COM 5335 Network Security Lec 12- IPSec & SSL/TLS

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Application-Transparent Security

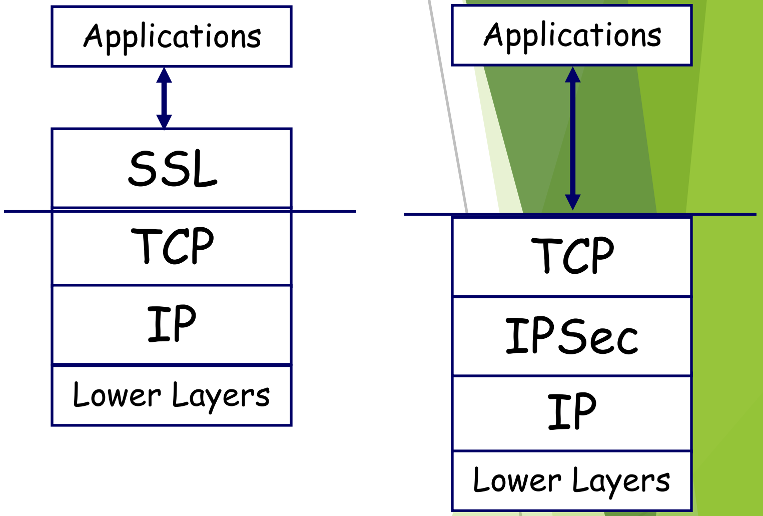
- We want to ask…
  - Should all applications employ their own authentication, integrity, and confidentiality mechanisms?
  - Can we make security transparent to applications?
  - At what layer should such security services be implemented?
  - Are there problems if we do take this approach?
- SSL and IPsec are two common ways of providing the same security services to all applications

At What Layer Should We Implement Security Services?

- Layers
  - SSL/TLS is said to be implemented at layer 4
  - IPSec is said to be implemented at layer 3
- Implications
  - Most OSs implement the IP stack up to layer 4 (including TCP)
  - SSL's philosophy is that the OS need not be changed
    - Simply create a superset of the API to TCP
    - Modifying applications to use SSL requires minimal effort
    - Transport layer security is really above the transport layer
  - IPsec's philosophy
    - If the OS implements security, all applications are automatically protected
    - No applications need be modified

Layering Implications

- If SSL is used
  - TCP has no idea if a packet is malicious
  - It may discard the real data if a malicious packet is inserted with the same sequence number
  - Cannot be used with UDP
- If IPsec is used
  - Only IP addresses are used for security
    - Although this isn't simple address filtering!
  - There is NO authentication of the user
    - Application may still need to use a login/password to determine the user's authenticity
  - Faster than SSL and hardware implementation is easier



Applications

SSL

TCP

IP

Lower Layers

Applications

TCP

IPSec

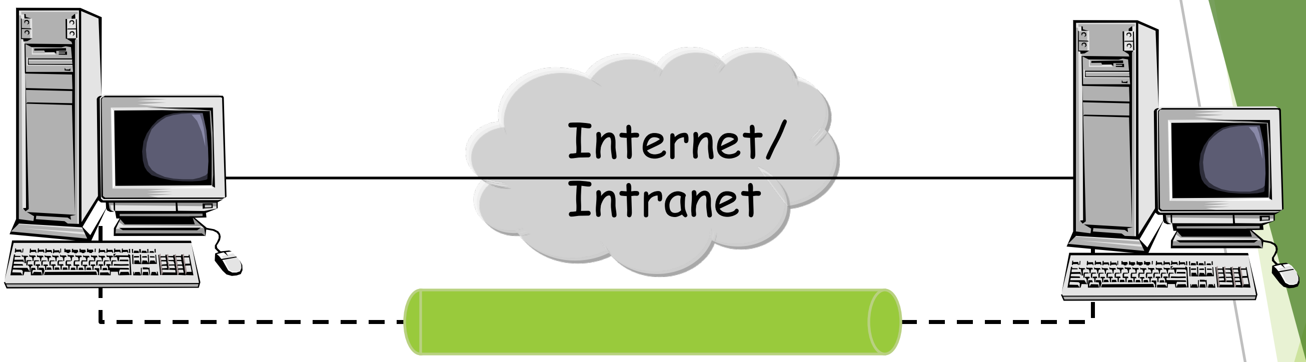
IP

Lower Layers

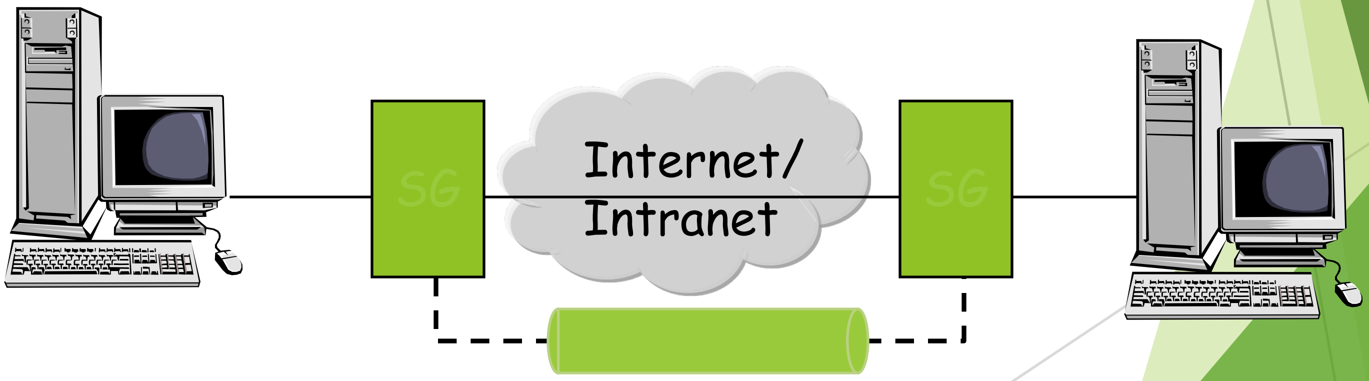
IPsec - Network Layer Security

- Encrypts and authenticates all traffic at the IP level
  - Use on LANs, WANs, public, and private networks
- Application independent
  - Web browsing, telnet, FTP, etc.
- Transparent to user
- Provides the following security services at the IP level
  - Access control
  - Connectionless integrity
  - Data origin authentication
  - Rejection of replayed packets
  - Data confidentiality
  - Limited traffic analysis confidentiality

Cases where IPsec can be used

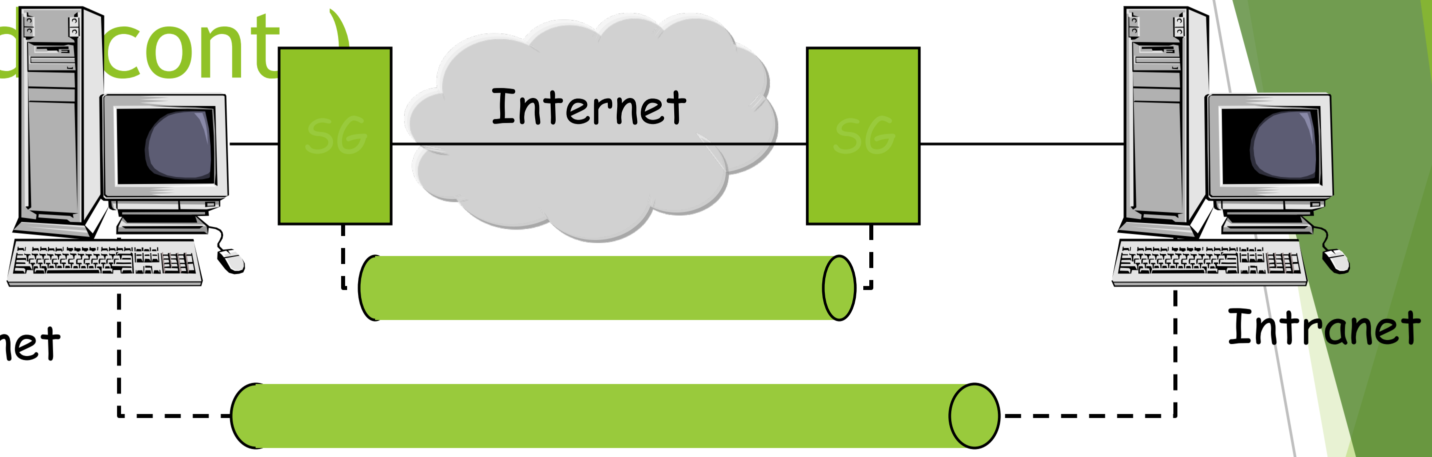


End-to-end security between two hosts

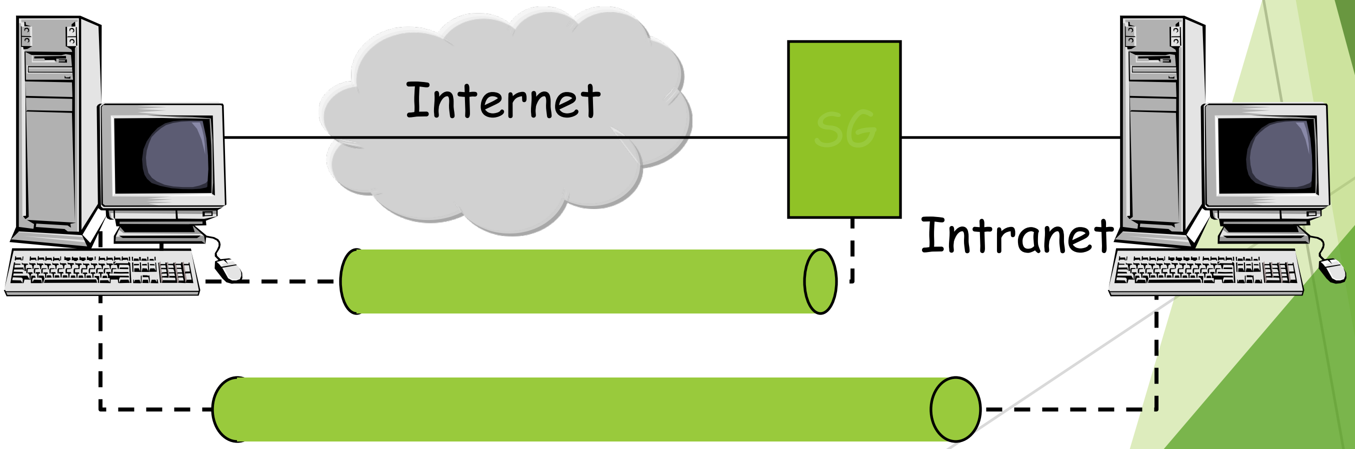


End-to-end security between two security gateways

Cases where IPsec can be used (cont.)



End-to-end security between two hosts + two gateways



End-to-end security between two hosts during dial-up

Protocols in IPsec

- Authentication Header (AH)
  - Ensures authentication and integrity of IP datagrams
  - Adds an additional field to the IP packet to ensure and check the authenticity of data
  - Uses sequence numbers to prevent/reject replayed datagrams
- Encapsulating security payload (ESP)
  - Primarily designed for confidentiality
  - May also be employed for authentication
- Internet Key Exchange (IKE)
  - Exchanging keys between entities that need to communicate over the Internet
  - What authentication methods to use, how long to use the keys, etc.

Security Association (SA)

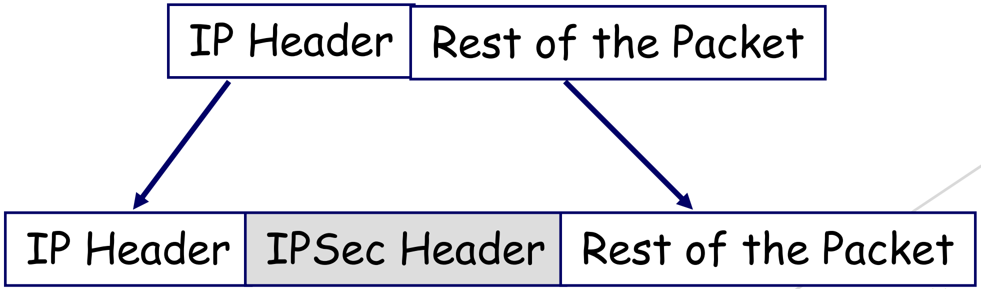
- Unidirectional relationship between a sender and a receiver
  - Two security associations are required for bidirectional operation
- Specifies the security services provided to the traffic carried on the SA
  - Example: Integrity only, integrity + confidentiality, etc.
- The SA is identified by three parameters
  - IP Destination Address (unicast vs. multicast)
  - Security Protocol Identifier
    - Specifies whether AH or ESP is being used
  - Security Parameters Index (SPI)
    - Specifies the security parameters associated with the SA

Security Association (cont.)

- Multiple security associations are used to provide required security services
  - Such security associations are called SA bundles
  - Example: we can have an AH protocol followed by ESP or vice versa
- A Security Association specifies
  - Mode of authentication in AH
  - The ESP encryption algorithm and authentication algorithms
  - Presence or absence of cryptographic synchronization
  - How often the keys have to be changed
  - Key lifetimes
  - Lifetime of the SA

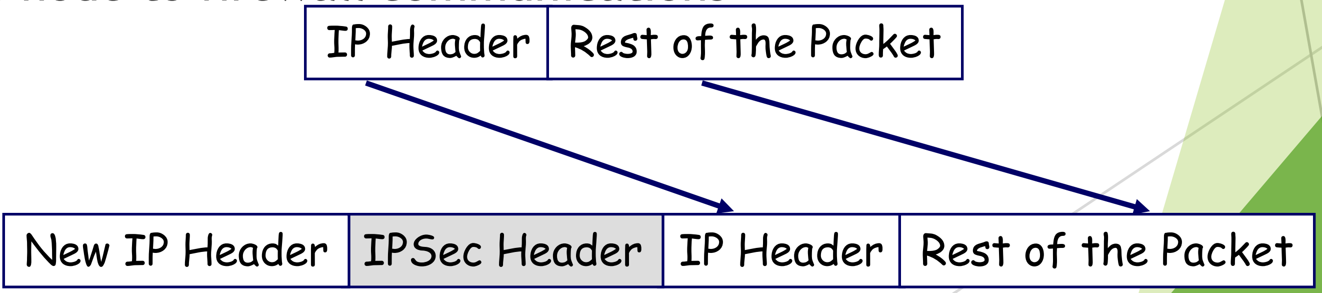
Transport Mode

- IPsec specifies two modes of operation
  - Transport mode
  - Tunnel mode
- In the transport mode, the IP headers are not completely protected
  - Protection is provided for the upper layers
  - Usually used in host-to-host communications
  - IPsec header is inserted between the IP header and the rest of the packet



Tunnel Mode

- In the tunnel mode the original IP headers are completely protected
  - Adds another IP header in the end (there is IP-in-IP tunneling)
  - Helps against traffic analysis
  - The original IP packet is untouched in the Internet
- Commonly used for firewall to firewall communications or end-node to firewall communications

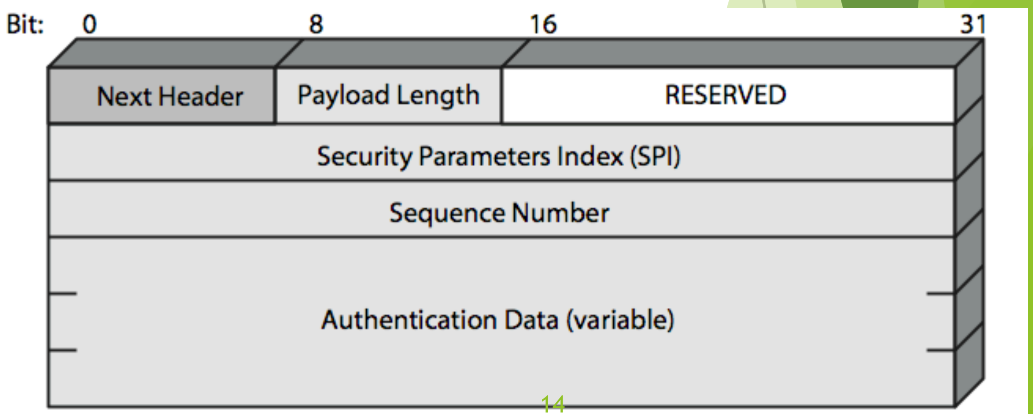


Authentication Header (AH)

- Provides
  - Support for data integrity and authentication of IP packets
  - Prevention of address spoofing and replay attacks
- Does not provide confidentiality of payload data
- Authentication is based on using a MAC
  - Parties must share a secret key
- Problem
  - NAT is not supported and using AH implies that NAT needs to be removed

AH Details

- Next header
  - Identifies what protocol header follows
- Payload length
  - Indicates the number of 32-bit words in the authentication header
- Security Parameters Index
  - Specifies to the receiver the algorithms, type of keys, and lifetime of the keys used
- Sequence number
  - Counter that increases with each IP packet sent from the same host to the same destination and SA
- Authentication Data
  - The MAC associated with it



Bit:
0
8
16
31
Next Header
Payload Length
RESERVED
Security Parameters Index (SPI)
Sequence Number
Authentication Data (variable)

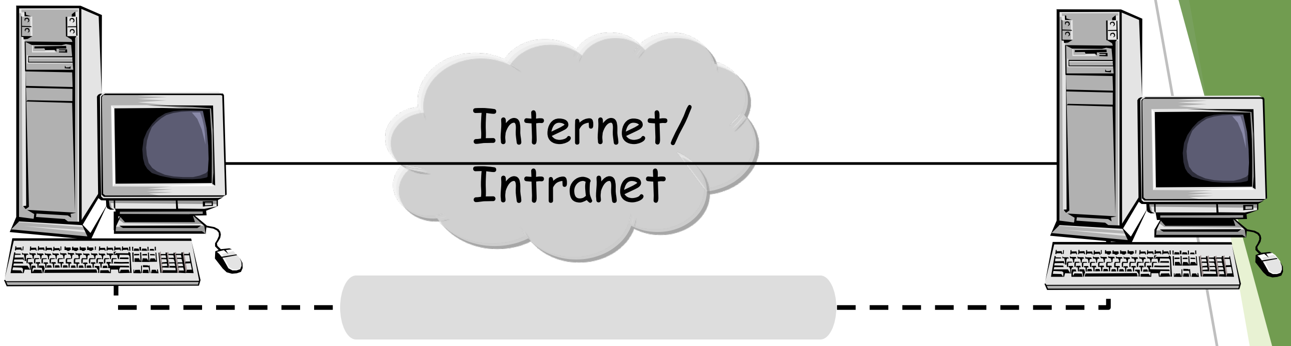
AH: Preventing Replay

- Using 32 bit sequence numbers helps detect replay of IP packets
- The sender initializes a sequence number for every SA at zero
  - Each succeeding IP packet within a SA increments the sequence number
  - The SA expires when 2^{32} packets are sent
- Receiver implements a window size of W to keep track of authenticated packets
- Receiver checks the MAC to see if the packet is authentic

AH: Transport Mode vs. Tunnel Mode

- Transport mode:
  - Provides protection primarily for upper-layer protocol payloads, by inserting the AH after the original IP header and before the IP payload
  - Typically, transport mode is used for end-to-end communication between two hosts
- Tunnel mode:
  - Provides protection to the entire IP, after the AH or ESP fields are added to the IP packet, the entire packet plus security fields is treated as the payload of new “outer”IP packet with a new outer IP header
  - Tunnel mode is used when one or both ends of an SA are a security gateway, such as a firewall or router that implements IPsec.

Transport Mode AH



Original IP Header	TCP Header	Payload Data

Without IPsec

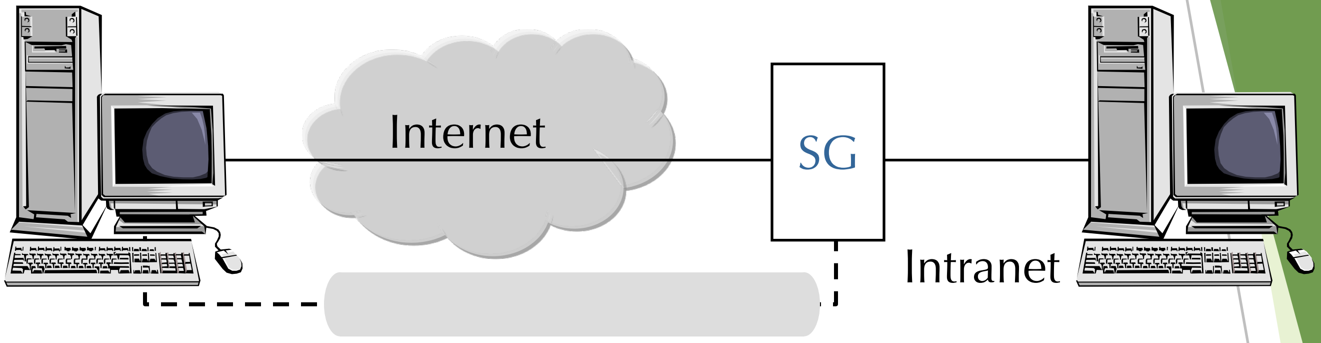
Original IP Header	Auth Header	TCP Header	Payload Data

Next Header	Payload Length	SPI	Seq. No.	MAC

Transport Mode AH (cont.)

- The MAC is calculated over
  - IP header fields that do not change in transit
    - These are called immutable fields
  - The AH fields outside of the MAC itself
  - Higher layer data
    - TCP segment for example
- The AH MAC is generated using HMAC (SHA or MD5)
  - The MAC is truncated to 96 bits

Tunnel Mode AH



Original IP Header	TCP Header	Payload Data

Without IPsec

New IP Header	Auth Header	Original IP Header	TCP Header	Payload Data

Next Header	Payload Length	SPI	Seq. No.	MAC

Tunnel Mode AH (cont.)

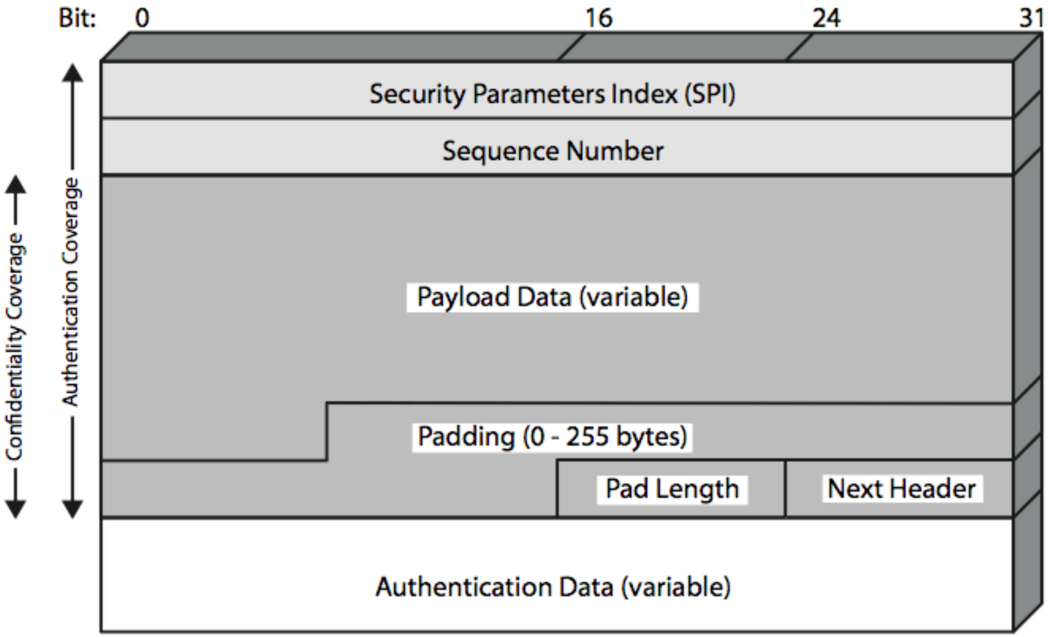
- The entire original IP packet is authenticated
- The AH is inserted between the original IP header and a new IP header
- The original IP header contains the ultimate source and destination addresses
- The new IP header may contain other IP addresses (like security gateway or firewall addresses)

Encapsulating Security Payload (ESP)

- Creates
  - A new header in addition to the IP header
  - A new trailer
- Services
  - Encrypts the payload data
  - Authenticates the security association
  - Prevents replay

ESP Details

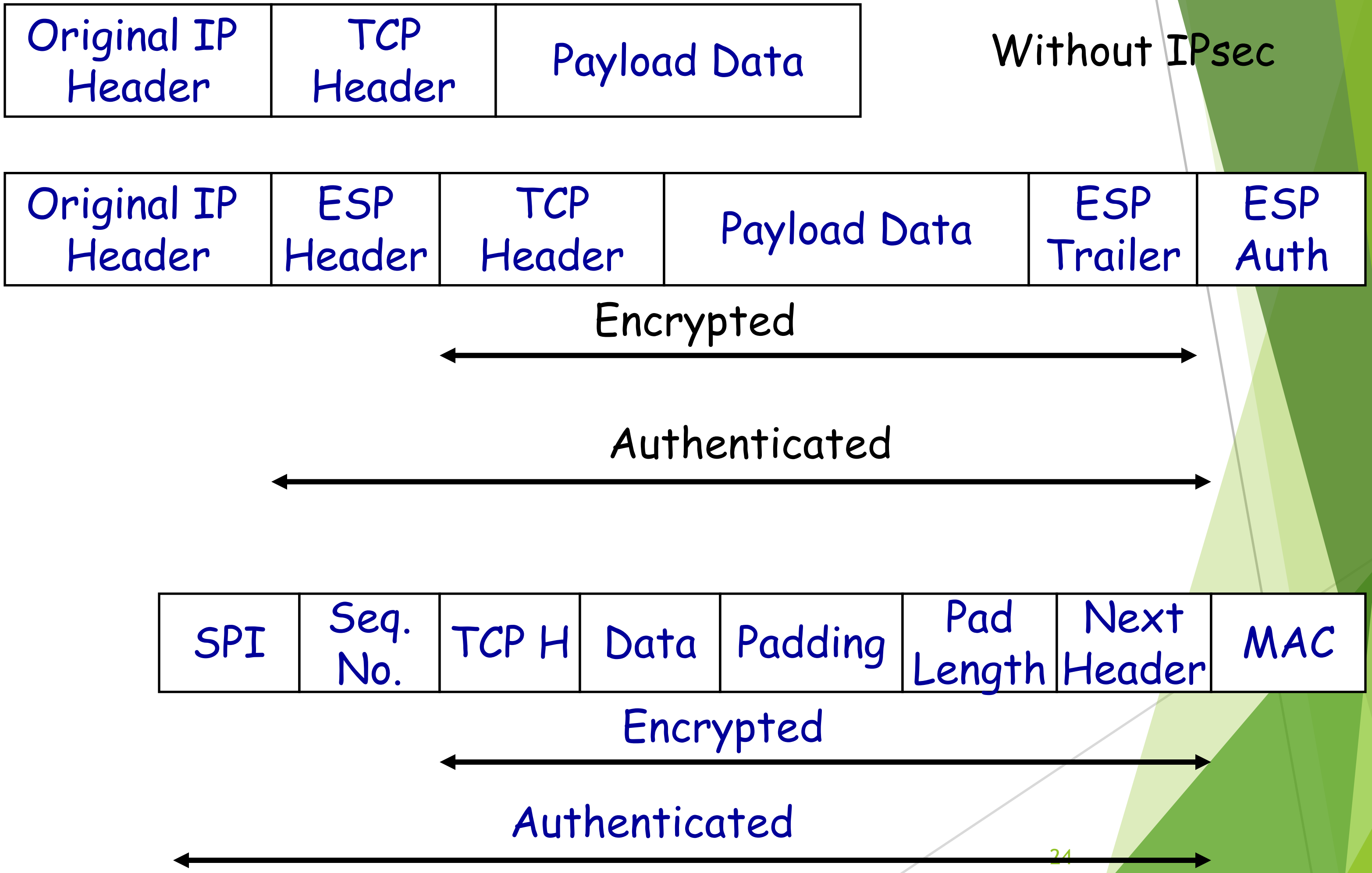
- Security Parameters Index (SPI)
  - Specifies to the receiver the algorithms, type of keys, and lifetime of the keys used
- Sequence number
  - Counter that increases with each IP packet sent from the same host to the same destination and SA
- Payload
  - Application data carried in the TCP segment
- Padding
  - 0 to 255 bytes of data to enable encryption algorithms to operate properly
  - To mislead sniffers from estimating the amount of data transmitted
- Next header
- Authentication Data
  - MAC created over the packet



ESP: Transport Mode vs. Tunnel Mode

- Transport mode is used to encrypt & optionally authenticate IP data
  - Data protected but header left in clear
  - 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
  - Good for VPNs, gateway to gateway security

Transport Mode ESP



Original IP Header	TCP Header	Payload Data

Without IPsec

Original IP Header	ESP Header	TCP Header	Payload Data	ESP Trailer	ESP Auth

Encrypted

Authenticated

SPI	Seq. No.	TCP H	Data	Padding	Pad Length	Next Header	MAC

Encrypted

Authenticated

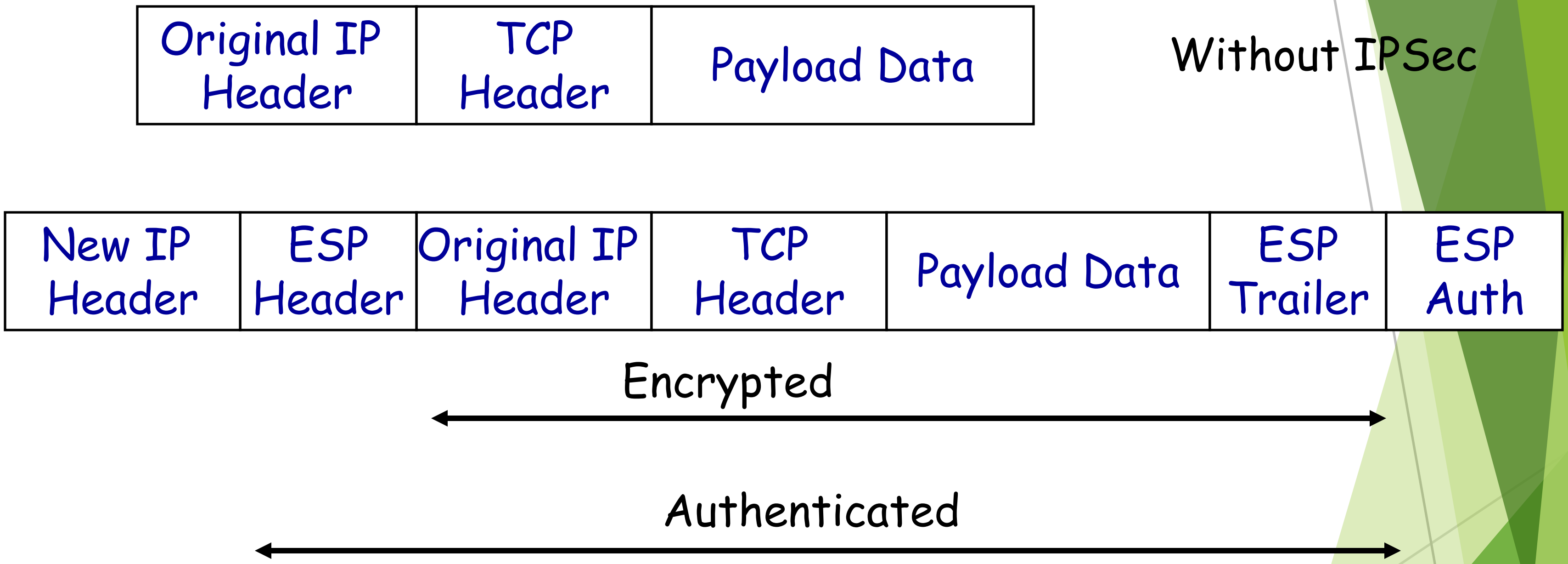
Transport Mode ESP (cont.)

- The block of data containing the ESP trailer and the transport layer segment is converted to ciphertext
- Authentication is optional
  - If selected, authentication covers the ciphertext and the ESP header only
  - Authentication does not cover the IP header

Encryption and Authentication Algorithms for ESP

- IPsec specifies that DES must be supported (mandatory)
- In addition, the following encryption algorithms might be used
  - 3DES, IDEA, Blowfish, CAST, and RC5
- For message authentication
  - HMAC with MD5 or SHA
  - Truncate the output to 96 bits

Tunnel Mode ESP



Original IP Header	TCP Header	Payload Data

Without IPSec

New IP Header	ESP Header	Original IP Header	TCP Header	Payload Data	ESP Trailer	ESP Auth

Encrypted

Authenticated

Tunnel Mode ESP (cont.)

- The entire IP packet is encrypted
  - Can counter traffic analysis
- The entire encrypted block is encapsulated in another IP packet and transmitted
  - This could be done by a firewall or a security gateway
- Useful if hosts within an Intranet are incapable of IPsec

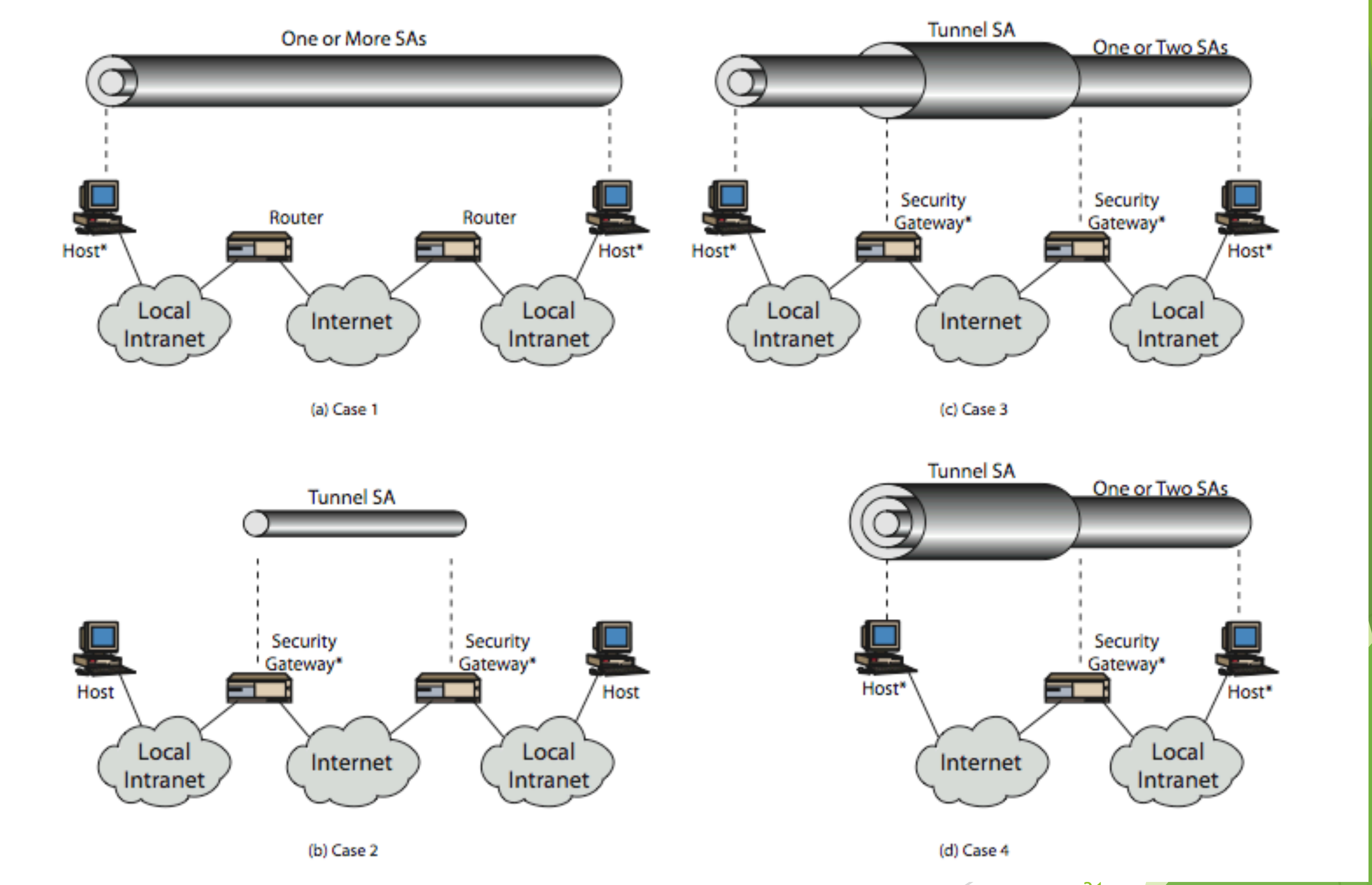
Combining Security Associations

- A single SA can specify either AH or ESP but not both
- In order to provide security services, we need to use multiple security associations
- A sequence of security associations executed in order on an IP packet is referred to as a security association bundle
- The SAs within a SA bundle may terminate at the same endpoints or different endpoints

Security Association Bundles

- Transport adjacency
  - Use more than one IPsec protocol without tunneling
  - Example: ESP followed by AH
  - Usually performed at the same end-points
- Iterated tunneling
  - Multiple IPsec protocols used with IP tunneling
  - Each tunnel can originate or end at different hosts along the route

Security Association Bundles:



(a) Case 1

(c) Case 3

(b) Case 2

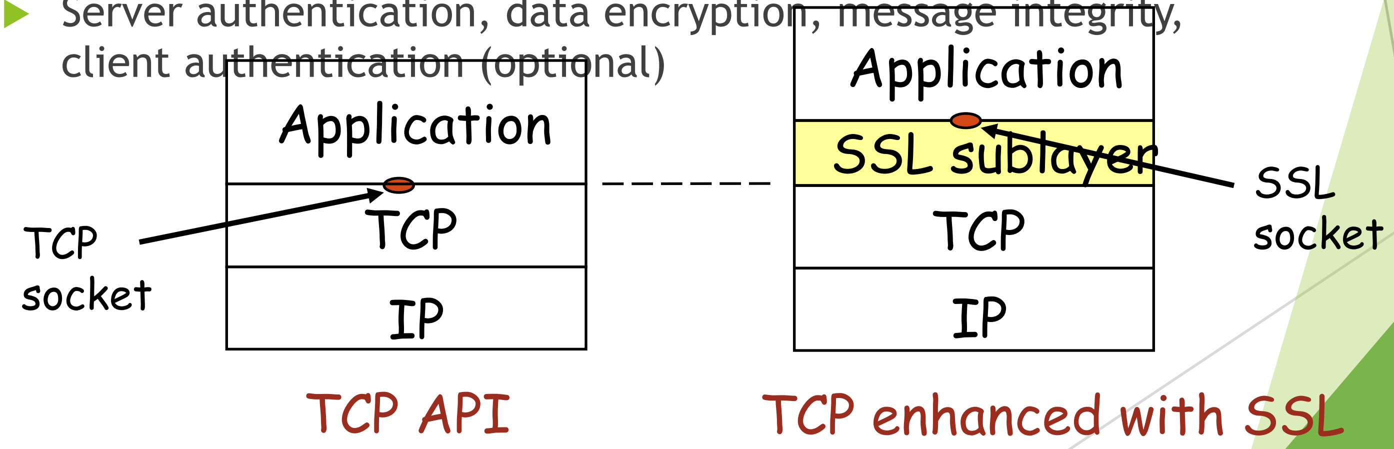
(d) Case 4

Internet Key Exchange (IKE)

- Idea: a protocol for
  - Agreement on which protocols, algorithms, and keys to use – negotiation services
  - Ensuring from the beginning that you are talking with an entity that you believe you are talking with – primary authentication services
  - Managing keys after they have been agreed upon – key management
  - Exchanging material for generating the keys safely
- Reality:
  - Confusing and chaotic - ISAKMP, IKE, Oakley…
  - Took almost 10 years to formulate and it is still too complex

Secure Sockets Layer (SSL)

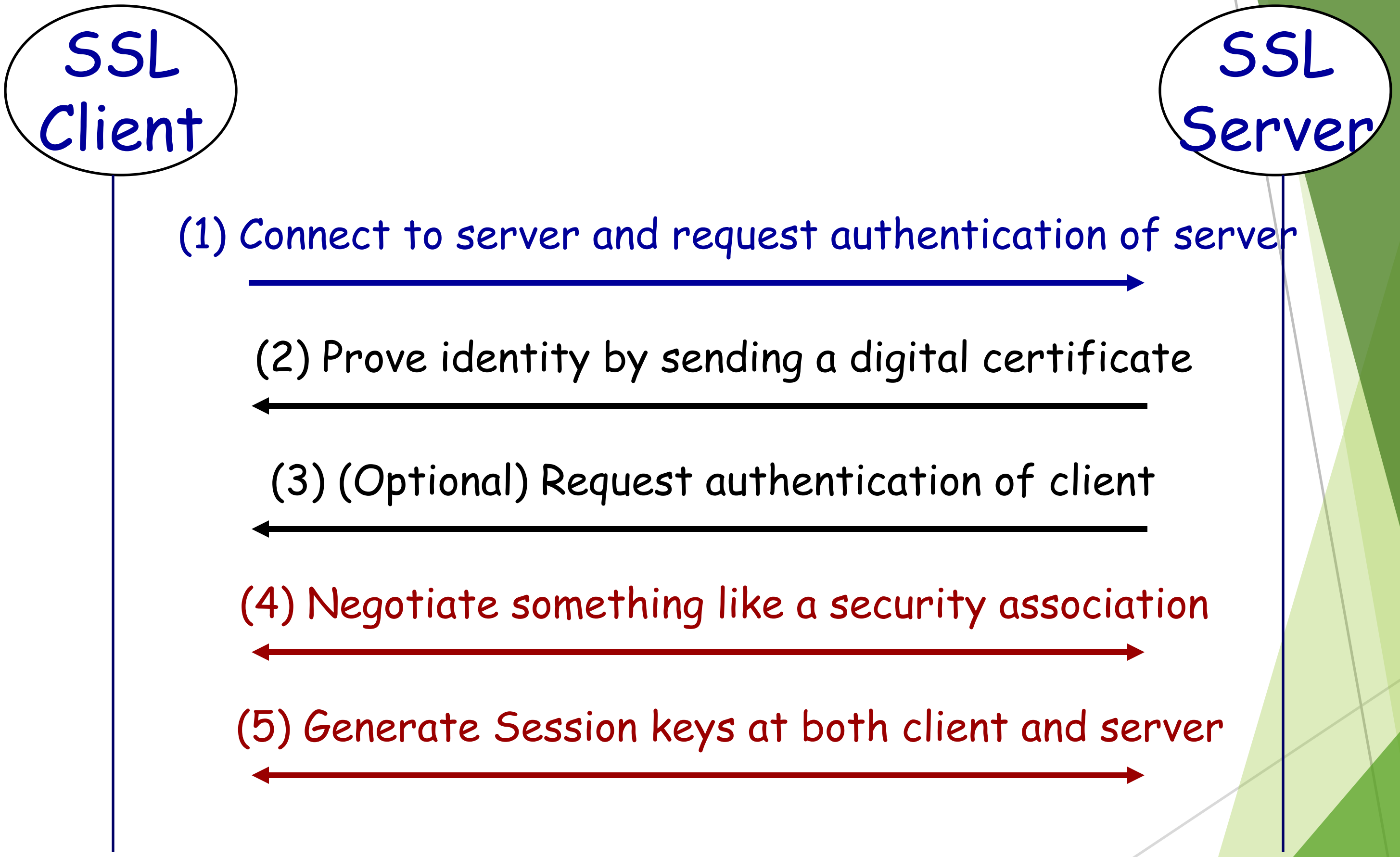
- Provides transport layer security to any TCP-based application.
  - e.g., between Web browsers, servers for e-commerce (shttp)
- Security services:
  - Server authentication, data encryption, message integrity, client authentication (optional)



SSL (cont.)

- Open protocol designed by Netscape
  - SSLv2 was the first deployed version
  - Microsoft created its own protocol called PCT (Private Communications Technology)
  - Netscape overhauled SSLv2 and created SSLv3
- Version 3 used public input and industry backing
- SSL subsequently became Internet standard known as TLS (Transport Layer Security)
- Uses TCP to provide a reliable end-to-end service

SSL: Simplified Protocol



(1) Connect to server and request authentication of server

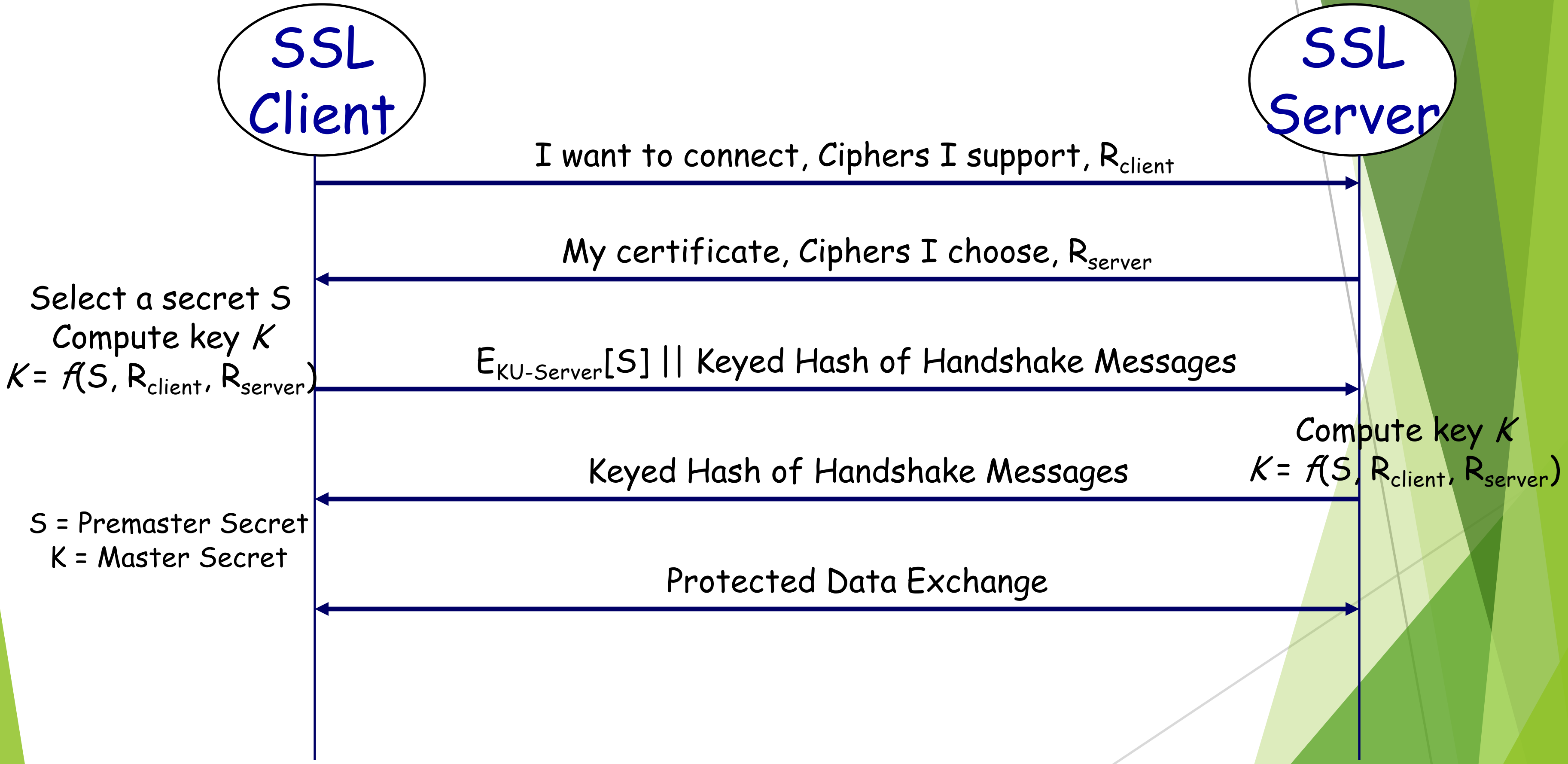
(2) Prove identity by sending a digital certificate

(3) (Optional) Request authentication of client

(4) Negotiate something like a security association

(5) Generate Session keys at both client and server

SSL: Simplified Protocol (More Details)



SSL Client

SSL Server

I want to connect, Ciphers I support, R_{client}

My certificate, Ciphers I choose, R_{server}

Select a secret S
Compute key *K*
$K = f(S, R_{client}, R_{server})$

$E_{KU\text{-}Server}[S]$ || Keyed Hash of Handshake Messages

Compute key *K*
$K = f(S, R_{client}, R_{server})$

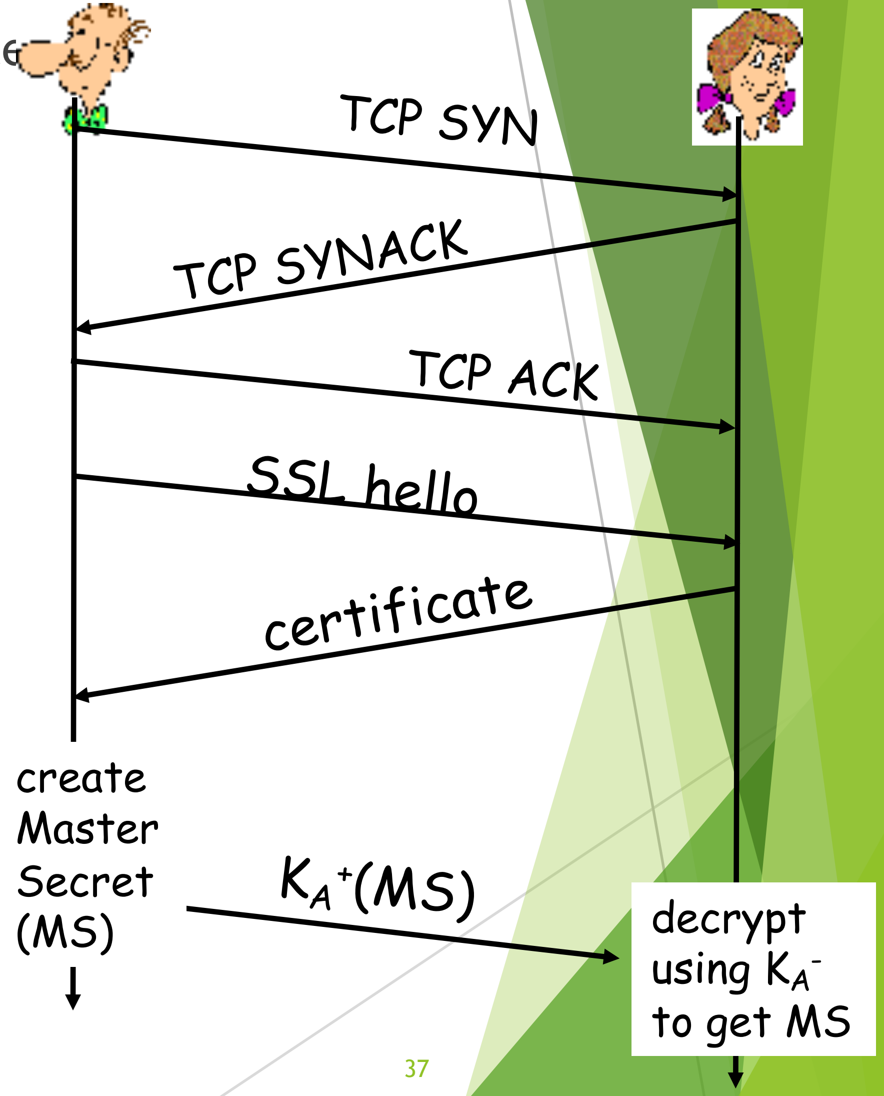
Keyed Hash of Handshake Messages

S = Premaster Secret
K = Master Secret

Protected Data Exchange

SSL: Phase 1 – Handshake

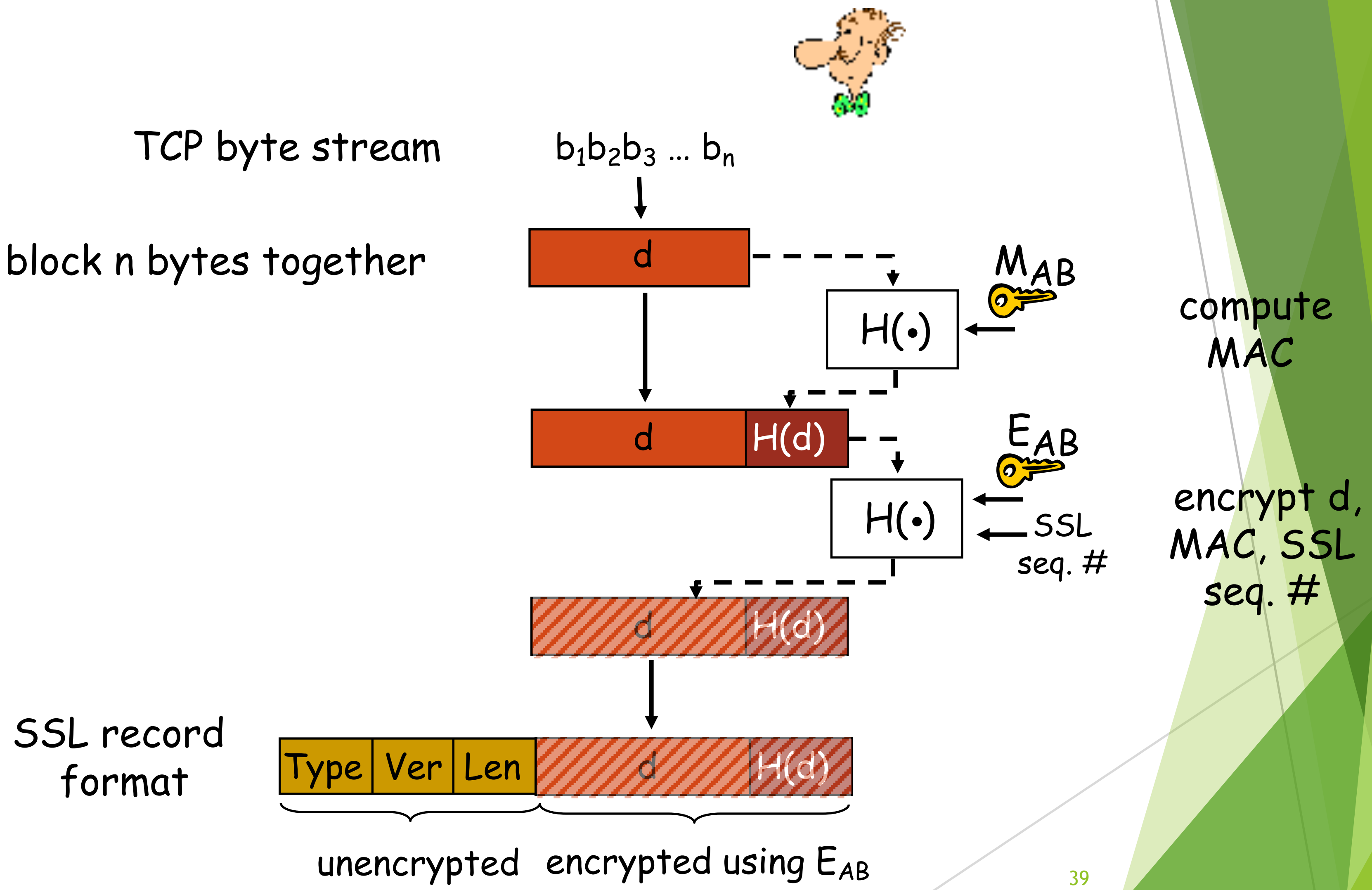
- Bob establishes TCP connection to Alice
- Authenticates Alice via CA signed certificate
- Creates, encrypts (using Alice's public key), sends master secret key to Alice
  - nonce exchange not shown



SSL: Phase 2 – Key Derivation

- Alice and Bob use shared secret (MS) to generate 4 keys:
  - E_{BA}: Bob->Alice data encryption key
  - E_{AB}: Alice->Bob data encryption key
  - M_{BA}: Bob->Alice MAC key
  - M_{AB}: Alice->Bob MAC key
- Encryption and MAC algorithms negotiable between Bob and Alice
- Why 4 keys?
  - One key for A -> B confidentiality
  - One for A -> B authentication/integrity

SSL: Phase 3 – Data Transfer



TCP byte stream

block n bytes together

compute MAC

encrypt d, MAC, SSL seq. #

SSL record format

SSL Connections and Sessions

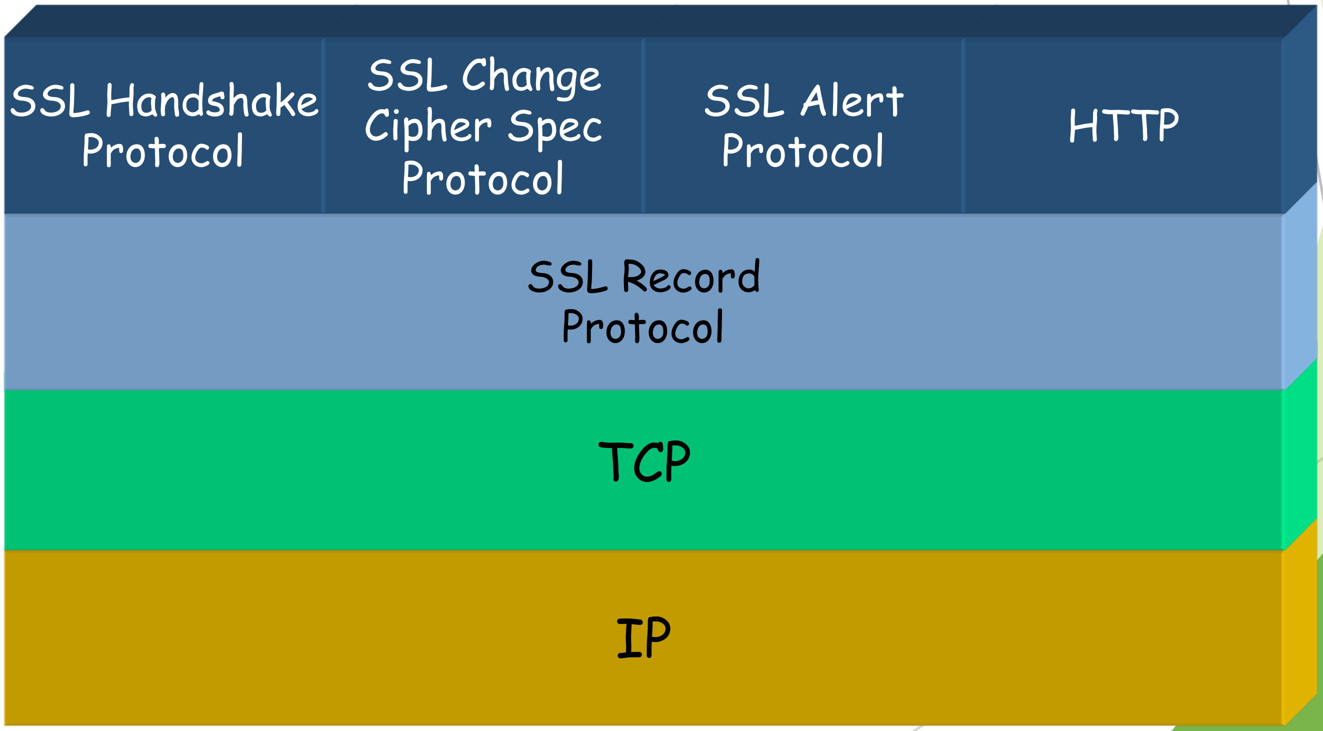
- SSL Connection
  - A transport that provides a suitable type of service
  - Peer-to-peer relationship
  - Short-lived TCP connections per web page or object on web page
  - Associated with a session
- SSL Session
  - Created by the handshake protocol
  - Specify a set of cryptographic parameters for the session (like a SA)
  - These parameters are used for each connection within the session
  - Association between a client and a server
    - Server stores a session ID and the associated master secret
    - If client presents a session ID that the server remembers, they can skip the public key portion of the handshake protocol

SSL Architecture

- SSL implements the initial steps in the simplified protocol using what is known as the “SSL Handshake Protocol”
  - Establish security capabilities and authenticate server using a certificate
- In addition, SSL specifies three other protocols:
  - SSL Record protocol
    - Handles all SSL communications
    - Carries the encrypted data with integrity protection
    - Also carries the other SSL protocols within it
  - SSL Change Cipher Spec Protocol
    - Indicate completion of handshake
    - Allow changes to cipher suites used if necessary
  - SSL Alert Protocol
    - Indicate errors or terminate a session

SSL Architecture (cont.)

- Standard HTTP uses TCP Port 80 by default
- SSL uses TCP Port 443 by default



SSL Handshake Protocol

SSL Change Cipher Spec Protocol

SSL Alert Protocol

HTTP

SSL Record Protocol

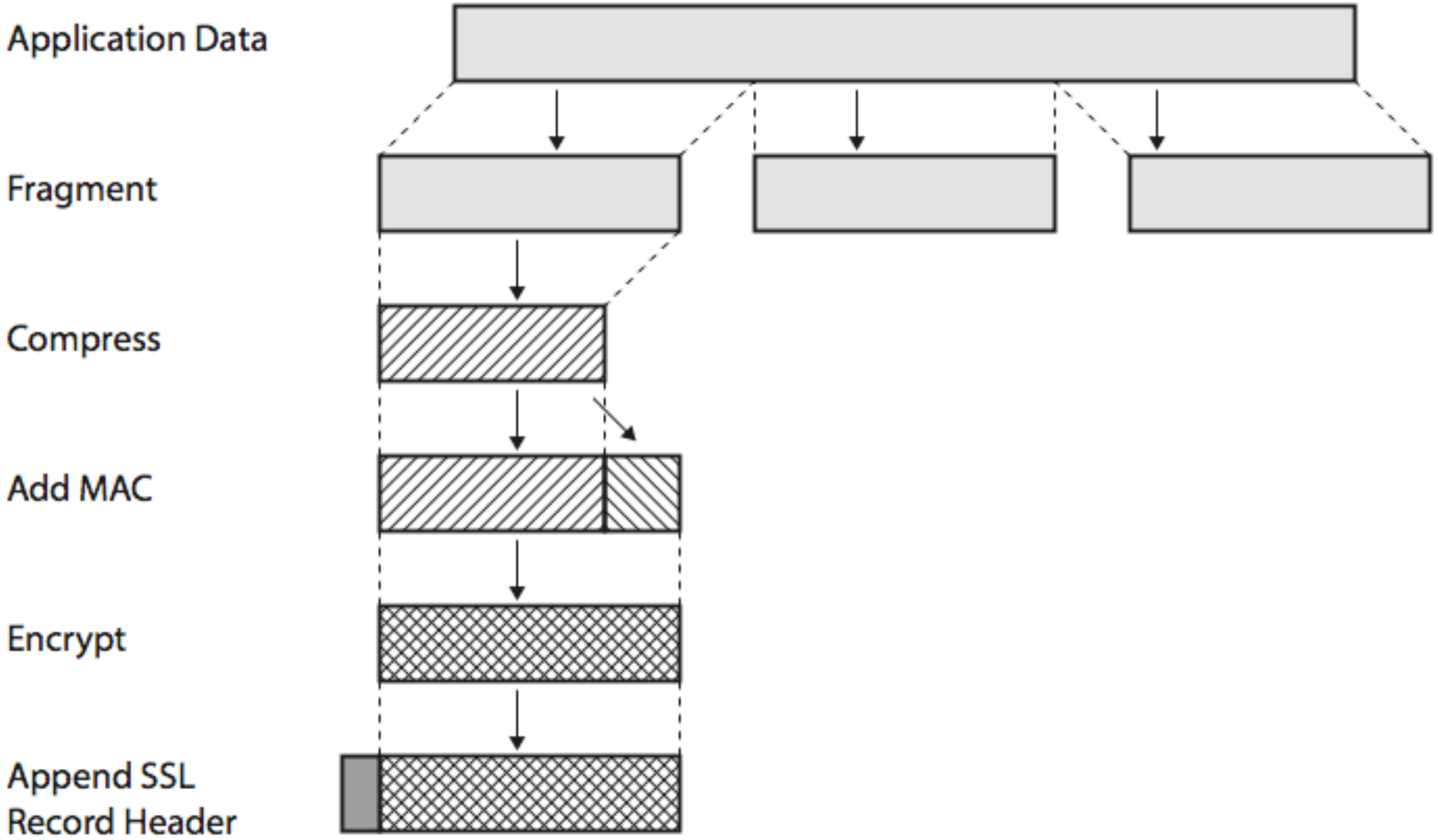
TCP

IP

SSL Record Protocol

- Provides basic security services to various higher layer protocols
  - Used to exchange higher layer data especially HTTP as well as the data of various SSL protocols
  - Record type specifies what is being carried by the record protocol
  - Also fragments and reassembles application data
  - Provides compression (optional)
- Provides two services for each SSL Connection
  - Confidentiality
    - Uses the shared secret encryption key for encryption
  - Message authentication
    - Uses the shared secret integrity key to create a MAC

SSL Record Protocol – Operation



Application Data

Fragment

Compress

Add MAC

Encrypt

Append SSL
Record Header

SSL Change Cipher Spec Protocol

- Simplest SSL Protocol (Record type=20)
- Has a single byte with the value 1
- Completes the handshake protocol
- Sets the security parameters for the rest of the connection or session
  - “Copy pending state to current state”
  - Says “From this point onwards, all records that are received will be protected using these agreed upon ciphers and keys”

SSL Alert Protocol

- Used to indicate errors or used to terminate a session (Record type=21)
- Alert messages are compressed and encrypted
- Messages consist of two bytes
  - First byte is “fatal” or “warning”
  - Second byte specifies the alert
- Some alert examples:
  - Fatal
    - bad_record_mac
    - handshake_failure
  - Warnings
    - no_certificate – client does not have one
    - close_notify
- If the level is fatal, the SSL terminates the connection

SSL Handshake Protocol

- Most complex of the SSL protocols
  - Record type = 22
- Allows the server and client to authenticate each other and negotiate an encryption algorithm/keys
- Each message has three fields
  - Type: One of ten messages
  - Length
  - Content: Parameters associated with a type, etc.
- Example: client_hello (type = 1) has parameters *version, random, session id, cipher suite, compression method*
- Example: certificate_verify (type = 15) has a parameter *signature*

SSL Handshake Protocol – Phase I

- Establish security capabilities
- Initiated by the client
  - Send a client_hello message
  - Specify highest version of SSL that can be understood by the client
  - A nonce consisting of a time stamp and a random number concatenated
  - List of cryptographic algorithms in decreasing order of preference
- Response from the server with a server_hello message with roughly the same parameters
  - Server specifies the selected cipher suite instead of a sequence of cipher suites
  - Server may send a session-id for use by client to resume session
  - Key exchange mechanism, MAC and hash sizes, initial vector for CBC mode, etc., are agreed upon

SSL Handshake Protocol – Phase II

- Server Authentication and Key Exchange
  - Server sends its digital certificate
  - X.509 certificates are used
    - Uses a message called “certificate” (type = 11) and one or more certificates as the parameters
  - Diffie-Hellman or RSA may be used
  - A signature only key is possible
    - This is for export reasons
    - In this case, the server will send an ephemeral shorter public key signed with its long-term private key
    - For this, a “server_key_exchange” message (type = 12) is used
- Concluded with a “server_hello_done” message (zero length)
  - This has type = 14
  - It has no parameters

SSL Handshake Protocol – Phase III

- Client authentication and key exchange
  - Client checks the server certificate and validates it
  - If the server requests a client certificate, the client either sends a certificate or replies with “no_certificate”
    - Server can use the “certificate_request” message (type = 13)
    - Client Authentication is optional
    - The client may ask the server to verify its certificate if it had sent one (“certificate_verify” - type = 15) by signing a hash of all the previous messages
- Client sends a 48-byte “pre-master-secret” encrypted with the public key of the server if RSA is being used
  - Only 46 bytes are random
  - For this, the “client_key_exchange” message is used (type = 16)
  - If Diffie-Hellman is being used, the DH parameters are transmitted

SSL Handshake Protocol – Phase IV

- Finishing the handshake protocol
  - Client and server need to know that the handshake is complete
- Steps
  - The client sends a “change_cipher_spec” message and copies the pending cipher specification state to the current state
  - It sends a “finished” message (type = 20) using the parameters of the new cipher specification
  - Server repeats this process as well
  - This verifies that the key exchange and authentication process were successful

SSL Handshake: Remarks

- The handshake protocol usually creates an SSL session
  - Each session can have multiple connections
  - Sessions avoid unnecessary and expensive negotiation of security parameters for each connection
  - Each session has a pending state and a current operating state
- The handshake protocol followed by the cipher spec change protocol makes the pending state the current state
  - The old current state is deleted
- The initial current state is always one with no encryption, no MAC and no compression

TLS (Transport Layer Security)

- Specified in RFC 2246 (January 1999)
  - Makes use of HMAC and not HMAC-like message authentication
  - Has more alert messages than SSLv3
  - Uses a pseudorandom function (PRF) based on HMAC to create keys
- TLS messages are used within EAP for WLAN authentication and key exchange
- WTLS is a variant of TLS that is used in the wireless application protocol (WAP)