UNIT – 4
IP SECURITY

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4.1. IP Security Overview

Applications of IPSec:

IPSec provides the capability to secure communications across a LAN, across private and public WANs, and across the Internet. Examples of its use include the following:

1. **Secure branch office connectivity over the Internet:** A company can build a secure virtual private network over the Internet or over a public WAN. This enables a business to rely heavily on the Internet and reduce its need for private networks, saving costs and network management overhead.
2. **Secure remote access over the Internet:** An end user whose system is equipped with IP security protocols can make a local call to an Internet service provider (ISP) and gain secure access to a company network. This reduces the cost of toll charges for traveling employees and telecommuters.
3. **Establishing extranet and intranet connectivity with partners:** IPSec can be used to secure communication with other organizations, ensuring authentication and confidentiality and providing a key exchange mechanism.
4. **Enhancing electronic commerce security:** Even though some Web and electronic commerce applications have built-in security protocols, the use of IPSec enhances that security.

An IP Security Scenario

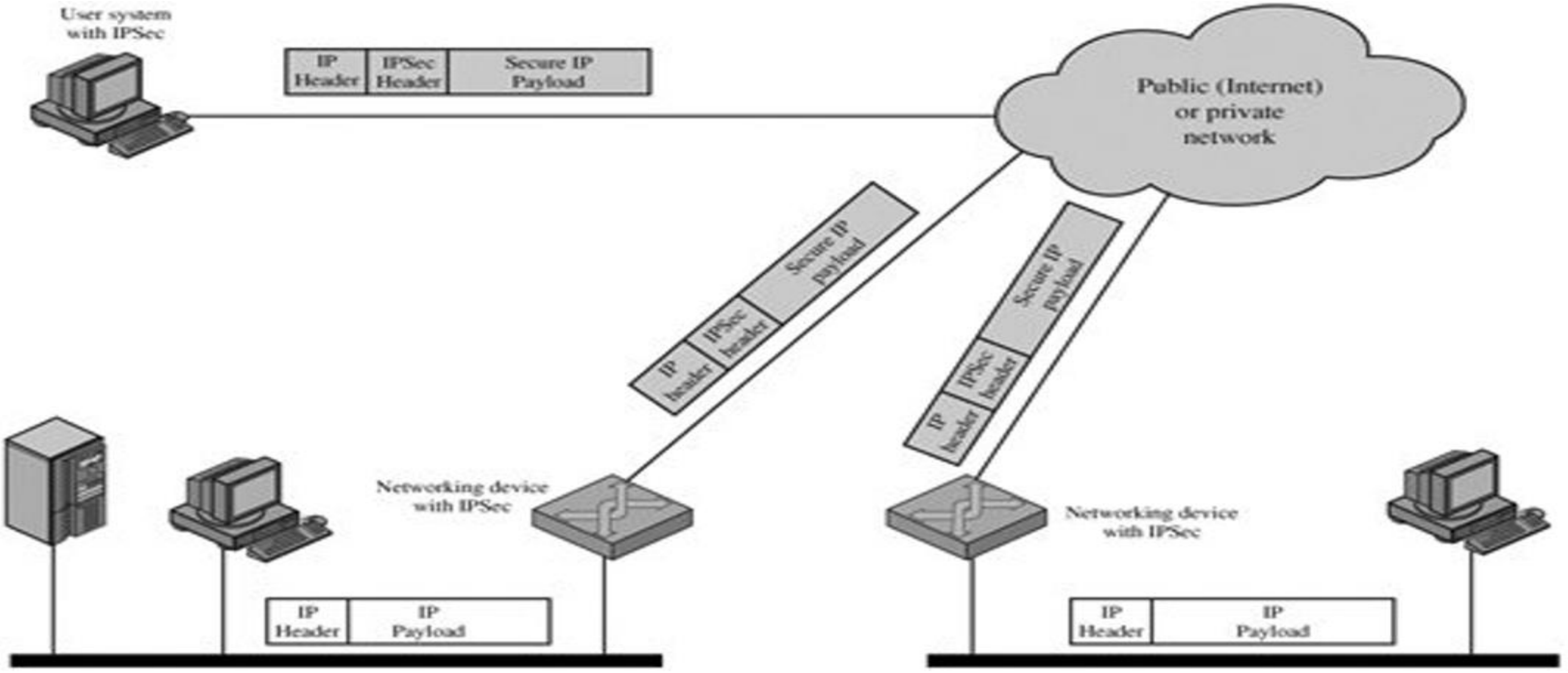


Figure 4.1. An IP Security Scenario

- Figure 4.1 is a typical scenario of IPSec usage.
- An organization maintains LANs at dispersed locations.
- Nonsecure IP traffic is conducted on each LAN. For traffic offsite, through some sort of private or public WAN, IPSec protocols are used. These protocols operate in networking devices, such as a router or firewall, that connect each LAN to the outside world.
- The IPSec networking device will typically encrypt and compress all traffic going into the WAN, and decrypt and decompress traffic coming from the WAN; these operations are transparent to workstations and servers on the LAN.
- Secure transmission is also possible with individual users who dial into the WAN. Such user workstations must implement the IPSec protocols to provide security.

Benefits of IPSec

- When IPSec is implemented in a firewall or router, it provides strong security that can be applied to all traffic crossing the perimeter. Traffic within a company or workgroup does not incur the overhead of security-related processing.
- IPSec in a firewall is resistant to bypass if all traffic from the outside must use IP, and the firewall is the only means of entrance from the Internet into the organization.
- IPSec is below the transport layer (TCP, UDP) and so is transparent to applications. There is no need to change software on a user or server system when IPSec is implemented in the firewall or router. Even if IPSec is implemented in end systems, upper-layer software, including applications, is not affected.
- IPSec can be transparent to end users. There is no need to train users on security mechanisms, issue keying material on a per-user basis, or revoke keying material when users leave the organization.
- IPSec can provide security for individual users if needed. This is useful for offsite workers and for setting up a secure virtual subnetwork within an organization for sensitive applications.

Routing Applications

IPSec can play a vital role in the routing architecture required for internetworking.

- IPSec can assure that:
- A router advertisement (a new router advertises its presence) comes from an authorized router .
- A neighbor advertisement (a router seeks to establish or maintain a neighbor relationship with a router in another routing domain) comes from an authorized router.
- A redirect message comes from the router to which the initial packet was sent.
- A routing update is not forged.

Without such security measures, an opponent can disrupt communications or divert some traffic. Routing protocols such as OSPF should be run on top of security associations between routers that are defined by IPSec.

4.2. IP Security Architecture

IPSec Documents

The IPSec specification consists of numerous documents. The most important of these, issued in November of 1998, are RFCs 2401, 2402, 2406, and 2408:

- RFC 2401: An overview of a security architecture
- RFC 2402: Description of a packet authentication extension to IPv4 and IPv6
- RFC 2406: Description of a packet encryption extension to IPv4 and IPv6
- RFC 2408: Specification of key management capabilities

IPSec Document Overview

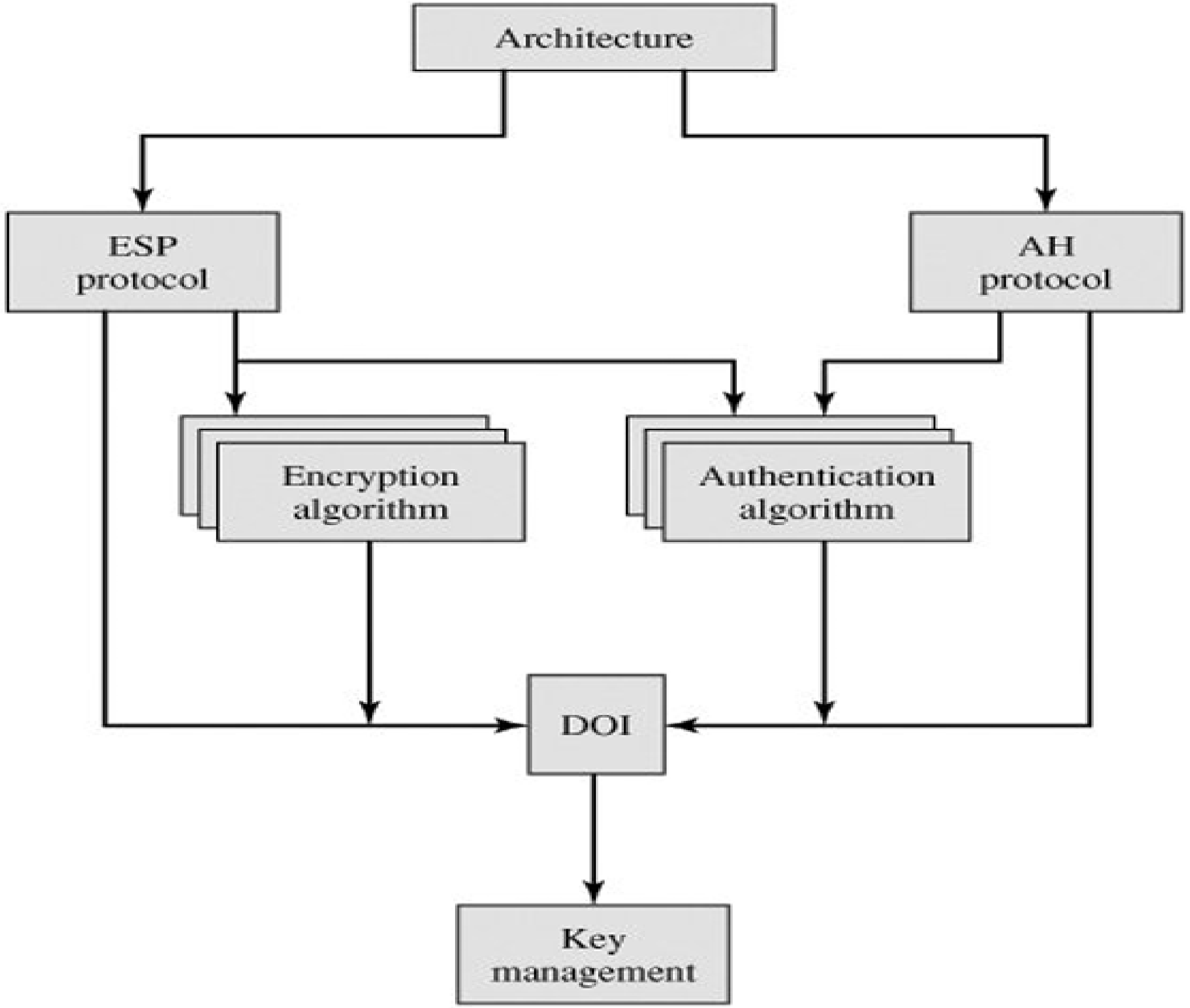


Figure 4.2. IPSec Document Overview

The documents are divided into seven groups:

- **Architecture:** Covers the general concepts, security requirements, definitions, and mechanisms defining IPSec technology.
- **Encapsulating Security Payload (ESP):** Covers the packet format and general issues related to the use of the ESP for packet encryption and, optionally, authentication.
- **Authentication Header (AH):** Covers the packet format and general issues related to the use of AH for packet authentication.
- **Encryption Algorithm:** A set of documents that describe how various encryption algorithms are used for ESP.
- **Authentication Algorithm:** A set of documents that describe how various authentication algorithms are used for AH and for the authentication option of ESP.
- **Key Management:** Documents that describe key management schemes.
- **Domain of Interpretation (DOI):** Contains values needed for the other documents to relate to each other. These include identifiers for approved encryption and authentication algorithms, as well as operational parameters such as key lifetime

IPSec Services

The services are:

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

	AH	ESP (encryption only)	ESP (encryption plus authentication)
Access control	✔	✔	✔
Connectionless integrity	✔		✔
Data origin authentication	✔		✔
Rejection of replayed packets	✔	✔	✔
Confidentiality		✔	✔
Limited traffic flow confidentiality		✔	✔

Security Associations

A security association is uniquely identified by three parameters:

- **Security Parameters Index (SPI):** A bit string assigned to this SA and having local significance only. The SPI is carried in AH and ESP headers to enable the receiving system to select the SA under which a received packet will be processed.
- **IP Destination Address:** Currently, only unicast addresses are allowed; this is the address of the destination endpoint of the SA, which may be an end user system or a network system such as a firewall or router.
- **Security Protocol Identifier:** This indicates whether the association is an AH or ESP security association

SA Parameters

A security association is normally defined by the following parameters:

- **Sequence Number Counter:** A 32-bit value used to generate the Sequence Number field in AH or ESP headers
- **Sequence Counter Overflow:** A flag indicating whether overflow of the Sequence Number Counter should generate an auditable event and prevent further transmission of packets on this SA (required for all implementations).
- **Anti-Replay Window:** Used to determine whether an inbound AH or ESP packet is a replay.
- **AH Information:** Authentication algorithm, keys, key lifetimes, and related parameters being used with AH (required for AH implementations)

- **ESP Information:** Encryption and authentication algorithm, keys, initialization values, key lifetimes, and related parameters being used with ESP (required for ESP implementations).
- **Lifetime of This Security Association:** A time interval or byte count after which an SA must be replaced with a new SA (and new SPI) or terminated, plus an indication of which of these actions should occur (required for all implementations).
- **IPSec Protocol Mode:** Tunnel, transport, or wildcard (required for all implementations). These modes are discussed later in this section.
- **Path MTU:** Any observed path maximum transmission unit (maximum size of a packet that can be transmitted without fragmentation) and aging variables (required for all implementations).

SA Selectors

Each SPD entry is defined by a set of IP and upper-layer protocol field values, called selectors. In effect, these selectors are used to filter outgoing traffic in order to map it into a particular SA. Outbound processing obeys the following general sequence for each IP packet:

- Compare the values of the appropriate fields in the packet (the selector fields) against the SPD to find a matching SPD entry, which will point to zero or more SAs.
- Determine the SA if any for this packet and its associated SPI.
- Do the required IPSec processing (i.e., AH or ESP processing)

The following selectors determine an SPD entry:

- **Destination IP Address:** This may be a single IP address, an enumerated list or range of addresses, or a wildcard (mask) address. The latter two are required to support more than one destination system sharing the same SA (e.g., behind a firewall).
- **Source IP Address:** This may be a single IP address, an enumerated list or range of addresses, or a wildcard (mask) address. The latter two are required to support more than one source system sharing the same SA (e.g., behind a firewall).
- **UserID:** A user identifier from the operating system. This is not a field in the IP or upper-layer headers but is available if IPSec is running on the same operating system as the user.
- **Data Sensitivity Level:** Used for systems providing information flow security (e.g., Secret or Unclassified).
- **Transport Layer Protocol:** Obtained from the IPv4 Protocol or IPv6 Next Header field. This may be an individual protocol number, a list of protocol numbers, or a range of protocol numbers.
- **Source and Destination Ports:** These may be individual TCP or UDP port values, an enumerated list of ports, or a wildcard port.

Transport and Tunnel Modes

Transport Mode

- Transport mode provides protection primarily for upper-layer protocols, extending to the payload of an IP packet.
- Examples of payloads include TCP or UDP segments or ICMP packets, which operate directly above IP in a host protocol stack.
- Typically used for end-to-end communication between two hosts, such as a client and a server or two workstations.
- For IPv4, the payload is the data that follows the IP header.
- For IPv6, the payload includes data following the IP header and any IPv6 extension headers, except possibly the destination options header.
- ESP in transport mode encrypts and optionally authenticates the IP payload but does not protect the IP header.
- AH in transport mode authenticates the IP payload and selected portions of the IP header.

Tunnel Mode

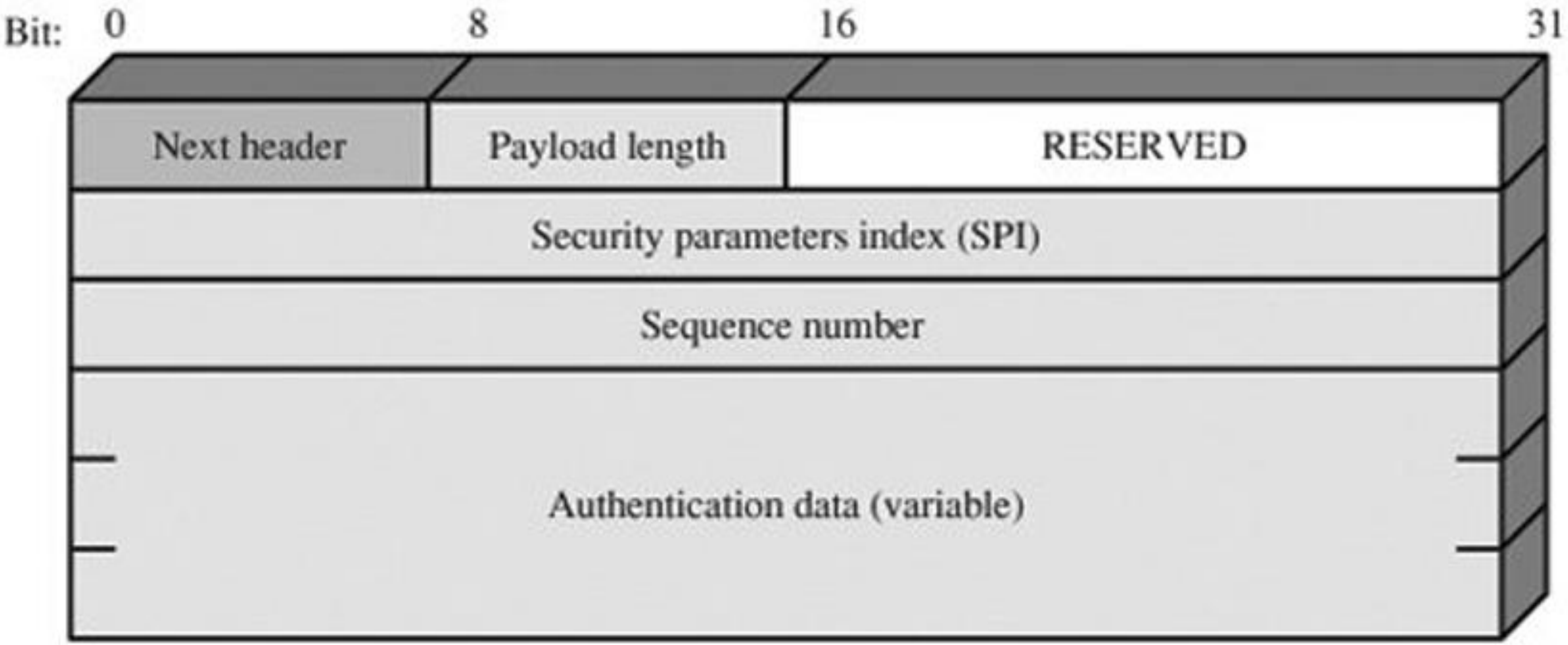
- Tunnel mode protects the entire IP packet by encapsulating it with a new outer IP header.
- Intermediate routers cannot access the inner IP header, enhancing security.
- Used when one or both ends of an SA are security gateways like firewalls or routers.
- Hosts behind firewalls communicate securely without implementing IPSec; the firewall handles tunneling.
- Example: A firewall encapsulates a packet from Host A to Host B with an outer header; Host B's firewall removes it and delivers the inner packet.
- ESP encrypts and optionally authenticates the entire inner packet.
- AH authenticates the inner packet and parts of the outer header.

Table 16.2. Tunnel Mode and Transport Mode Functionality

	Transport Mode SA	Tunnel Mode SA
AH	Authenticates IP payload and selected portions of IP header and IPv6 extension headers.	Authenticates entire inner IP packet (inner header plus IP payload) plus selected portions of outer IP header and outer IPv6 extension headers.
ESP	Encrypts IP payload and any IPv6 extension headers following the ESP header.	Encrypts entire inner IP packet.
ESP with Authentication	Encrypts IP payload and any IPv6 extension headers following the ESP header. Authenticates IP payload but not IP header.	Encrypts entire inner IP packet. Authenticates inner IP packet.

4.3. Authentication Header

Figure 16.3. IPSec Authentication Header



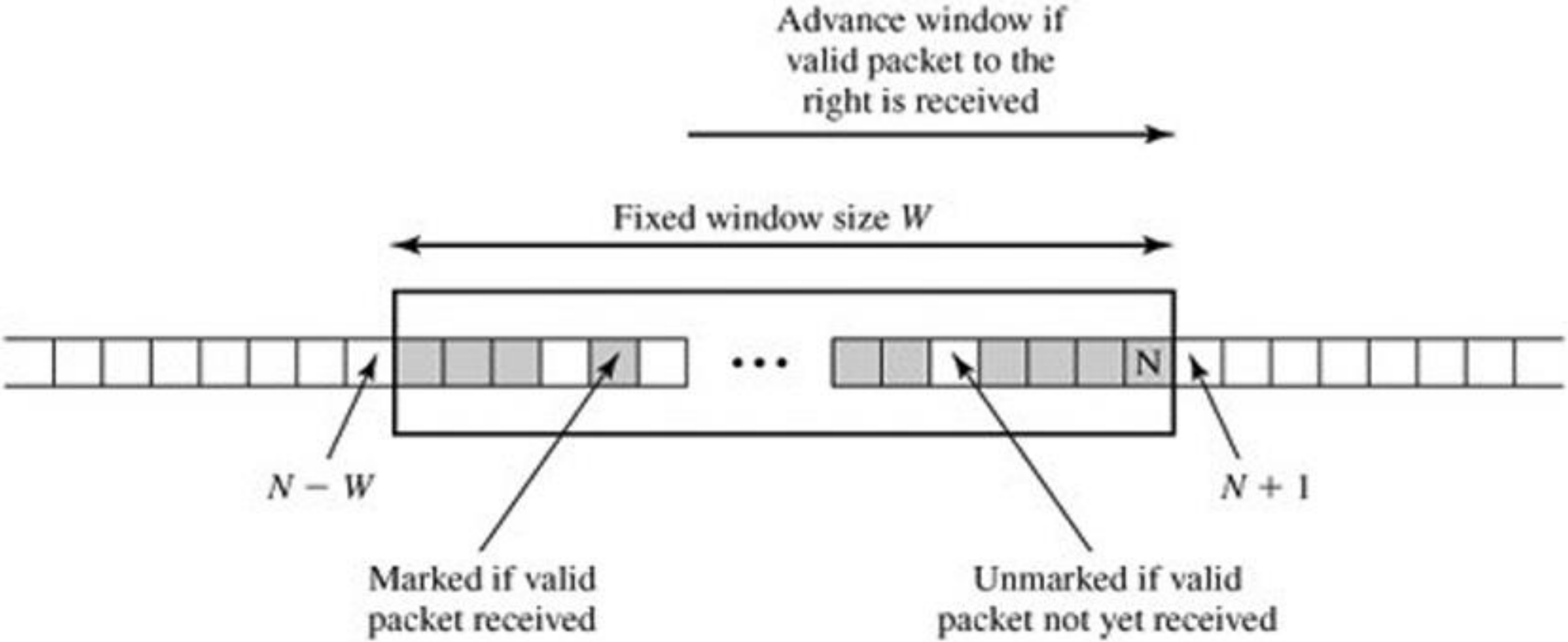
Authentication Header consists of the following fields:

- **Next Header (8 bits):** Identifies the type of header immediately following this header.
- **Payload Length (8 bits):** Length of Authentication Header in 32-bit words, minus 2. For example, the default length of the authentication data field is 96 bits, or three 32-bit words. With a three-word fixed header, there are a total of six words in the header, and the Payload Length field has a value of 4.
- **Reserved (16 bits):** For future use.
- **Security Parameters Index (32 bits):** Identifies a security association.
- **Sequence Number (32 bits):** A monotonically increasing counter value, discussed later.
- **Authentication Data (variable):** A variable-length field (must be an integral number of 32-bit words) that contains the Integrity Check Value (ICV), or MAC, for this packet, discussed later.

Anti-Replay Service

- If the received packet falls within the window and is new, the MAC is checked. If the packet is authenticated, the corresponding slot in the window is marked.
- If the received packet is to the right of the window and is new, the MAC is checked. If the packet is authenticated, the window is advanced so that this sequence number is the right edge of the window, and the corresponding slot in the window is marked.
- If the received packet is to the left of the window, or if authentication fails, the packet is discarded; this is an auditable event.

Figure 16.4. Antireplay Mechanism



Integrity Check Value

The MAC is calculated over

- IP header fields that either do not change in transit (immutable) or that are predictable in value upon arrival at the endpoint for the AH SA. Fields that may change in transit and whose value on arrival are unpredictable are set to zero for purposes of calculation at both source and destination.
- The AH header other than the Authentication Data field. The Authentication Data field is set to zero for purposes of calculation at both source and destination.
- The entire upper-level protocol data, which is assumed to be immutable in transit (e.g., a TCP segment or an inner IP packet in tunnel mode).

Transport and Tunnel Modes

Figure 16.5. End-to-End versus End-to-Intermediate Authentication

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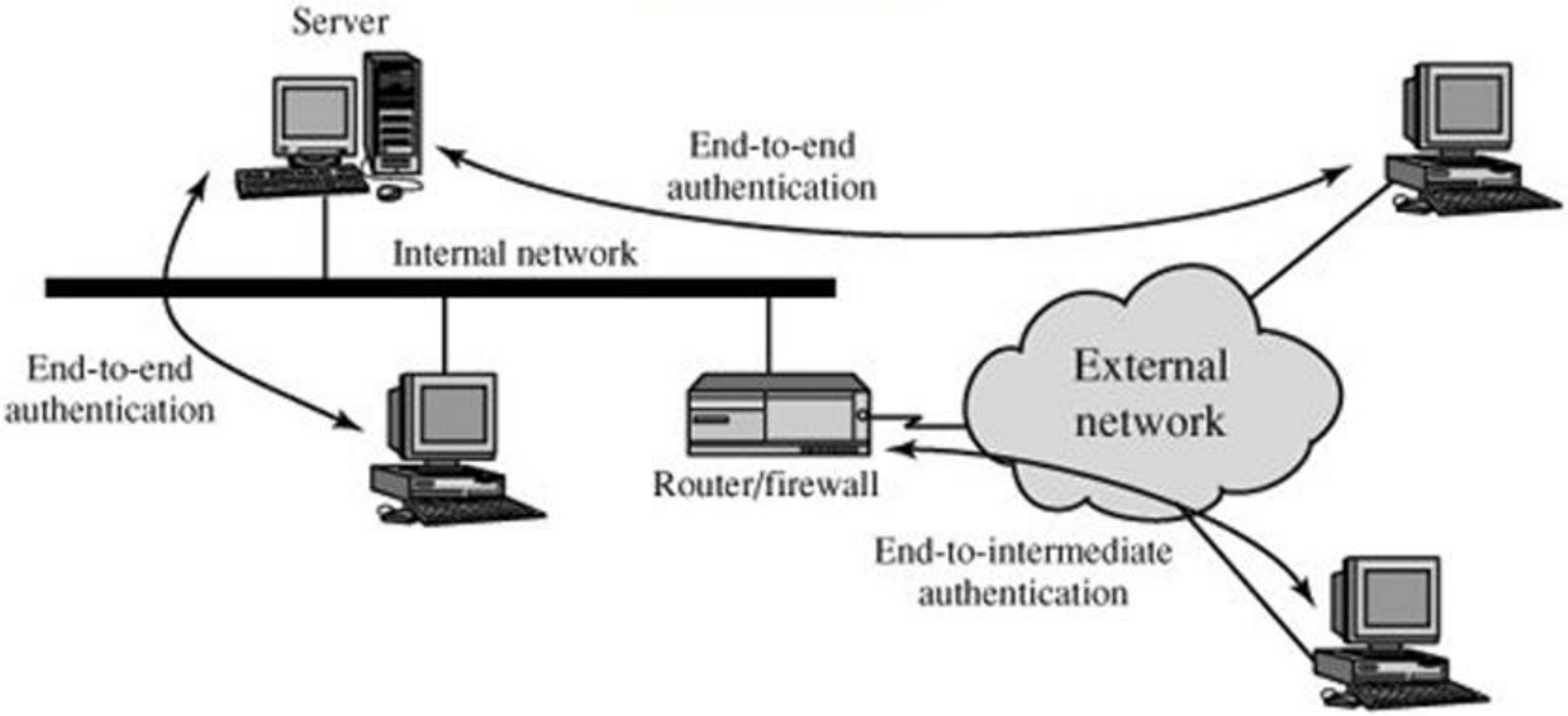
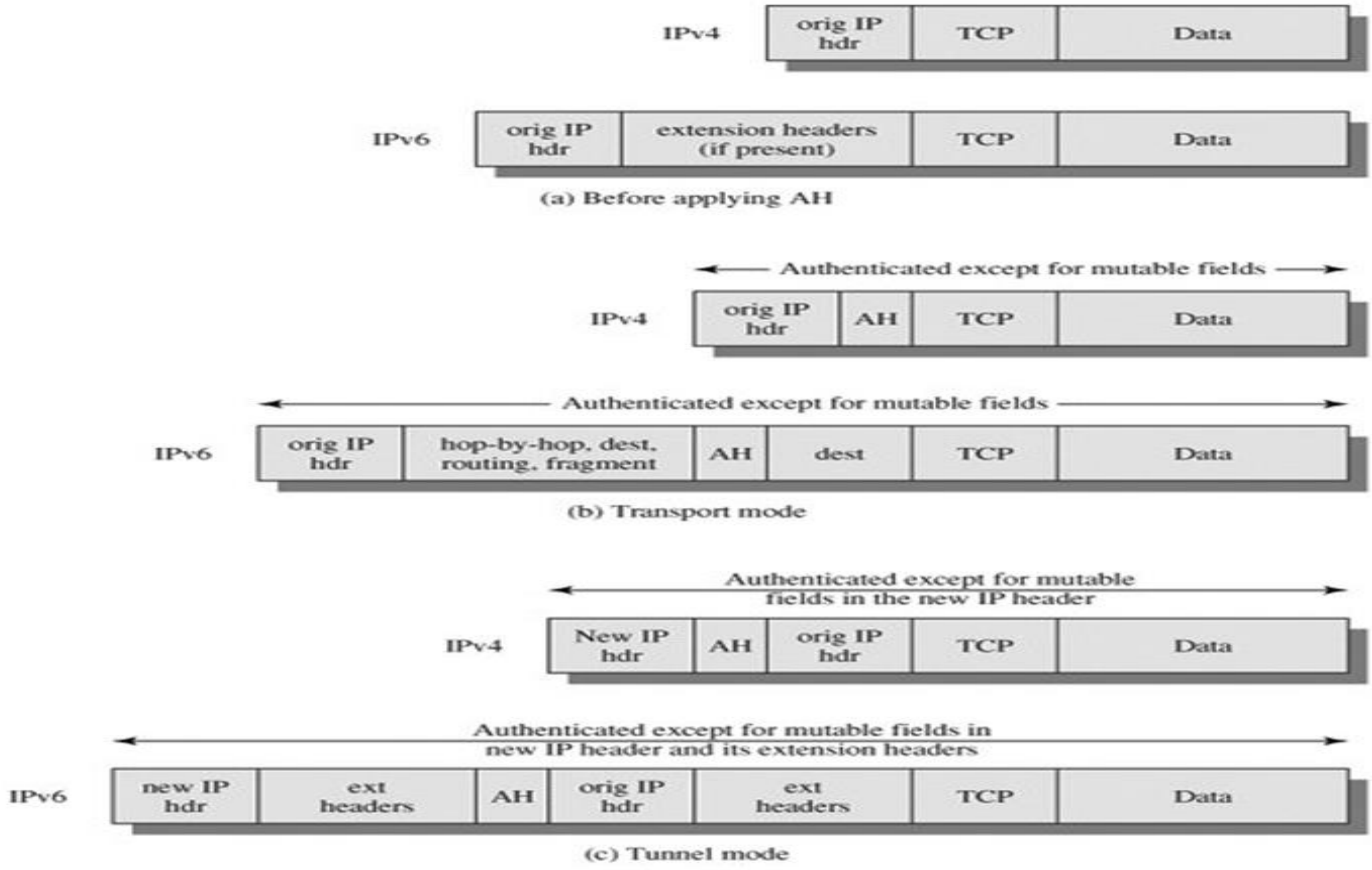


- Figure 16.5 shows two ways in which the IPSec authentication service can be used.
- In one case, authentication is provided directly between a server and client workstations; the workstation can be either on the same network as the server or on an external network.
- As long as the workstation and the server share a protected secret key, the authentication process is secure.
- This case uses a transport mode SA.
- In the other case, a remote workstation authenticates itself to the corporate firewall, either for access to the entire internal network or because the requested server does not support the authentication feature.
- This case uses a tunnel mode SA.

Scope of AH Authentication

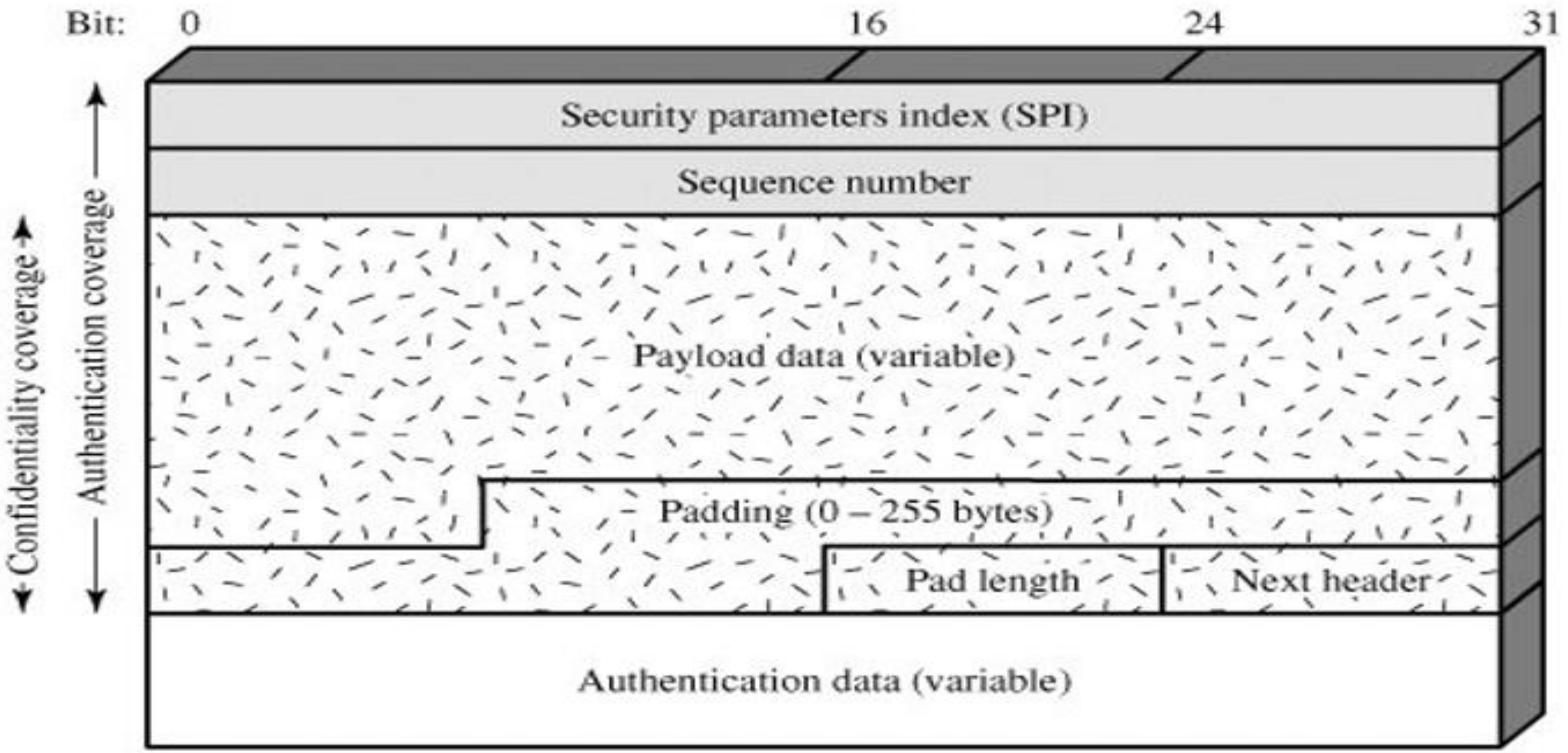


4.4. Encapsulating Security Payload

The Encapsulating Security Payload provides confidentiality services, including confidentiality of message contents and limited traffic flow confidentiality.

ESP Format

Figure 16.7. IPSec ESP format



- **Security Parameters Index (32 bits):** Identifies a security association.
- **Sequence Number (32 bits):** A monotonically increasing counter value; this provides an anti replay function, as discussed for AH.
- **Payload Data (variable):** This is a transport-level segment (transport mode) or IP packet (tunnel mode) that is protected by encryption.
- **Padding (0255 bytes):** The purpose of this field is discussed later.
- **Pad Length (8 bits):** Indicates the number of pad bytes immediately preceding this field.
- **Next Header (8 bits)**: Identifies the type of data contained in the payload data field by identifying the first header in that payload (for example, an extension header in IPv6, or an upper-layer protocol such as TCP).
- **Authentication Data (variable):** A variable-length field (must be an integral number of 32-bit words) that contains the Integrity Check Value computed over the ESP packet minus the Authentication Data field.

Encryption and Authentication Algorithms

these include

- Three-key triple DES
- IDEA
- Three-key triple IDEA
- Blowfish

Padding

The Padding field serves several purposes:

- If an encryption algorithm requires the plaintext to be a multiple of some number of bytes (e.g., the multiple of a single block for a block cipher), the Padding field is used to expand the plaintext (consisting of the Payload Data, Padding, Pad Length, and Next Header fields) to the required length.
- The ESP format requires that the Pad Length and Next Header fields be right aligned within a 32 bit word. Equivalently, the ciphertext must be an integer multiple of 32 bits. The Padding field is used to assure this alignment.
- Additional padding may be added to provide partial traffic flow confidentiality by concealing the actual length of the payload.

Transport and Tunnel Modes

Figure 16.8. Transport-Mode vs. Tunnel-Mode Encryption

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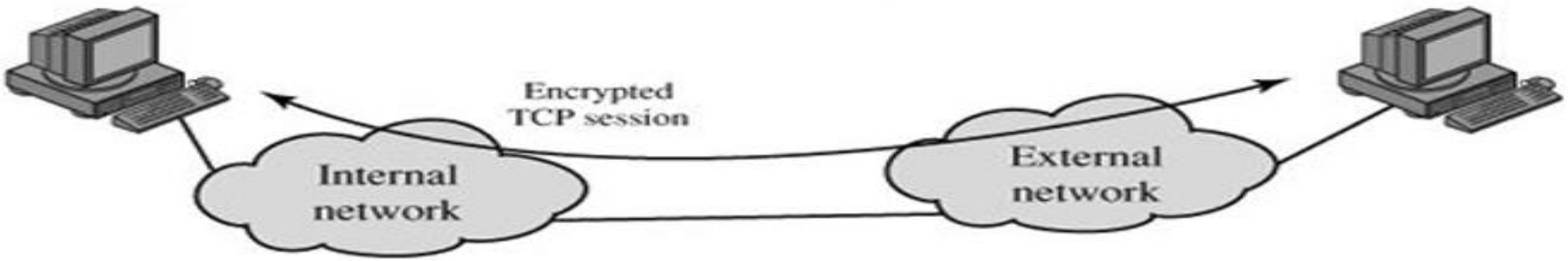
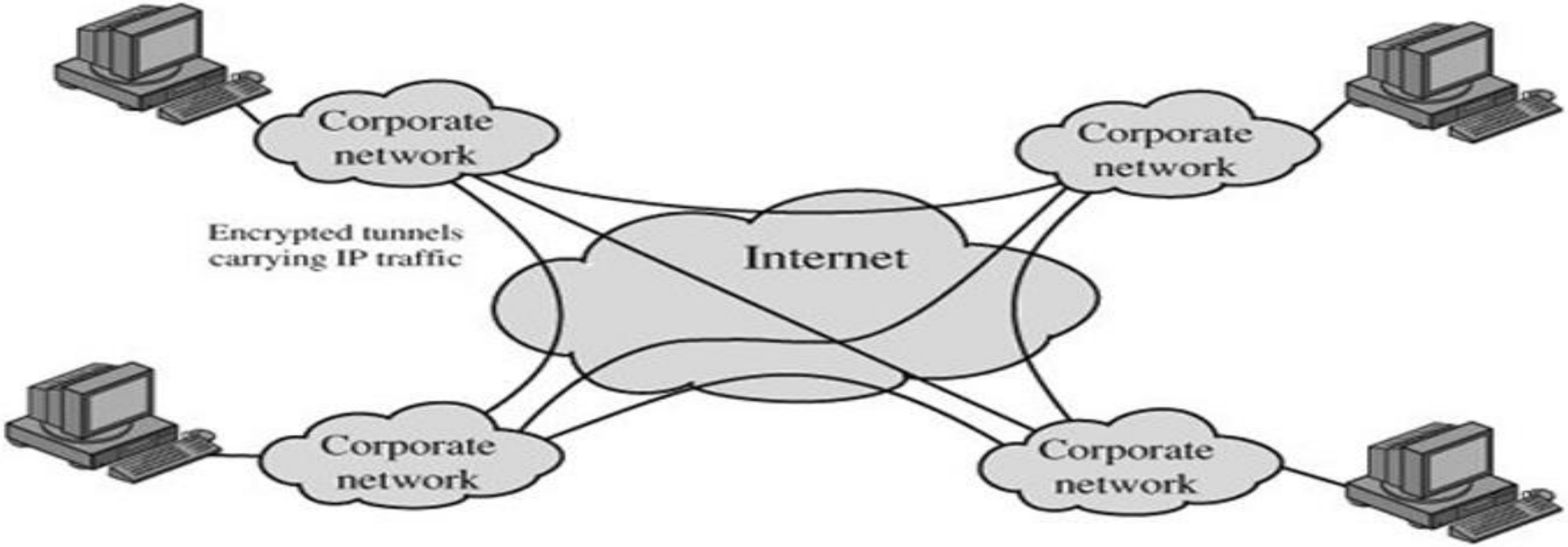


(a) Transport-level security



(b) A virtual private network via tunnel mode

- Figure 16.8 shows two ways in which the IPSec ESP service can be used. In the upper part of the figure, encryption (and optionally authentication) is provided directly between two hosts. Figure 16.8b shows how tunnel mode operation can be used to set up a virtual private network. In this example, an organization has four private networks interconnected across the Internet.
- Hosts on the internal networks use the Internet for transport of data but do not interact with other Internet-based hosts.
- By terminating the tunnels at the security gateway to each internal network, the configuration allows the hosts to avoid implementing the security capability. The former technique is support by a transport mode SA, while the latter technique uses a tunnel mode SA.

Transport Mode ESP

Figure 16.9. Scope of ESP Encryption and Authentication

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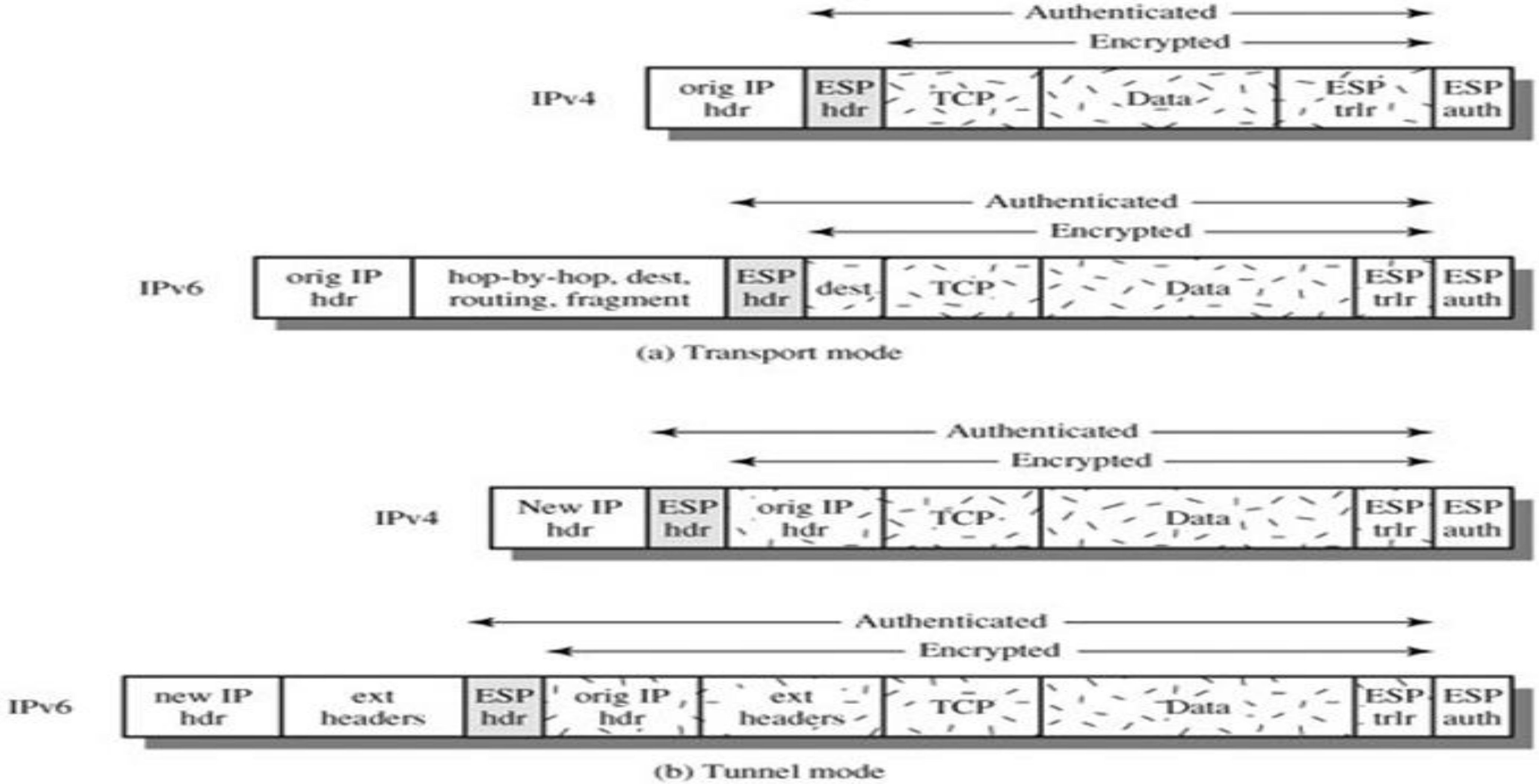


- At the source, the block of data consisting of the ESP trailer plus the entire transport-layer segment is encrypted and the plaintext of this block is replaced with its ciphertext to form the IP packet for transmission. Authentication is added if this option is selected.
- The packet is then routed to the destination. Each intermediate router needs to examine and process the IP header plus any plaintext IP extension headers but does not need to examine the ciphertext.
- The destination node examines and processes the IP header plus any plaintext IP extension headers. Then, on the basis of the SPI in the ESP header, the destination node decrypts the remainder of the packet to recover the plaintext transport-layer segment.

Tunnel Mode ESP

- The source prepares an inner IP packet with a destination address of the target internal host. This packet is prefixed by an ESP header; then the packet and ESP trailer are encrypted and Authentication Data may be added. The resulting block is encapsulated with a new IP header (base header plus optional extensions such as routing and hop-by-hop options for IPv6) whose destination address is the firewall; this forms the outer IP packet.
- The outer packet is routed to the destination firewall. Each intermediate router needs to examine and process the outer IP header plus any outer IP extension headers but does not need to examine the ciphertext.
- The destination firewall examines and processes the outer IP header plus any outer IP extension headers. Then, on the basis of the SPI in the ESP header, the destination node decrypts the remainder of the packet to recover the plaintext inner IP packet. This packet is then transmitted in the internal network.
- The inner packet is routed through zero or more routers in the internal network to the destination host.

4.5. Combining Security Associations

Security associations may be combined into bundles in two ways:

- **Transport adjacency:** Refers to applying more than one security protocol to the same IP packet, without invoking tunneling. This approach to combining AH and ESP allows for only one level of combination; further nesting yields no added benefit since the processing is performed at one IPsec instance: the (ultimate) destination.
- **Iterated tunneling:** Refers to the application of multiple layers of security protocols effected through IP tunneling. This approach allows for multiple levels of nesting, since each tunnel can originate or terminate at a different IPsec site along the path.

Transport Adjacency

- Authentication after encryption can use two transport SAs: inner ESP SA (without authentication) and outer AH SA.
- ESP encrypts the IP payload, while AH in transport mode authenticates the ESP and original IP header (excluding mutable fields).
- Advantage: Covers more fields, including source and destination IP addresses.
- Disadvantage: Higher overhead with two SAs compared to one

Transport-Tunnel Bundle

- Authentication before encryption ensures the authentication data is protected and prevents undetected alterations.
- It allows storing authentication information for reference without reencrypting the message.
- Implemented using an inner AH transport SA and an outer ESP tunnel SA.
- AH authenticates the IP payload and header (excluding mutable fields), and ESP encrypts the authenticated packet with a new outer IP header.

Basic Combinations of Security Associations

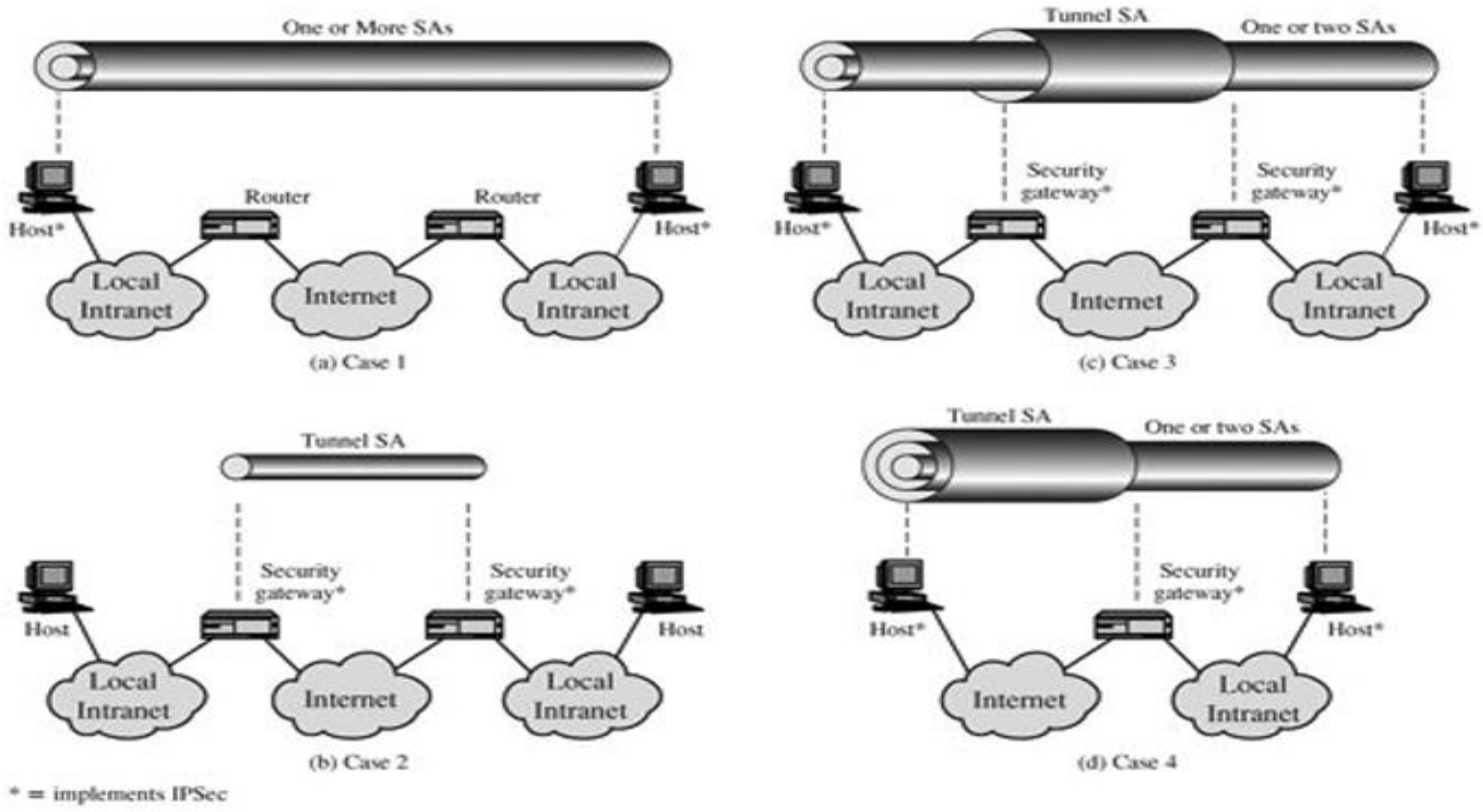


Figure 16.10. Basic Combinations of Security Associations

In **Case 1**, all security is provided between end systems that implement IPSec. For any two end systems to communicate via an SA, they must share the appropriate secret keys. Among the possible combinations:

a. AH in transport mode
b. ESP in transport mode
c. ESP followed by AH in transport mode (an ESP SA inside an AH SA)
d. Any one of a, b, or c inside an AH or ESP in tunnel mode

For **Case 2**, security is provided only between gateways (routers, firewalls, etc.) and no hosts implement IPSec. This case illustrates simple virtual private network support. The security architecture document specifies that only a single tunnel SA is needed for this case. The tunnel could support AH, ESP, or ESP with the authentication option. Nested tunnels are not required because the IPSec services apply to the entire inner packet.

Case 3 builds on Case 2 by adding end-to-end security. The same combinations discussed for cases 1 and 2 are allowed here. The gateway-to-gateway tunnel provides either authentication or confidentiality or both for all traffic between end systems. When the gateway-to-gateway tunnel is ESP, it also provides a limited form of traffic confidentiality. Individual hosts can implement any additional IPSec services required for given applications or given users by means of end-to-end SAs.

Case 4 provides support for a remote host that uses the Internet to reach an organization's firewall and then to gain access to some server or workstation behind the firewall. Only tunnel mode is required between the remote host and the firewall. As in Case 1, one or two SAs may be used between the remote host and the local host.

4.6. Key Management

The key management portion of IPSec involves the determination and distribution of secret keys. A typical requirement is four keys for communication between two applications: transmit and receive pairs for both AH and ESP. The IPSec Architecture document mandates support for two types of key management:

- **Manual:** A system administrator manually configures each system with its own keys and with the keys of other communicating systems. This is practical for small, relatively static environments.
- **Automated:** An automated system enables the on-demand creation of keys for SAs and facilitates the use of keys in a large distributed system with an evolving configuration.

The default automated key management protocol for IPSec is referred to as ISAKMP/Oakley and consists of the following elements:

- **Oakley Key Determination Protocol:** Oakley is a key exchange protocol based on the Diffie Hellman algorithm but providing added security.
- **Internet Security Association and Key Management Protocol (ISAKMP):** ISAKMP provides a framework for Internet key management

Oakley Key Determination Protocol

The man-in-the-middle attack proceeds as follows:

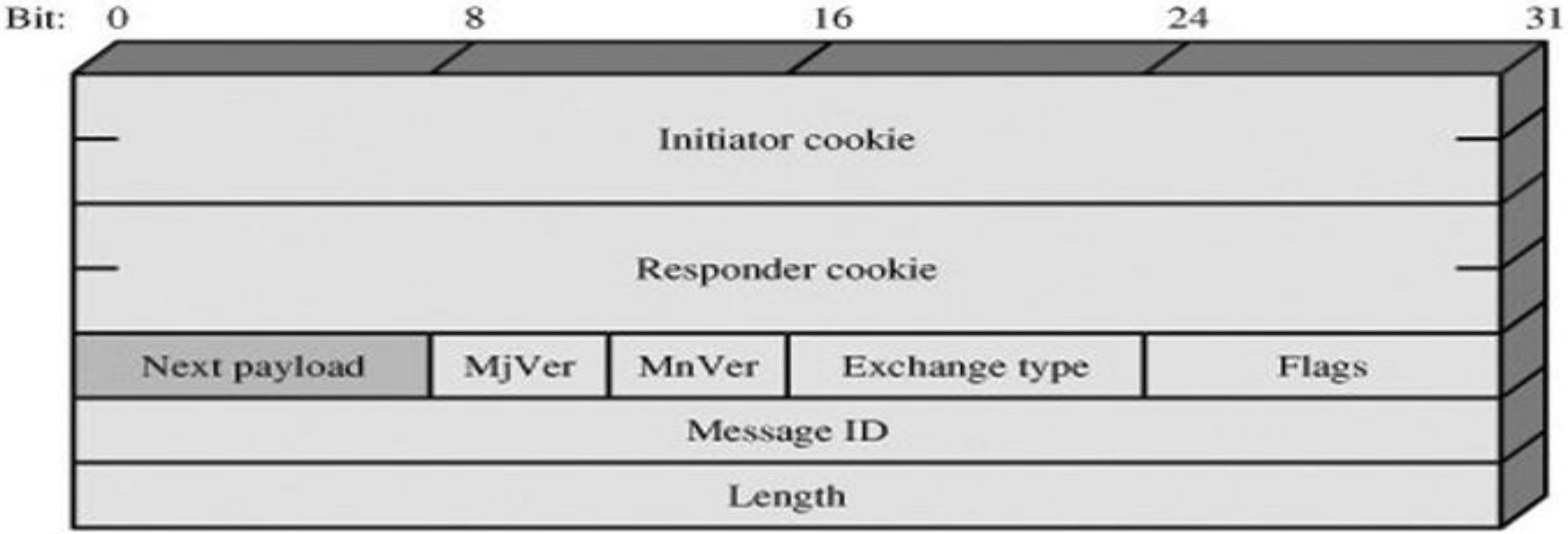
- B sends his public key YB in a message addressed to A
- The enemy (E) intercepts this message. E saves B's public key and sends a message to A that has B's User ID but E's public key YE. This message is sent in such a way that it appears as though it was sent from B's host system. A receives E's message and stores E's public key with B's User ID. Similarly, E sends a message to B with E's public key, purporting to come from A.
- B computes a secret key K1 based on B's private key and YE. A computes a secret key K2 based on A's private key and YE. E computes K1 using E's secret key XE and YB and computer K2 using YE and YB.
- From now on E is able to relay messages from A to B and from B to A, appropriately changing their encipherment en route in such a way that neither A nor B will know that they share their communication with E.

Features of Oakley

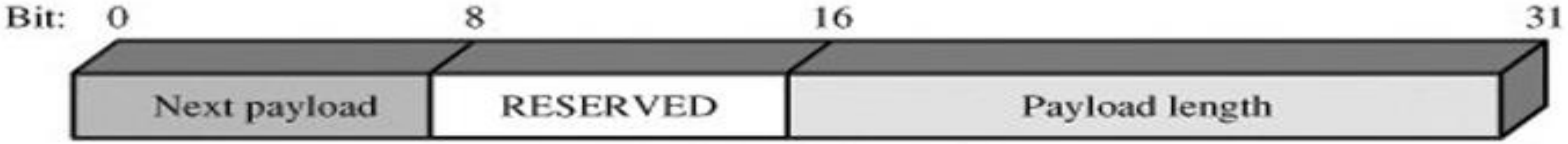
The Oakley algorithm is characterized by five important features:

- It employs a mechanism known as cookies to thwart clogging attacks.
- It enables the two parties to negotiate a group; this, in essence, specifies the global parameters of the Diffie-Hellman key exchange.
- It uses nonces to ensure against replay attacks.
- It enables the exchange of Diffie-Hellman public key values
- It authenticates the Diffie-Hellman exchange to thwart man-in-the-middle attacks.

ISAKMP Header Format



(a) ISAKMP header



(b) Generic payload header

- **Initiator Cookie (64 bits):** Cookie of entity that initiated SA establishment, SA notification, or SA deletion.
- **Responder Cookie (64 bits):** Cookie of responding entity; null in first message from initiator.
- **Next Payload (8 bits):** Indicates the type of the first payload in the message; payloads are discussed in the next subsection.
- **Major Version (4 bits):** Indicates major version of ISAKMP in use.
- **Minor Version (4 bits):** Indicates minor version in use.
- **Exchange Type (8 bits):** Indicates the type of exchange; these are discussed later in this section.
- **Flags (8 bits):** Indicates specific options set for this ISAKMP exchange. Two bits so far defined: The Encryption bit is set if all payloads following the header are encrypted using the encryption algorithm for this SA. The Commit bit is used to ensure that encrypted material is not received prior to completion of SA establishment.
- **Message ID (32 bits):** Unique ID for this message.
- **Length (32 bits):** Length of total message (header plus all payloads) in octets.