Cryptography and Network Security Chapter 19

Chapter 19 – IP Security

If a secret piece of news is divulged by a spy before the time is ripe, he must be put to death, together with the man to whom the secret was told.

—*The Art of War*, Sun Tzu

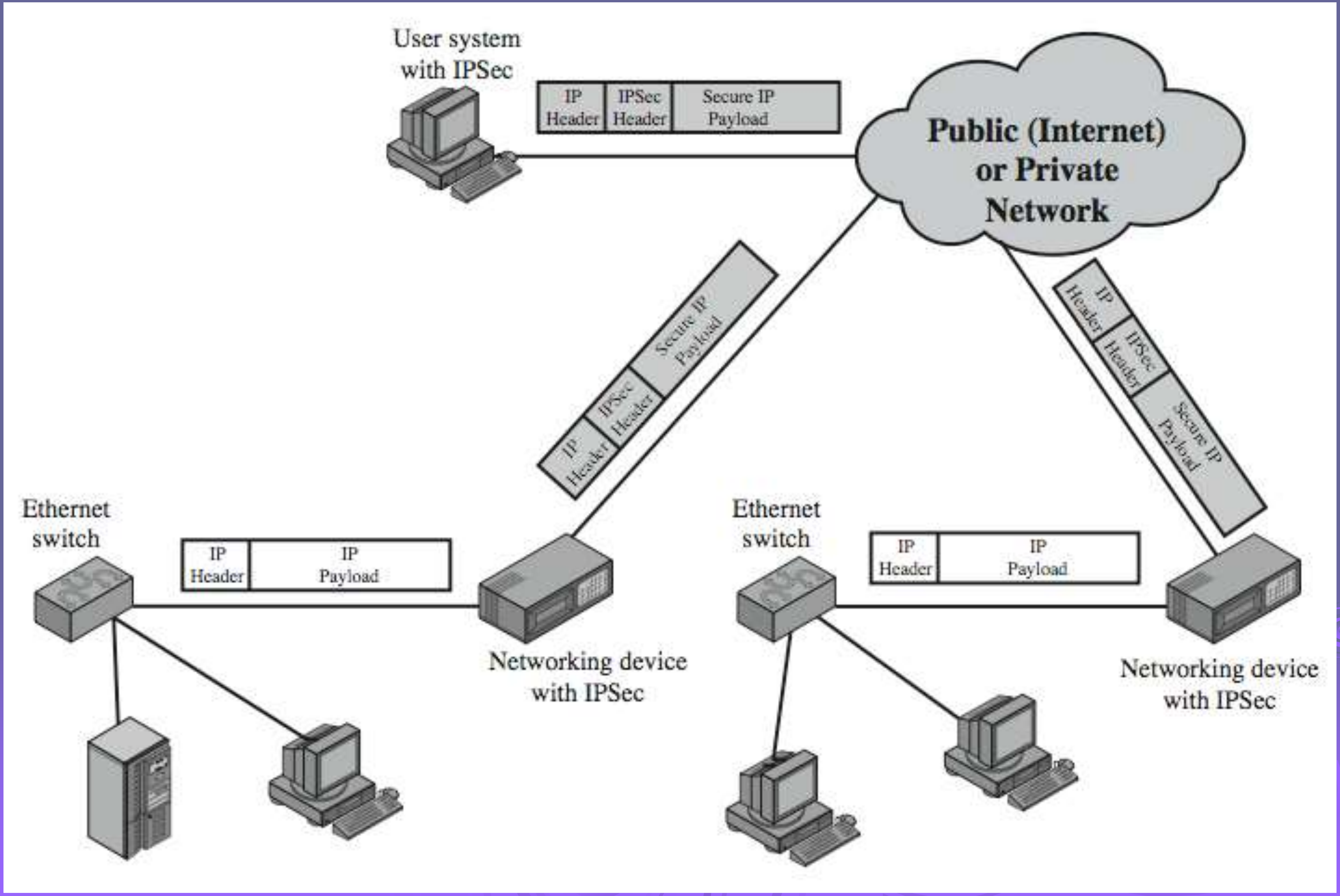
IP Security

- have a range of application specific security mechanisms
  - eg. S/MIME, PGP, Kerberos, SSL/HTTPS
- however there are security concerns that cut across protocol layers
- would like security implemented by the network for all applications

IP Security

- general IP Security mechanisms
- provides
  - authentication
  - confidentiality
  - key management
- applicable to use over LANs, across public & private WANs, & for the Internet
- need identified in 1994 report
  - need authentication, encryption in IPv4 & IPv6

IP Security Uses



Benefits of IPSec

- in a firewall/router provides strong security to all traffic crossing the perimeter
- in a firewall/router is resistant to bypass
- is below transport layer, hence transparent to applications
- can be transparent to end users
- can provide security for individual users
- secures routing architecture

IP Security Architecture

- specification is quite complex, with groups:
  - Architecture
    - RFC4301 *Security Architecture for Internet Protocol*
  - Authentication Header (AH)
    - RFC4302 *IP Authentication Header*
  - Encapsulating Security Payload (ESP)
    - RFC4303 *IP Encapsulating Security Payload (ESP)*
  - Internet Key Exchange (IKE)
    - RFC4306 *Internet Key Exchange (IKEv2) Protocol*
  - Cryptographic algorithms
  - Other

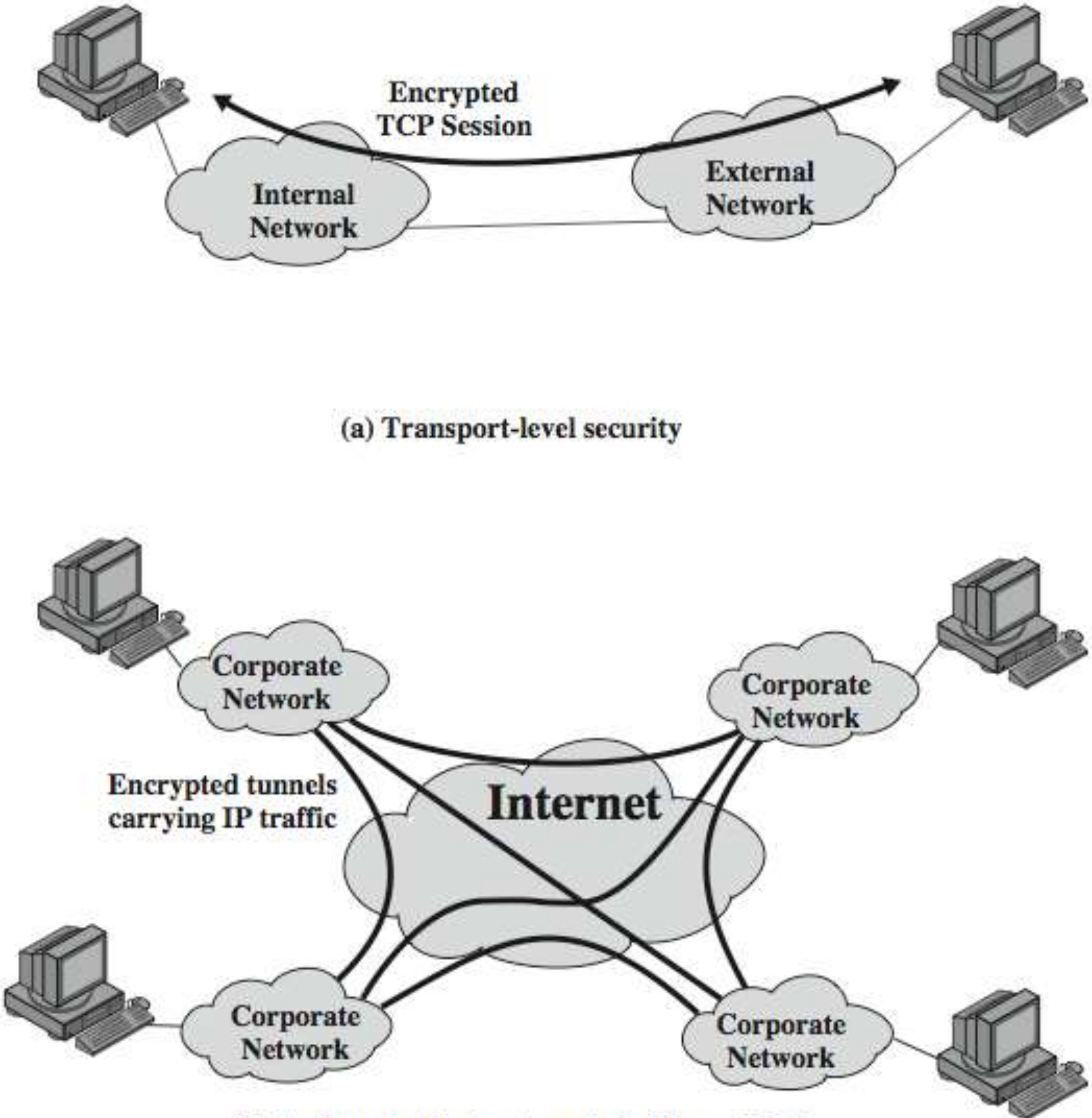
IPSec Services

- Access control
- Connectionless integrity
- Data origin authentication
- Rejection of replayed packets
  - a form of partial sequence integrity
- Confidentiality (encryption)
- Limited traffic flow confidentiality

Transport and Tunnel Modes

- Transport Mode
  - to encrypt & optionally authenticate IP data
  - can do traffic analysis but is efficient
  - good for ESP host to host traffic
- Tunnel Mode
  - encrypts entire IP packet
  - add new header for next hop
  - no routers on way can examine inner IP header
  - good for VPNs, gateway to gateway security

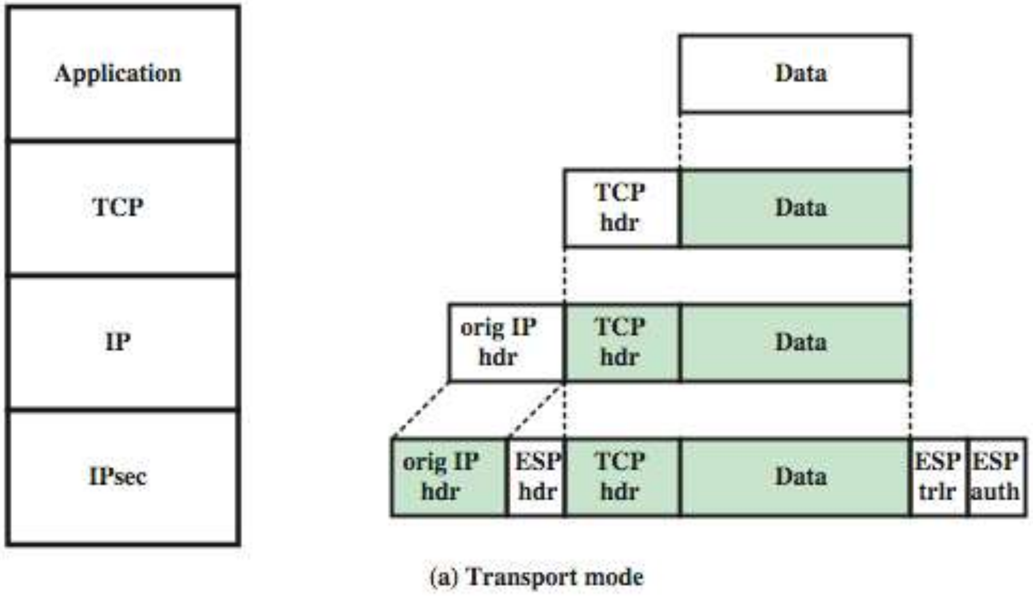
Transport and Tunnel Modes



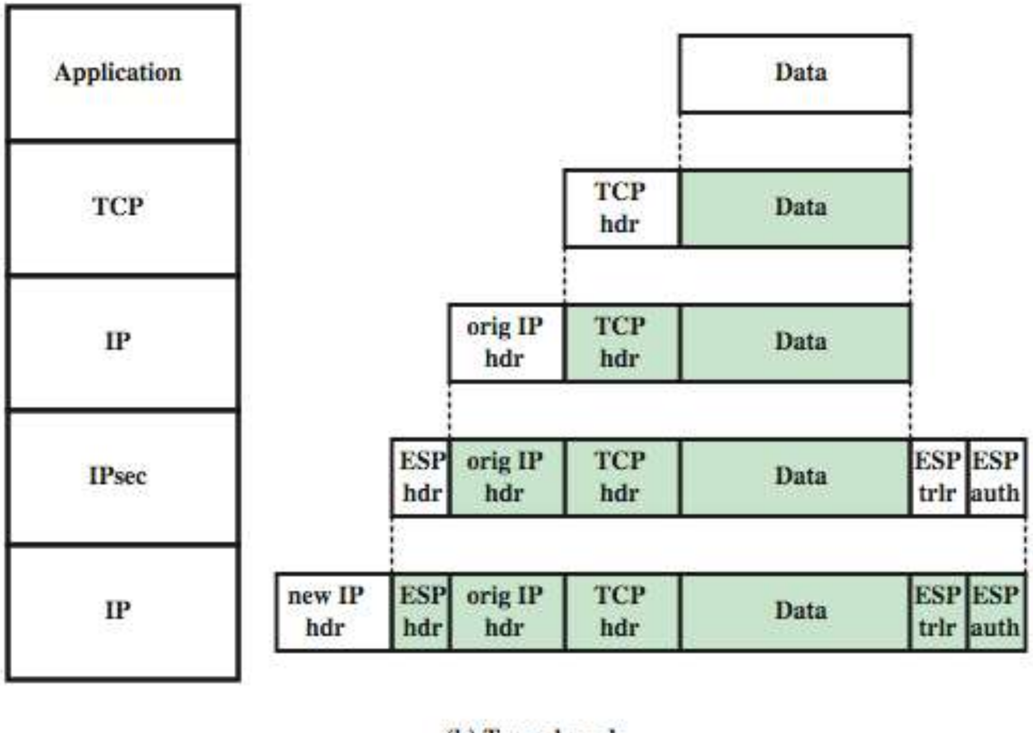
(a) Transport-level security

(b) A virtual private network via Tunnel Mode

Transport and Tunnel Mode Protocols



(a) Transport mode



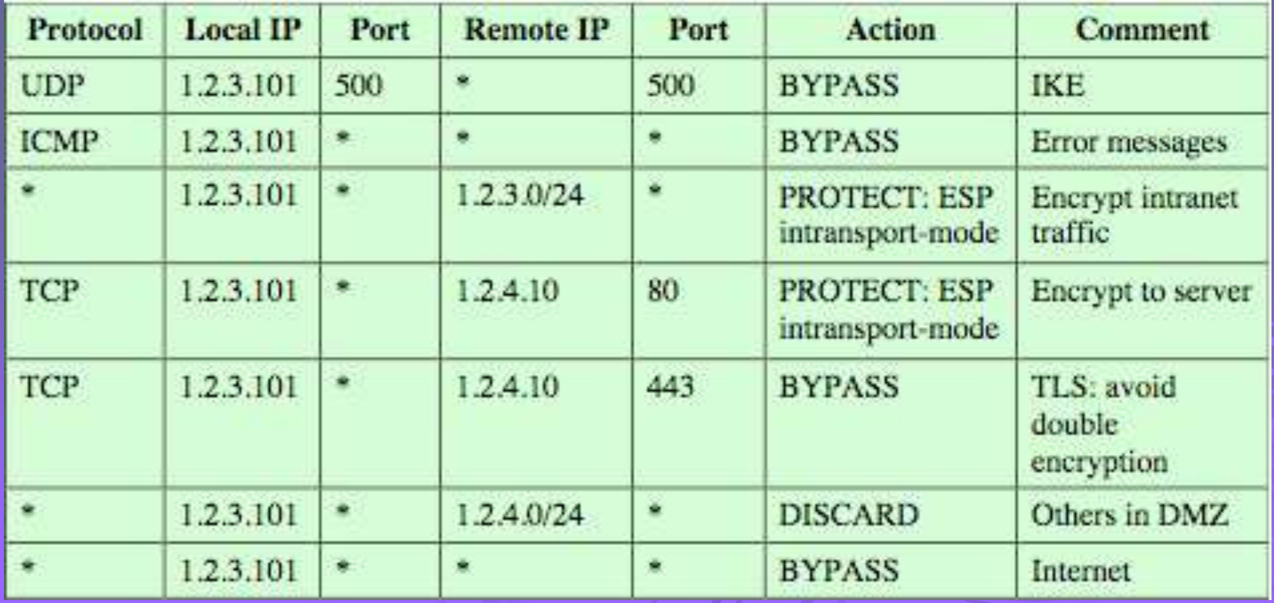
(b) Tunnel mode

Security Associations

- a one-way relationship between sender & receiver that affords security for traffic flow
- defined by 3 parameters:
  - Security Parameters Index (SPI)
  - IP Destination Address
  - Security Protocol Identifier
- has a number of other parameters
  - seq no, AH & EH info, lifetime etc
- have a database of Security Associations

Security Policy Database

- relates IP traffic to specific SAs
  - match subset of IP traffic to relevant SA
  - use selectors to filter outgoing traffic to map
  - based on: local & remote IP addresses, next layer protocol, name, local & remote ports

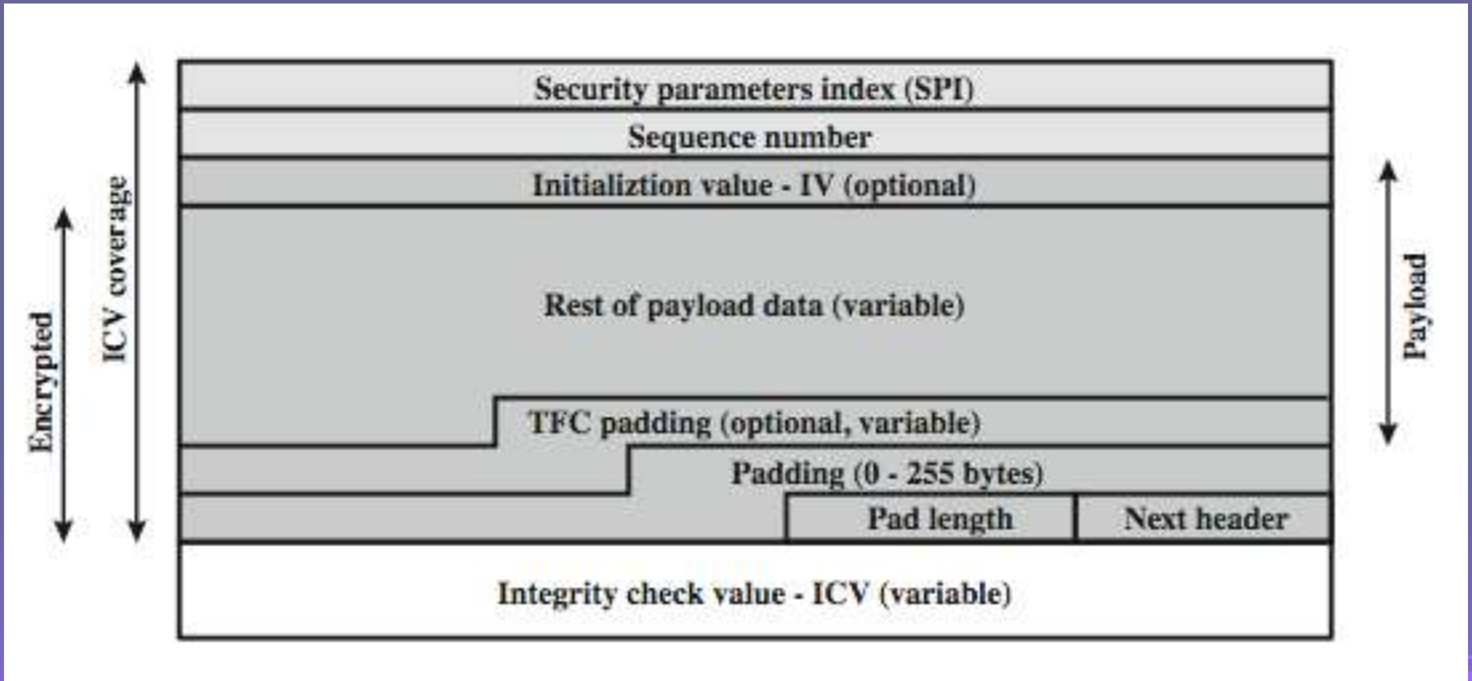


Protocol	Local IP	Port	Remote IP	Port	Action	Comment
UDP	1.2.3.101	500	*	500	BYPASS	IKE
ICMP	1.2.3.101	*	*	*	BYPASS	Error messages
*	1.2.3.101	*	1.2.3.0/24	*	PROTECT: ESP intransport-mode	Encrypt intranet traffic
TCP	1.2.3.101	*	1.2.4.10	80	PROTECT: ESP intransport-mode	Encrypt to server
TCP	1.2.3.101	*	1.2.4.10	443	BYPASS	TLS: avoid double encryption
*	1.2.3.101	*	1.2.4.0/24	*	DISCARD	Others in DMZ
*	1.2.3.101	*	*	*	BYPASS	Internet

Encapsulating Security Payload (ESP)

- provides message content confidentiality, data origin authentication, connectionless integrity, an anti-replay service, limited traffic flow confidentiality
- services depend on options selected when establish Security Association (SA), net location
- can use a variety of encryption & authentication algorithms

Encapsulating Security Payload


Security parameters index (SPI)
Sequence number
Initializtion value - IV (optional)
Rest of payload data (variable)
TFC padding (optional, variable)
Padding (0 - 255 bytes)
Pad length
Next header
Integrity check value - ICV (variable)
Encrypted
ICV coverage
Payload

Encryption & Authentication Algorithms & Padding

- ESP can encrypt payload data, padding, pad length, and next header fields
  - if needed have IV at start of payload data
- ESP can have optional ICV for integrity
  - is computed after encryption is performed
- ESP uses padding
  - to expand plaintext to required length
  - to align pad length and next header fields
  - to provide partial traffic flow confidentiality

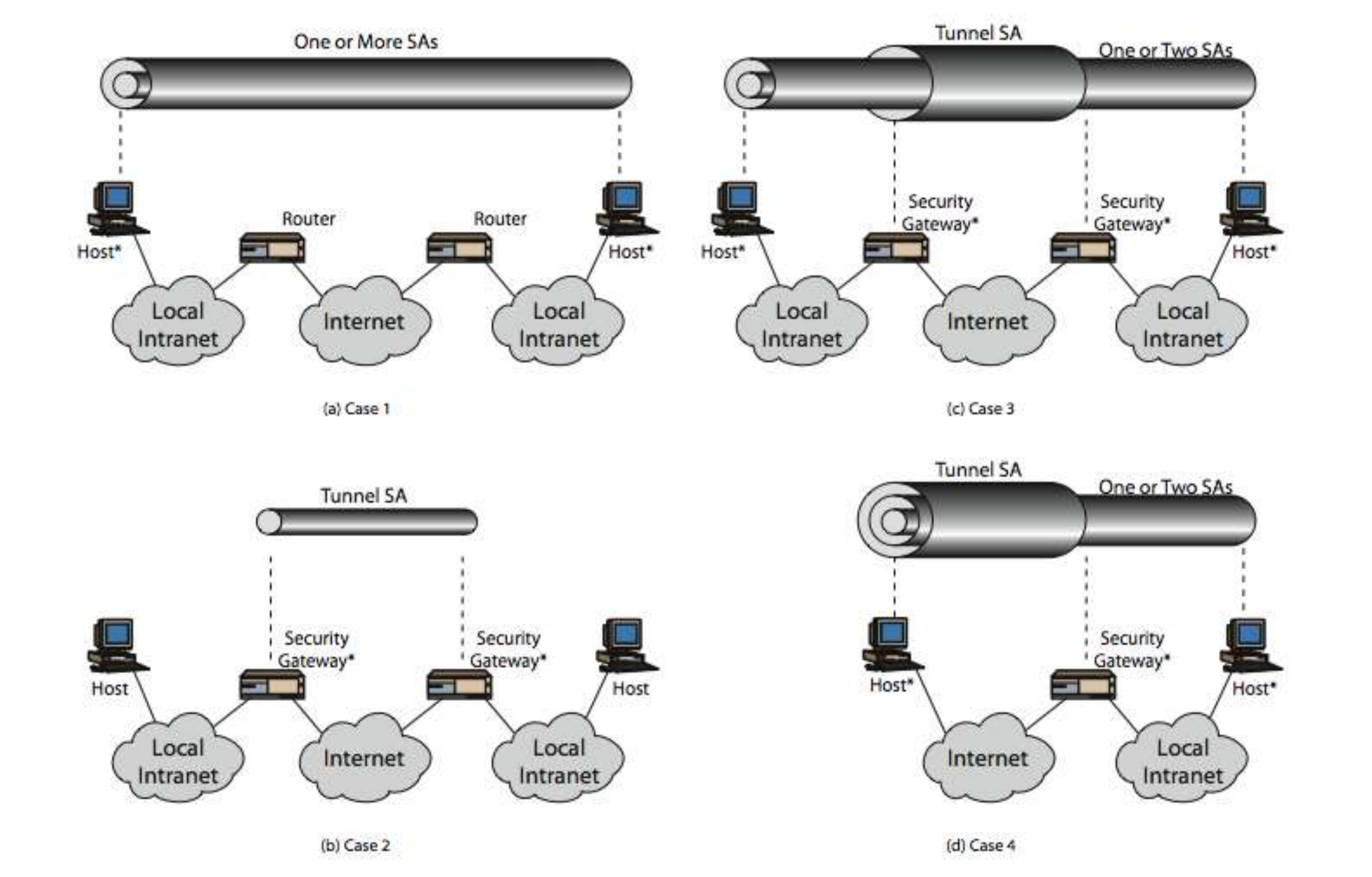
Anti-Replay Service

- replay is when attacker resends a copy of an authenticated packet
- use sequence number to thwart this attack
- sender initializes sequence number to 0 when a new SA is established
  - increment for each packet
  - must not exceed limit of $2^{32} – 1$
- receiver then accepts packets with seq no within window of (*N –W+1*)

Combining Security Associations

- SA’s can implement either AH or ESP
- to implement both need to combine SA’s
  - form a security association bundle
  - may terminate at different or same endpoints
  - combined by
    - transport adjacency
    - iterated tunneling
- combining authentication & encryption
  - ESP with authentication, bundled inner ESP & outer AH, bundled inner transport & outer ESP

Combining Security Associations



(a) Case 1

(c) Case 3

(b) Case 2

(d) Case 4

IPSec Key Management

- handles key generation & distribution
- typically need 2 pairs of keys
  - 2 per direction for AH & ESP
- manual key management
  - sysadmin manually configures every system
- automated key management
  - automated system for on demand creation of keys for SA's in large systems
  - has Oakley & ISAKMP elements

Summary

- have considered:
  - IPSec security framework
  - IPSec security policy
  - ESP
  - combining security associations
  - internet key exchange
  - cryptographic suites used

What is a Firewall?

- a choke point of control and monitoring
- interconnects networks with differing trust
- imposes restrictions on network services
- only authorized traffic is allowed
- auditing and controlling access
- can implement alarms for abnormal behaviour
- provide NAT & usage monitoring
- implement VPNs using IPSec
- must be immune to penetration

Firewall Limitations:

- cannot protect from attacks bypassing it
  eg: sneaker net, utility modems, trusted organisations, trusted services (eg SSL/SSH)

- cannot protect against internal threats
  eg: disgruntled or colluding employees

- cannot protect against transfer of all virus infected programs or files because of huge range of O/S & file types

- A laptop, PDA, or portable storage device may be used and infected outside the corporate network, and then attached and used internally.

Firewall Characterstics:

- All traffic from inside to outside, and vice versa, must pass through the firewall. This is achieved by physically blocking all access to the local network except via the firewall.
- Only authorized traffic, as defined by the local security policy, will be allowed to pass. Various types of firewalls are used, which implement various types of security policies.
- The firewall itself is immune to penetration. This implies the use of a hardened system with a secured operating system. Trusted computer systems are suitable for hosting a firewall and often required in government applications.

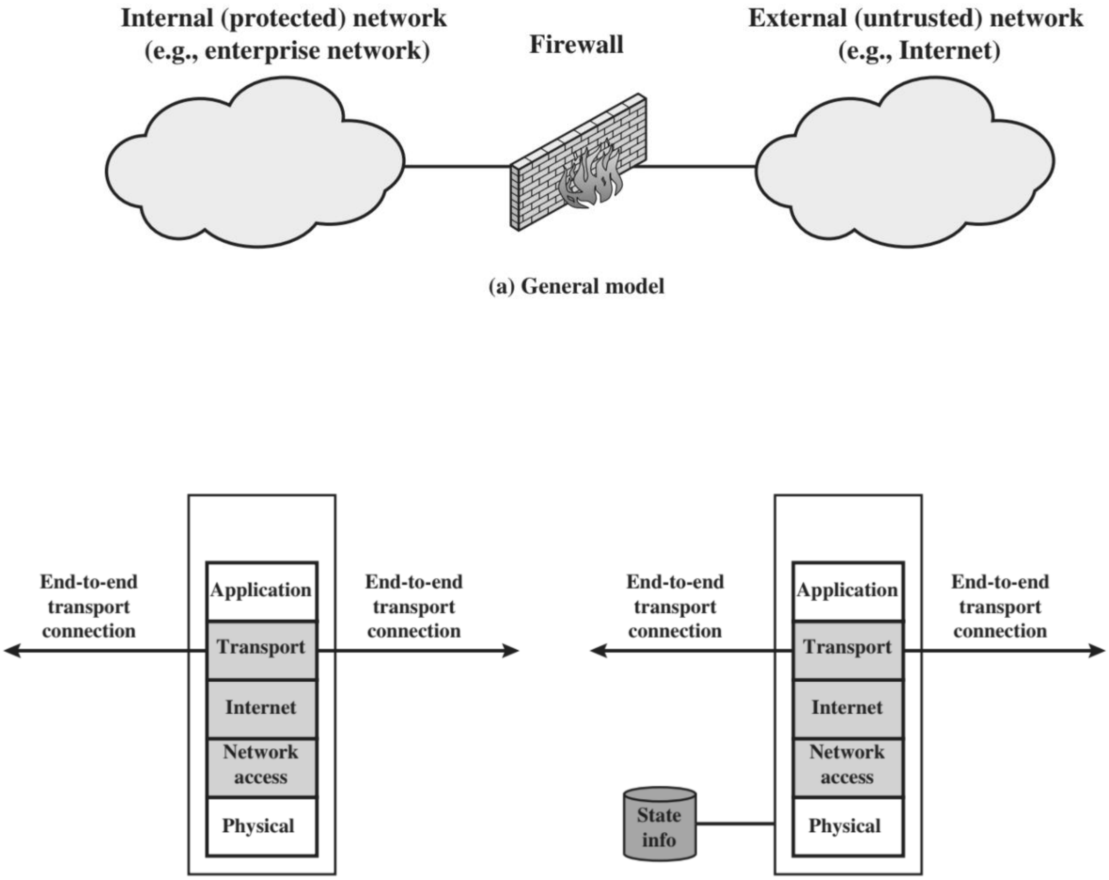
Four general techniques that firewalls use to control access and enforce the site's security policy:

- **Service control:** Determines the types of Internet services that can be accessed, inbound or outbound. The firewall may filter traffic on the basis of IP address, protocol, or port number
- **Direction control:** Determines the direction in which particular service requests may be initiated and allowed to flow through the firewall.
- **User control:** Controls access to a service according to which user is attempting to access it.
- **Behaviour control:** Controls how particular services are used. For example, the firewall may filter e-mail to eliminate spam, or it may enable external access to only a portion of the information on a local Web server.

Types of Firewall :

- A firewall may act as a packet filter. It can operate as a positive filter, allowing to pass only packets that meet specific criteria, or as a negative filter, rejecting any packet that meets certain criteria.
- Depending on the type of firewall, it may examine one or more protocol headers in each packet, the payload of each packet, or the pattern generated by a sequence of packets.

22-6 CHAPTER 22 / FIREWALLS



(a) General model

(b) Packet filtering firewall

(c) Stateful inspection firewall

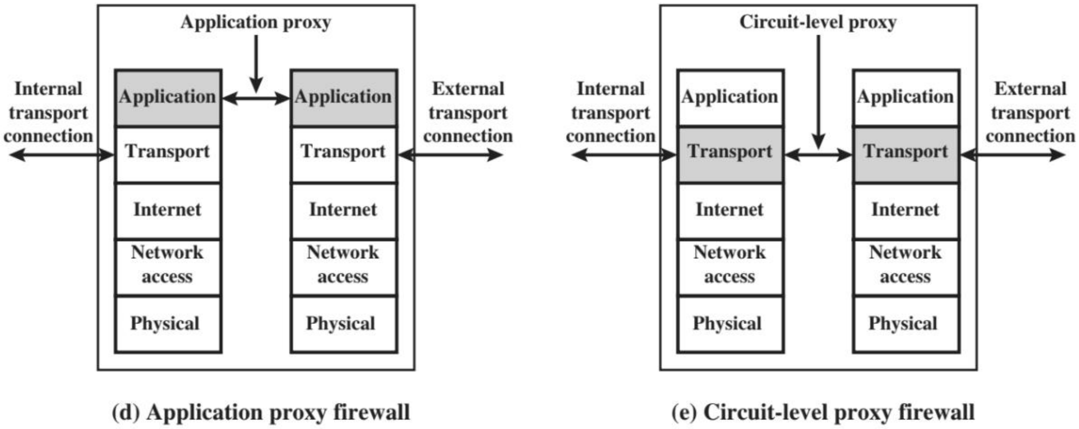


Figure 22.1 Types of Firewalls

1)Packet Filter :

- A packet filtering firewall applies a set of rules to each incoming and outgoing IP packet and then forwards or discards the packet.
- The firewall is typically configured to filter packets going in both directions (from and to the internal network).
- Filtering rules are based on information contained in a network packet:
  • **Source IP address**: The IP address of the system that originated the IP packet (e.g., 192.178.1.1)
  • **Destination IP address**: The IP address of the system the IP packet is trying to reach (e.g., 192.168.1.2)
  • **Source and destination transport-level address**: The transport-level (e.g., TCP or UDP) port number, which defines applications such as SNMP or TELNET
  • **IP protocol field**: Defines the transport protocol
  • **Interface**: For a firewall with three or more ports, which interface of the firewall the packet came from or which interface of the firewall the packet is destined for
- The packet filter is typically set up as a list of rules based on matches to fields in the IP or TCP header. If there is a match to one of the rules, that rule is invoked to determine whether to forward or discard the packet. If there is no match to any rule, then a default action is taken. Two default policies are possible:
  - Default = discard: That which is not expressly permitted is prohibited.
  - Default = forward: That which is not expressly prohibited is permitted.

Screeing policy actions

Forward : The package is forwarded to the intended recipient
Drop : The packages is dropped (without notification)
Reject : The package is rejected (with notification)
Log : The packages appearance is logged (to be combined)
Alarm : The packages appearance triggers an alarm (to be combined)

Screening policies

There should always be some default rules

- The last rule should be “Drop everything from Everyone” which enforce a defensive strategy
- Network monitoring and control messages should be considered

Attacks on Packet Filters

IP address spoofing

- fake source address to be trusted
- add filters on router to block

source routing attacks

- attacker sets a route other than default
- block source routed packets

tiny fragment attacks

- split header info over several tiny packets
- either discard or reassemble before check

2) Stateful Inspection Firewalls

A traditional packet filter makes filtering decisions on an individual packet basis and does not take into consideration any higher layer context.

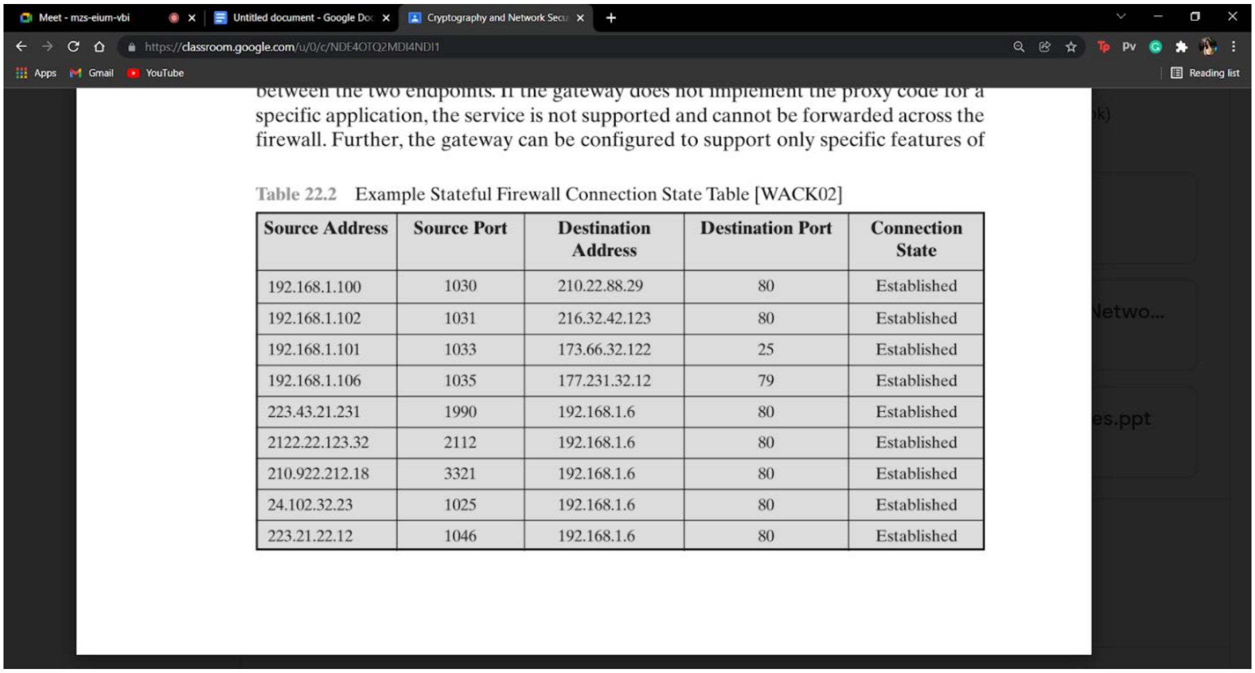
- Most standardized applications that run on top of TCP follow a client/server model.
- For example, for the Simple Mail Transfer Protocol (SMTP), e-mail is transmitted from a client system to a server system. The client system generates new e-mail messages, typically from user input. The server system accepts incoming e-mail messages and places them in the appropriate user mailboxes.
- SMTP operates by setting up a TCP connection between client and server, in which the TCP server port number, which identifies the SMTP server application, is 25. The TCP port number for the SMTP client is a number between 1024 and 65535 that is generated by the SMTP client.
- In general, when an application that uses TCP creates a session with a remote host, it creates a TCP connection in which the TCP port number for the remote (server) application is a number less than 1024 and the TCP port number for the local (client) application is a number between 1024 and 65535.The numbers less than 1024 are the “well-known” port numbers and are assigned permanently to particular applications (e.g., 25 for server SMTP). The numbers between 1024 and 65535 are generated dynamically and have temporary significance only for the lifetime of a TCP connection.
- A simple packet filtering firewall must permit inbound network traffic on all these high-numbered ports for TCP-based traffic to occur. This creates a vulnerability that can be exploited by unauthorized users.

A stateful inspection packet firewall tightens up the rules for TCP traffic by creating a directory of outbound TCP connections, as shown in Table 22.2. There is an entry for each currently established connection. The packet filter will now allow incoming traffic to high-numbered ports only for those packets that fit the profile of one of the entries in this directory. A stateful packet inspection firewall reviews the same packet information as a packet filtering firewall, but also records information about TCP connections (Figure 22.1c). Some stateful firewalls also keep track of TCP sequence numbers to prevent attacks that depend on the sequence number, such as session hijacking.

3) Application-Level Gateway

An application-level gateway, also called an application proxy, acts as a relay of application-level traffic (Figure 22.1d).

- The user contacts the gateway using a TCP/IP application, such as Telnet or FTP, and the gateway asks the user for the name of the remote host to be accessed. When the user responds and provides a valid user ID and authentication information, the gateway contacts the application on the remote host and relays TCP segments containing the application data between the two endpoints.
- If the gateway does not implement the proxy code for a specific application, the service is not supported and cannot be forwarded across the firewall.
- Application-level gateways tend to be more secure than packet filters
- the application-level gateway need only scrutinize a few allowable applications. In addition, it is easy to log and audit all incoming traffic at the application level.
- A prime disadvantage of this type of gateway is the additional processing overhead on each connection. In effect, there are two spliced connections between the end users, with the gateway at the splice point, and the gateway must examine and forward all traffic in both directions.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between the two endpoints. If the gateway does not implement the proxy code for a specific application, the service is not supported and cannot be forwarded across the firewall. Further, the gateway can be configured to support only specific features of

Table 22.2 Example Stateful Firewall Connection State Table [WACK02]

Source Address	Source Port	Destination Address	Destination Port	Connection State
192.168.1.100	1030	210.22.88.29	80	Established
192.168.1.102	1031	216.32.42.123	80	Established
192.168.1.101	1033	173.66.32.122	25	Established
192.168.1.106	1035	177.231.32.12	79	Established
223.43.21.231	1990	192.168.1.6	80	Established
2122.22.123.32	2112	192.168.1.6	80	Established
210.922.212.18	3321	192.168.1.6	80	Established
24.102.32.23	1025	192.168.1.6	80	Established
223.21.22.12	1046	192.168.1.6	80	Established

4) Circuit-Level Gateway

A fourth type of firewall is the circuit-level gateway or circuit-level proxy. 22.1e).

- This can be a stand-alone system or it can be a specialized function performed by an application-level gateway for certain applications.
- As with an application gateway, a circuit-level gateway does not permit an end-to-end TCP connection; rather, the gateway sets up two TCP connections, one between itself and a TCP user on an inner host and one between itself and a TCP user on an outside host.
- Once the two connections are established, the gateway typically relays TCP segments from one connection to the other without examining the contents. The security function consists of determining which connections will be Allowed.

- A typical use of circuit-level gateways is a situation in which the system administrator trusts the internal users.
- The gateway can be configured to support application-level or proxy service on inbound connections and circuit-level functions for outbound connections. In this configuration, the gateway can incur the processing overhead of examining incoming application data for forbidden functions but does not incur that overhead on outgoing data.
- An example of a circuit-level gateway implementation is the SOCKS package [KOBL92]; version 5 of SOCKS is specified in RFC 1928. The RFC defines SOCKS in the following fashion:

The protocol described here is designed to provide a framework for client-server applications in both the TCP and UDP domains to conveniently and securely use the services of a network firewall.

The protocol is conceptually a “shim-layer” between the application layer and the transport layer, and as such does not provide network- layer gateway services, such as forwarding of ICMP messages.

SOCKS consists of the following components:

• The SOCKS server, which often runs on a UNIX-based firewall. SOCKS is also implemented on Windows systems.

• The SOCKS client library, which runs on internal hosts protected by the firewall.

• SOCKS-ified versions of several standard client programs such as FTP and TELNET.

The implementation of the SOCKS protocol typically involves either the recompilation or relinking of TCP-based client applications, or the use of alternate dynamically loaded libraries, to use the appropriate encapsulation routines in the SOCKS library.

When a TCP-based client wishes to establish a connection to an object that is reachable only via a firewall (such determination is left up to the implementation), it must open a TCP connection to the appropriate SOCKS port on the SOCKS server system.The SOCKS service is located on TCP port 1080. If the connection request succeeds, the client enters a negotiation for the authentication method to be used, authenticates with the chosen method, and then sends a relay request. The SOCKS server evaluates the request and either establishes the appropriate connection or denies it. UDP exchanges are handled in a similar fashion. In essence, a TCP connection is opened to authenticate a user to send and receive UDP segments, and the UDP segments are forwarded as long as the TCP connection is open.

- ## Firewall basing

It is common to base a firewall on a stand-alone machine running a common operating system, such as UNIX or Linux. Firewall functionality can also be implemented as a software module in a router or LAN switch. In this section, we look at some additional firewall basing considerations

- Bastion Host:

A bastion host is a system identified by the firewall administrator as a critical strong point in the network's security. Typically, the bastion host serves as a platform for an application-level or circuit-level gateway.

- characteristics of a bastion host are as follows:

• The bastion host hardware platform executes a secure version of its operating system, making it a hardened system.
• Only the services that the network administrator considers essential are installed on the bastion host. These could include proxy applications for DNS, FTP, HTTP, and SMTP.
• The bastion host may require additional authentication before a user is allowed access to the proxy services. In addition, each proxy service may require its own authentication before granting user access.
• Each proxy is configured to support only a subset of the standard application's command set.
• Each proxy is configured to allow access only to specific host systems. This means that the limited command/feature set may be applied only to a subset of systems on the protected network

- Host-Based Firewalls:

A host-based firewall is a software module used to secure an individual host. Such modules are available in many operating systems or can be provided as an add-on package. Like conventional stand-alone firewalls, host-resident firewalls filter and restrict the flow of packets. A common location for such firewalls is a server.

- advantages to the use of a server-based :

Filtering rules can be tailored to the host environment. Specific corporate security policies for servers can be implemented, with different filters for servers used for different applications.

• Protection is provided independently of topology. Thus both internal and external attacks must pass through the firewall.

• Used in conjunction with stand-alone firewalls, the host-based firewall provides an additional layer of protection. A new type of server can be added to the network, with its own firewall, without the necessity of altering the network firewall configuration.

- Personal Firewall

A personal firewall controls the traffic between a personal computer or workstation on one side and the Internet or enterprise network on the other side. Personal firewall functionality can be used in the home environment and on corporate intranets. Typically, the personal firewall is a software module on the personal computer. In a home environment with multiple computers connected to the Internet, firewall functionality can also be housed in a router that connects all of the home computers to a DSL, cable modem, or other Internet interfaces.

Personal firewalls are typically much less complex than either server-based firewalls or stand-alone firewalls. The primary role of the personal firewall is to deny unauthorized remote access to the computer. The firewall can also monitor outgoing activity in an attempt to detect and block worms and other malware.

An example of a personal firewall is the capability built into the Mac OS X operating system. When the user enables the personal firewall in Mac OS X, all inbound connections are denied except for those the user explicitly permits.

- Firewall Location and Configurations:Firewall Location and Configurations (brainkart.com)

a firewall is positioned to provide a protective barrier between an external, potentially untrusted source of traffic and an internal network. With that general principle in mind, a security administrator must decide on the location and on the number of firewalls needed.

- DMZ Network:

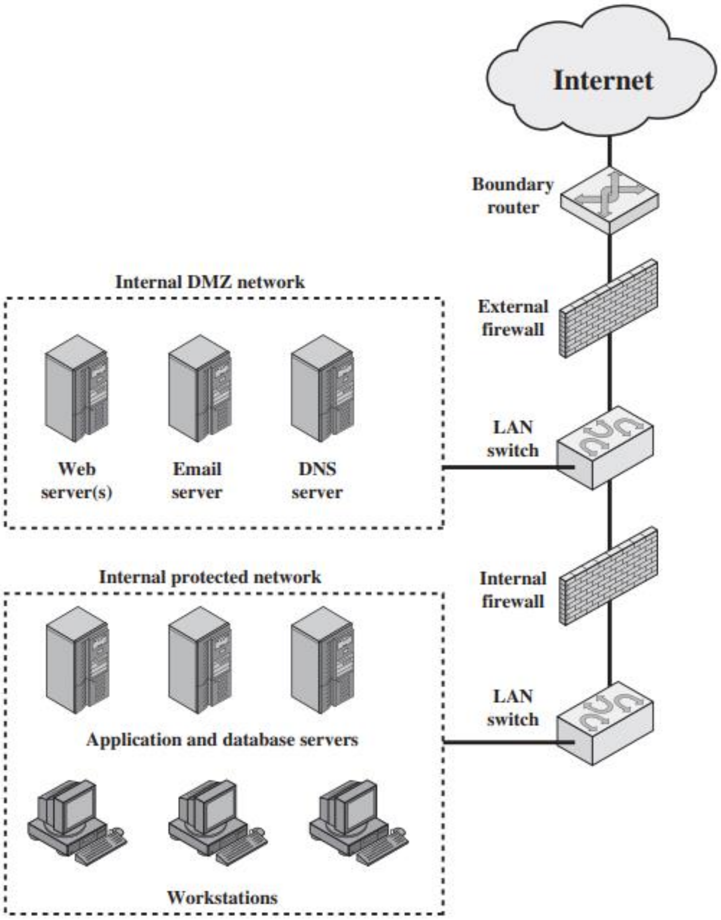

Figure 22.3 Example Firewall Configuration

Figure 22.3 suggests the most common distinction, that between an internal and an external firewall. An external firewall is placed at the edge of a local or enterprise network, just inside the boundary router that connects to the Internet or some wide area network (WAN). One or more internal firewalls protect the bulk of the enter- prise network. Between these two types of firewalls are one or more networked devices in a region referred to as a DMZ (demilitarized zone) network. Systems that are externally accessible but need some protections are usually located on DMZ networks. Typically, the systems in the DMZ require or foster external con- nectivity, such as a corporate Web site, an e-mail server, or a DNS (domain name system) server.

The external firewall provides a measure of access control and protection for the DMZ systems consistent with their need for external connectivity. The external firewall also provides a basic level of protection for the remainder of the enterprise network. In this type of configuration, internal firewalls serve three purposes:

1. The internal firewall adds more stringent filtering capability, compared to the external firewall, in order to protect enterprise servers and workstations from external attack.
2. The internal firewall provides two-way protection with respect to the DMZ. First, the internal firewall protects the remainder of the network from attacks launched from DMZ systems. Such attacks might originate from worms, rootkits, bots, or other malware lodged in a DMZ system. Second, an internal firewall can protect the DMZ systems from attack from the internal protected network.

3. Multiple internal firewalls can be used to protect portions of the internal network from each other. For example, firewalls can be configured so that internal servers are protected from internal workstations and vice versa. A common practice is to place the DMZ on a different network interface on the external firewall from that used to access the internal networks.