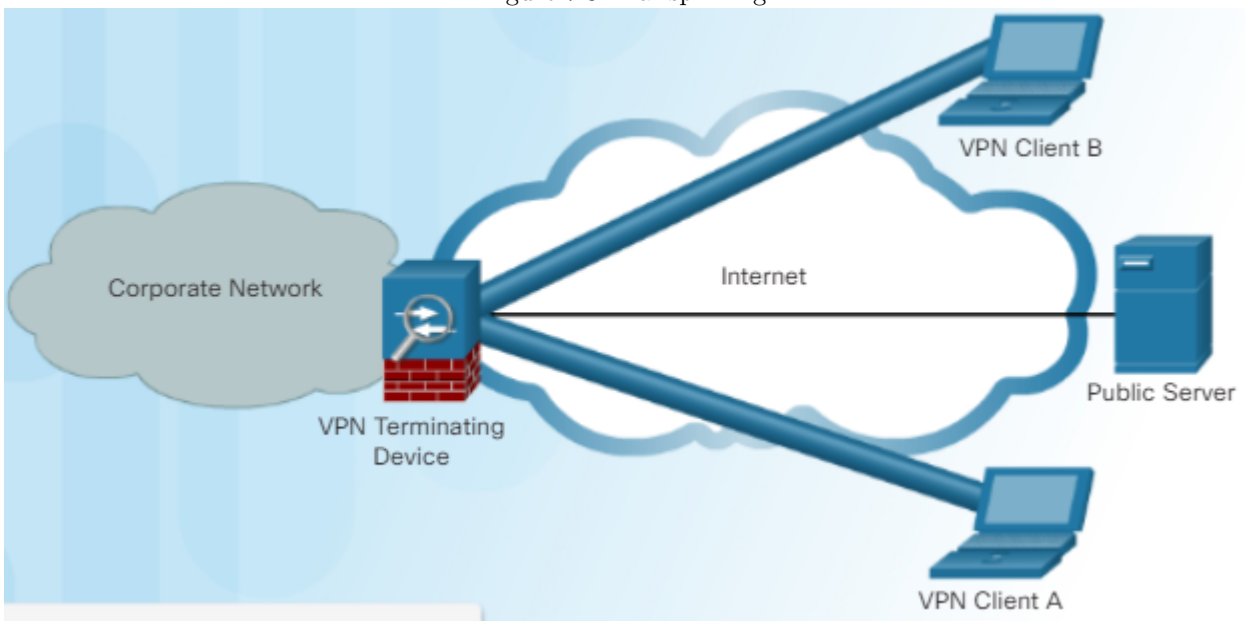
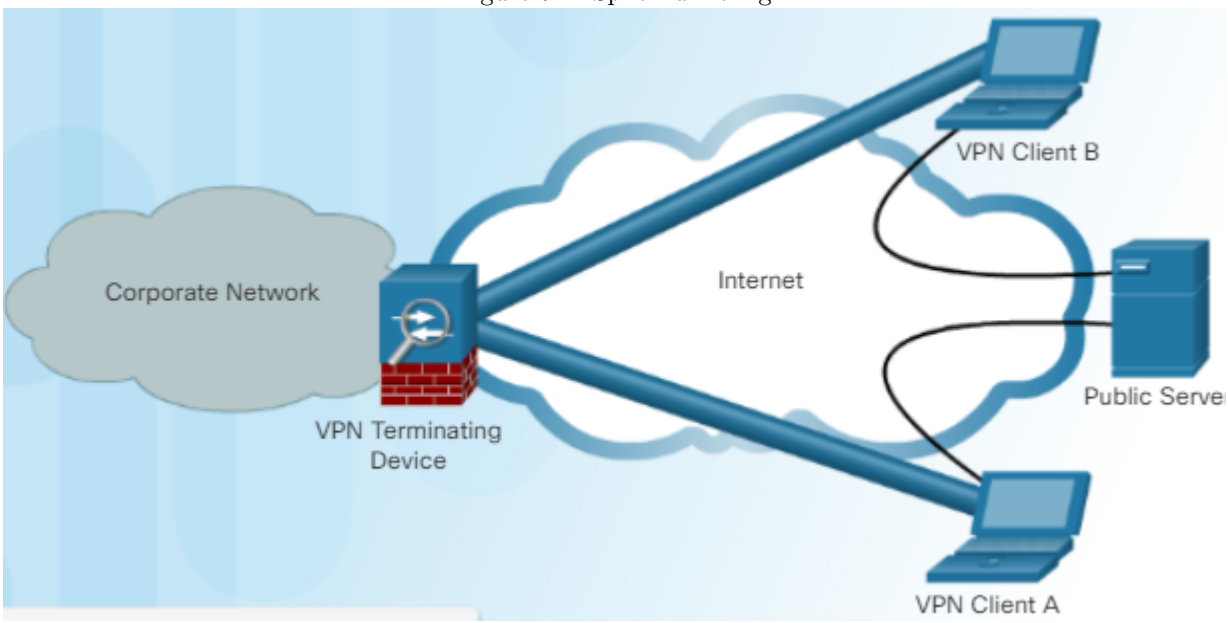


Figure 7.4: Split Tunneling



7.2 IPsec introduction

IPsec is an IETF standard that defines how a VPN can be secured across IP networks. IPsec is not bound to any specific rules for secure communications (Figure 7.5). This flexibility of the framework allows IPsec to easily integrate new security technologies without updating the existing IPsec standards. The level of security and reliability is increased from left to right, meaning that the right-most is the most secure and reliable.

Figure 7.5: IPsec framework

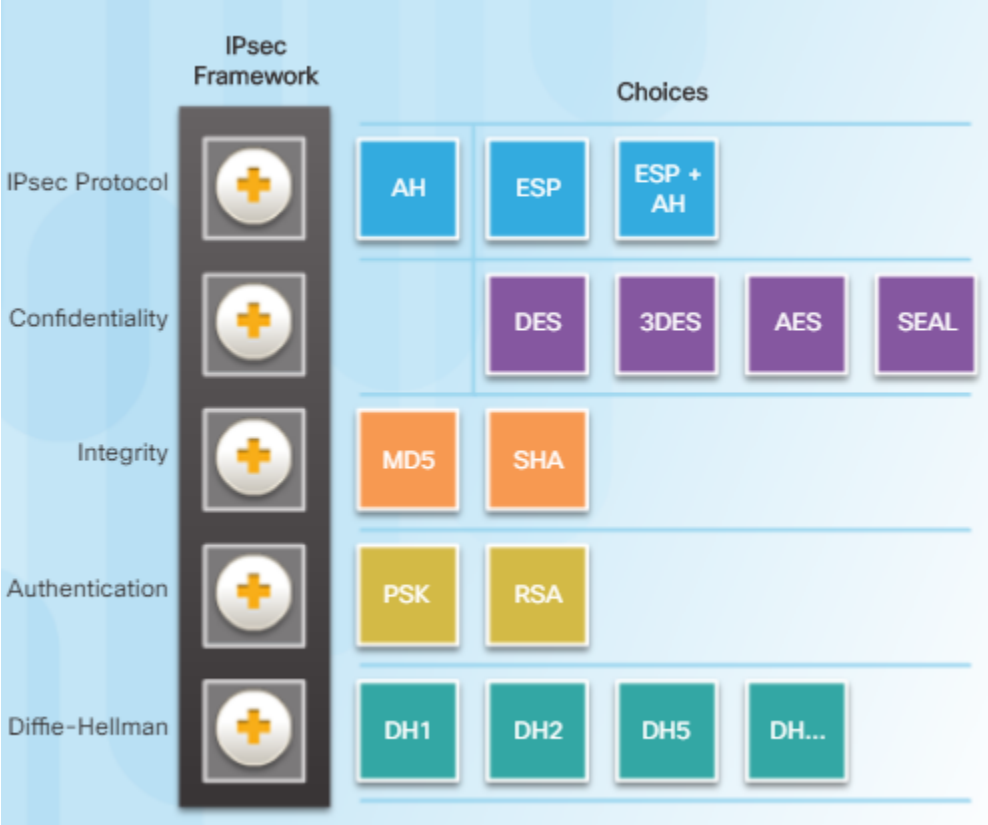


Figure 7.6 shows examples of security associations (SAs) for two different implementations. An SA is the basic building block of IPsec. When establishing a VPN link, the peers must share the same SA.

7.3 IPsec protocols

Having said that IPsec framework contains a variety of protocols. This section introduce Authentication Header (AH) protocol and Encapsulation Security Protocol (ESP). Refer to figure 7.5, you can see that AH and ESP are both IPsec protocols, the first layer of IPsec framework.

7.3.1 Authentication Header (AH) protocol

AH achieves **authenticity** by applying a **keyed one-way** hash function to the packet to create a hash or message digest. AH supports MD5 and SHA algorithms. AH may not work if the environment uses NAT. The AH process occurs in this order:

1. The IP header and data payload are hashed using the shared secret key.
2. The hash builds a new AH header, which is inserted into the original packet (Figure 2).
3. The new packet is transmitted to the IPsec peer router.

Figure 7.6: IPsec implementations

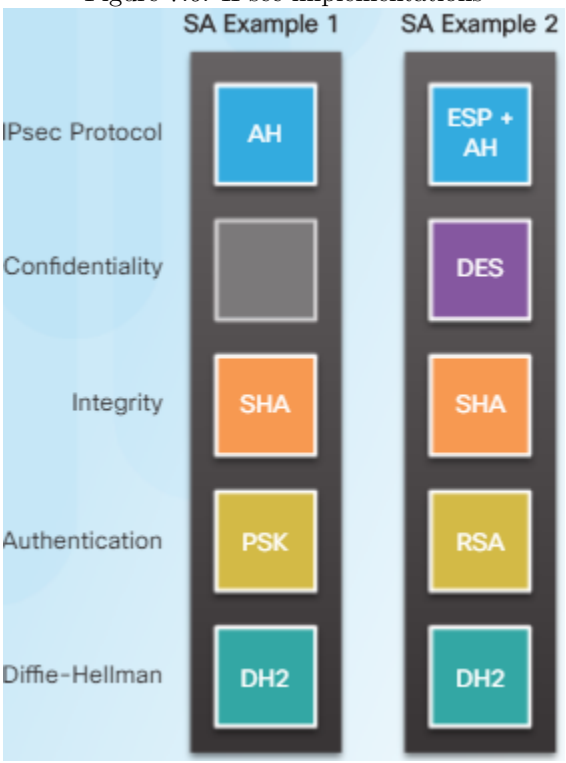
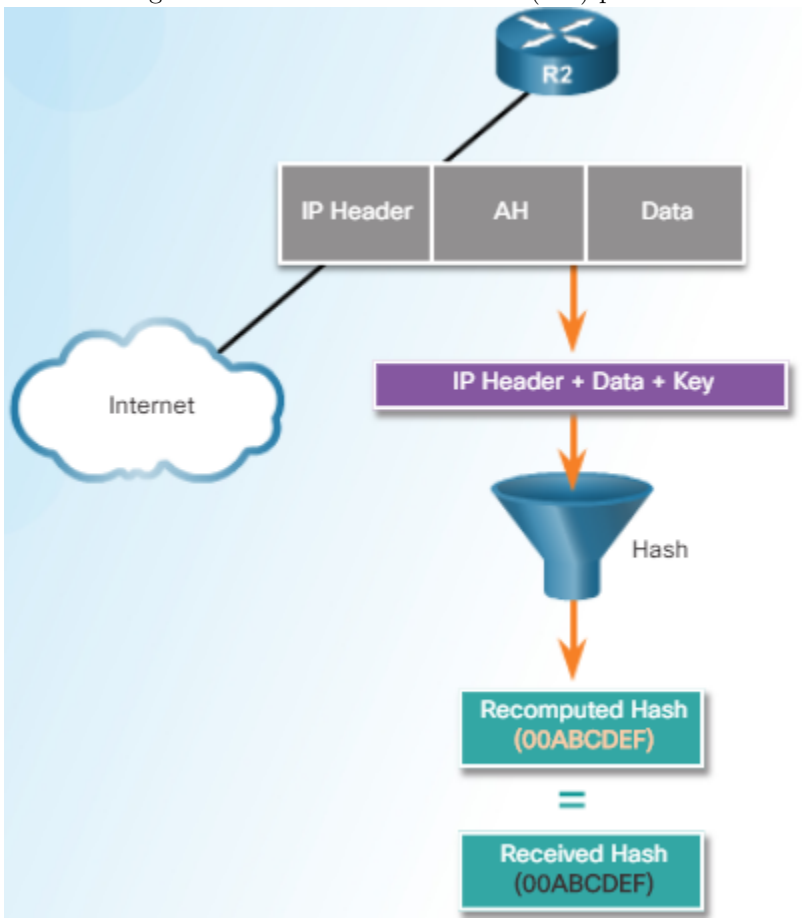


Figure 7.7: Authentication header (AH) process

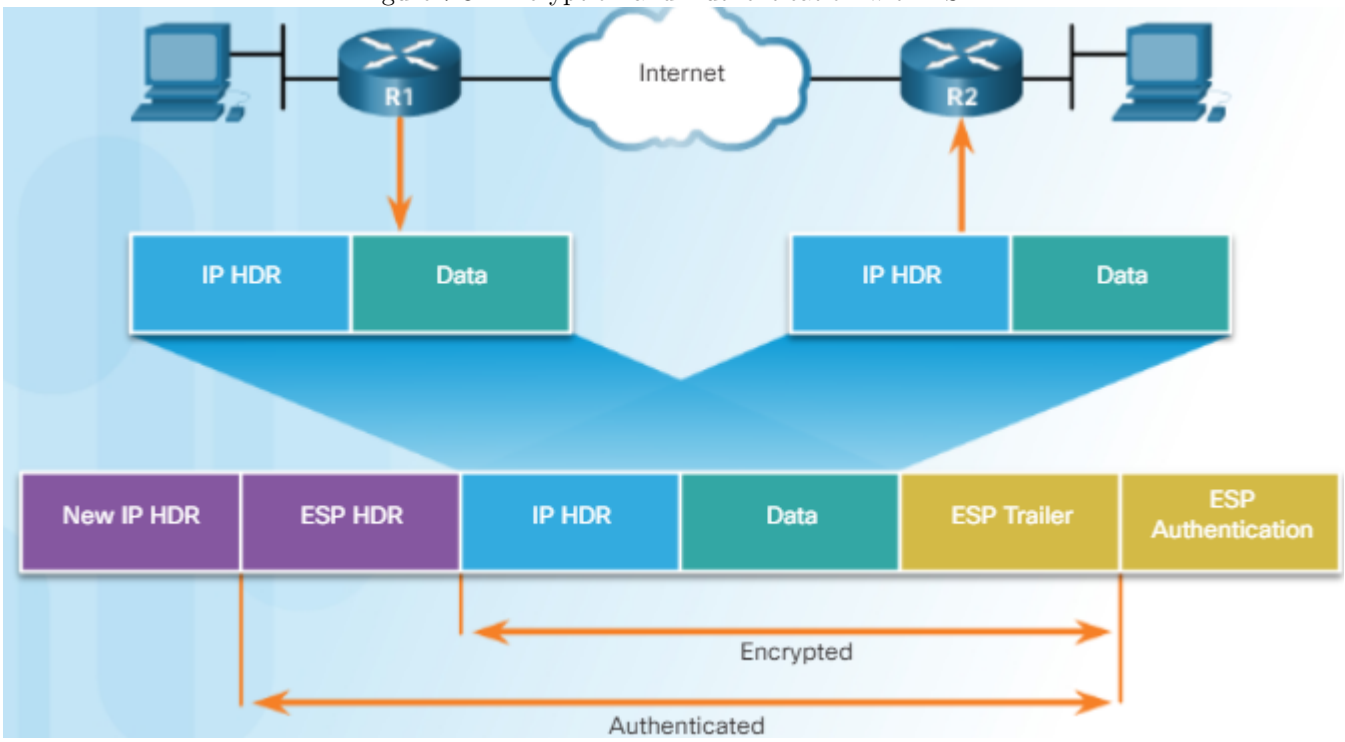


4. The peer router hashes the IP header and data payload using the shared secret key, extracts the transmitted hash from the AH header, and compares the two hashes (Figure 7.7). The hashes must match exactly.

7.3.2 Encapsulation Security Protocol (ESP)

ESP provides **confidentiality** by encrypting the entire original IP datagram and ESP trailer. If ESP is selected as the IPsec protocol, an encryption algorithm must also be selected. The default algorithm for IPsec is 56-bit DES. ESP can also provide **integrity** and **authentication**.

Figure 7.8: Encryption and Authentication with ESP



Optionally, ESP can also enforce anti-replay protection. **Anti-replay protection** verifies that each packet is unique and is not duplicated. This protection ensures that a hacker cannot intercept packets and insert changed packets into the data stream. Anti-replay works by keeping track of packet sequence numbers and using a sliding window on the destination end.
Looking at figure 7.8, ESP process starts with encrypting the payload (IP datagram and ESP trailer). Then, the newly encrypted data and the ESP header are included in the hashing process. Next, a new IP header is attached to the authenticated payload. The new IP address is used to route the packet through the Internet.

7.3.3 Transport and Tunnel modes

ESP and AH can be applied to IP packets in two different modes, transport mode and tunnel mode.

In **ESP transport mode**, security is provided only for the transport layer of the OSI model and above. Transport mode protects the payload of the packet but leaves the original IP address in plaintext. The original IP address is used to route the packet through the Internet. ESP transport mode is used between hosts.

ESP tunnel mode provides security for the complete original IP packet. The original IP packet is encrypted and then it is encapsulated in another IP packet. This is known as IP-in-IP encryption. The IP address on the outside IP packet is used to route the packet through the Internet. ESP tunnel mode is used between a host and a security gateway, or between two security gateways.

AH transport mode provides authentication and integrity for the entire packet. It does not encrypt the data, but it is protected from modification.

AH tunnel mode encapsulates the IP packet with an AH and a new IP header, and signs the entire packet for integrity and authentication.

7.4 IPsec key exchange

7.4.1 IKE protocol

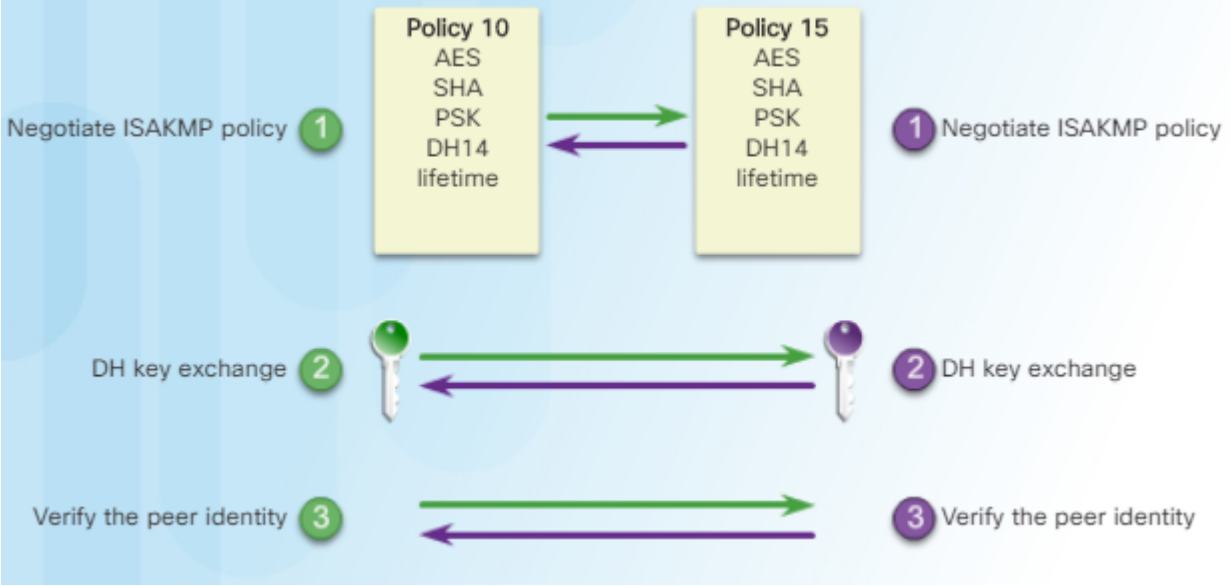
The Internet Key Exchange (IKE) protocol is a key management protocol standard. IKE is used in conjunction with the IPsec standard. IKE automatically negotiates IPsec security associations and enables IPsec secure communications.

Instead of transmitting keys directly across a network, IKE calculates shared keys based on the exchange of a series of data packets. This disables a third party from decrypting the keys even if the third party captured all of the exchanged data that was used to calculate the keys.

IKE uses **UDP port 500** to exchange IKE information between the security gateways. UDP port 500 packets must be permitted on any IP interface that is connecting a security gateway peer.

7.4.2 IKE phase 1

Figure 7.9: IKE phase 1 – Negotiate ISAKMP policy to create a tunnel



IKE uses ISAKMP for phase 1 and phase 2 of key negotiation. In Phase 1 (figure 7.9), the following tasks are performed in order:

1. IPsec peers authenticate each other.
2. Negotiate a matching IKE SA policy to protect the exchange
3.

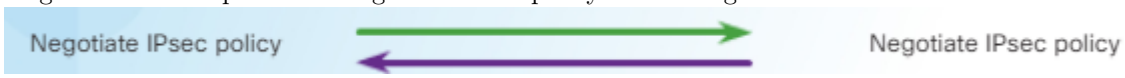
two IPsec peers perform the initial negotiation to ensure that SAs (ISAKMP policy) on both sides are matched. This phase also authenticates the peers, and sets up a secure tunnel between the peers. This tunnel will then be used in Phase 2 to negotiate the IPsec policy.

Phase 1 can be implemented in main mode or aggressive mode. When **main mode** is used, the identities of the two IKE peers are hidden. **Aggressive mode** takes less time than main mode to negotiate keys between peers. However, since the authentication hash is sent unencrypted before the tunnel is established, aggressive mode is vulnerable to brute-force attacks.

7.4.3 IKE phase 2

The purpose of IKE Phase 2 is to negotiate the IPsec security parameters (figure 7.10). IKE Phase 2 is called quick mode and can only occur after IKE has established a secure tunnel in Phase 1. In this phase, the SAs that IPsec uses are unidirectional; therefore, a separate key exchange is required for each data flow.

Figure 7.10: IKE phase 2 – Negotiate IPsec policy for sending secure traffic accross the tunnel



Quick mode also renegotiates a new IPsec SA when the IPsec SA lifetime expires. Basically, quick mode refreshes the keying material that creates the shared secret key. This is based on the keying material that is derived from the DH exchange in Phase 1.

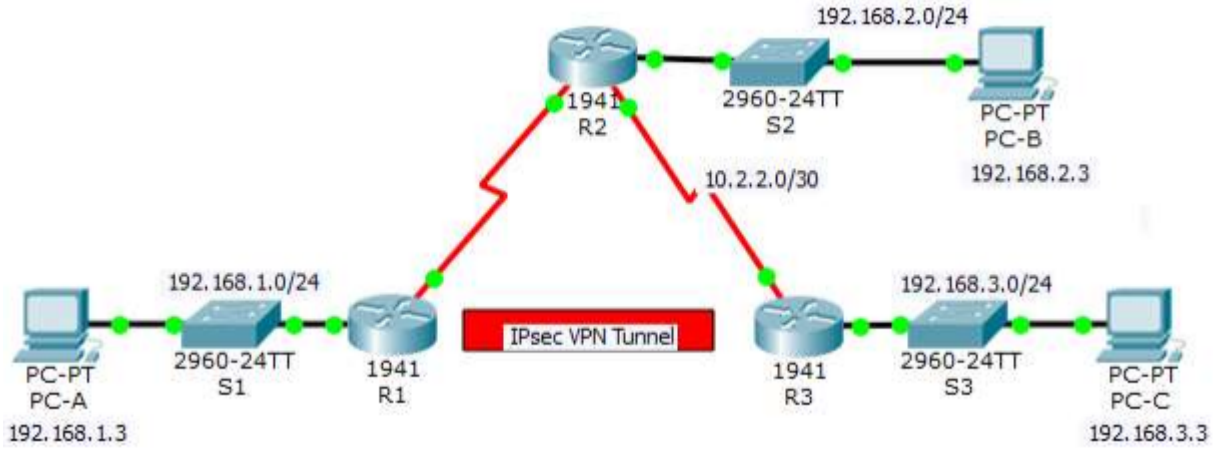
7.4.4 IPsec negotiation

IPsec negotiation to establish a VPN involves five steps, which include IKE Phase 1 and Phase 2:

1. An ISAKMP tunnel is initiated when host A sends "interesting" traffic to host B. Traffic is considered interesting when it travels between the peers and meets the criteria that are defined in an ACL.
2. IKE Phase 1 begins. The peers negotiate the ISAKMP SA policy. When the peers agree on the policy and are authenticated, a secure tunnel is created.
3. IKE Phase 2 begins. The IPsec peers use the authenticated secure tunnel to negotiate the IPsec SA policy. The negotiation of the shared policy determines how the IPsec tunnel is established.
4. The IPsec tunnel is created, and data is transferred between the IPsec peers based on the IPsec SAs.
5. The IPsec tunnel terminates when the IPsec SAs are manually deleted, or when their lifetime expires.

7.5 Site-to-site IPsec configuration

Figure 7.11: Site-to-site VPN topology



The configuration tasks for the topology in figure 7.11 are shown in order as below:

1. Test connectivity
2. Enable the Security Technology package
3. Identify interesting traffic: Configure ACL to identify the traffic from the LAN on R1 to the LAN on R3 as interesting. This interesting traffic will trigger the IPsec VPN to be implemented when there is traffic between the R1 to R3 LANs.
4. Configure the IKE Phase 1 ISAKMP policy on R1 (encryption method, key exchange method, and DH method)
5. Configure the IKE Phase 2 IPsec policy on R1. First, we create the transform-set VPN-SET to use esp-aes and esp-sha-hmac. Next, a crypto map VPN-MAP is created to bind all of the Phase 2 parameters together. Use sequence number 10 and identify it as an ipsec-isakmp map.
6. Configure the crypto map on the outgoing interface.
7. Repeat the above steps on R3.

Listing 31: Site-to-site IPsec

```
#STEP 2
license boot module c1900 technology-package securityk9

#STEP 3
access-list 110 permit ip 192.168.1.0 0.0.0.255 192.168.3.0
0.0.0.255

#STEP 4
crypto isakmp policy 10
        encryption aes 256
        authentication pre-share
        group 5
        exit
crypto isakmp key vpnpa55 address 10.2.2.2

#STEP 5
crypto ipsec transform-set VPN-SET esp-aes esp-sha-hmac
crypto map VPN-MAP 10 ipsec-isakmp
        description VPN connection to R3
        set peer 10.2.2.2
        set transform-set VPN-set
        match address 110
        exit

#STEP 6
interface s0/0/0
        crypto map VPN-MAP
        exit

#VERIFICATION
show crypto isakmp sa
show crypto ipsec sa
```