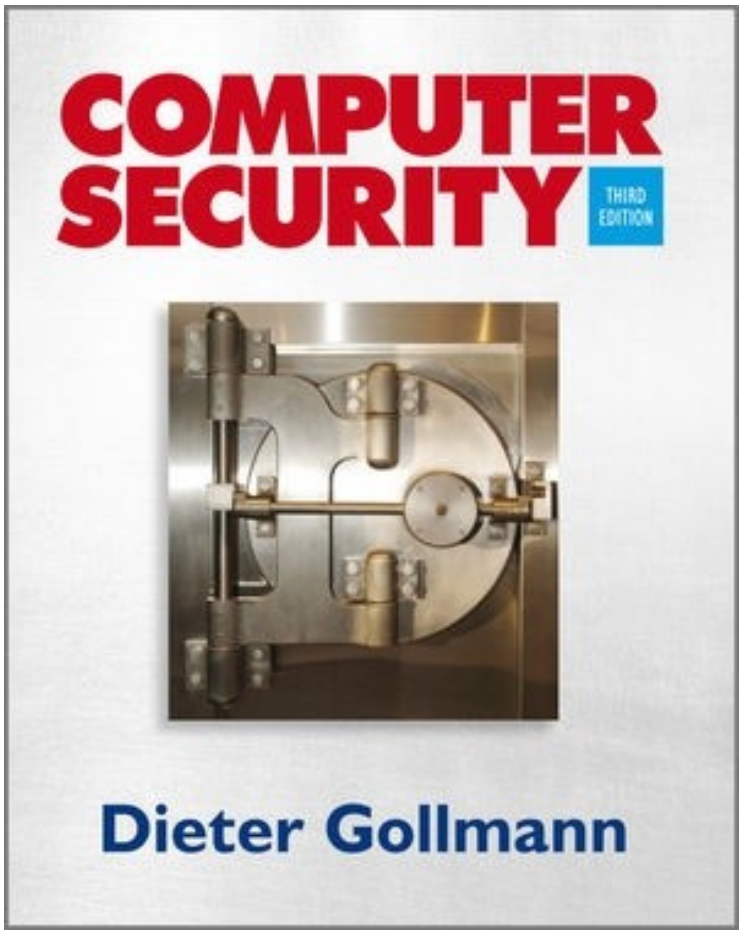
Computer Security 3e

Dieter Gollmann



Chapter 16: Communications Security

Agenda

- Threat model
- Secure tunnels
- Protocol design principles
- IPsec
- SSL/TLS
- EAP

Threat Model

- Attacker has access to communications link between two end points: can see and modify messages.
- The job of a communications security service is done once data has been delivered to an end point.
- This is the ‘old’ secret service threat model.
- A passive attacker just listens to traffic.
  - When the attacker is interested in the content of messages, we talk about eavesdropping, wiretapping, or sniffing.
  - Traffic analysis tries to identify communications patterns; may be possible even when attacker cannot read individual messages.
  - Attacker might also be interested in a target’s location.

Active Attackers

- Active attacker may modify messages, insert new messages, or corrupt network management information like the mapping between DNS names and IP addresses.
- In spoofing attacks messages come with forged sender addresses.
- In flooding (bombing) attacks a large number of messages is directed at the victim.
- In squatting attacks, the attacker claims to be at the victim's location.
- Active attacks are not necessarily more difficult than passive attacks; e.g., in practice it is easier to send an email with a forged sender address than to intercept an email intended for someone else.

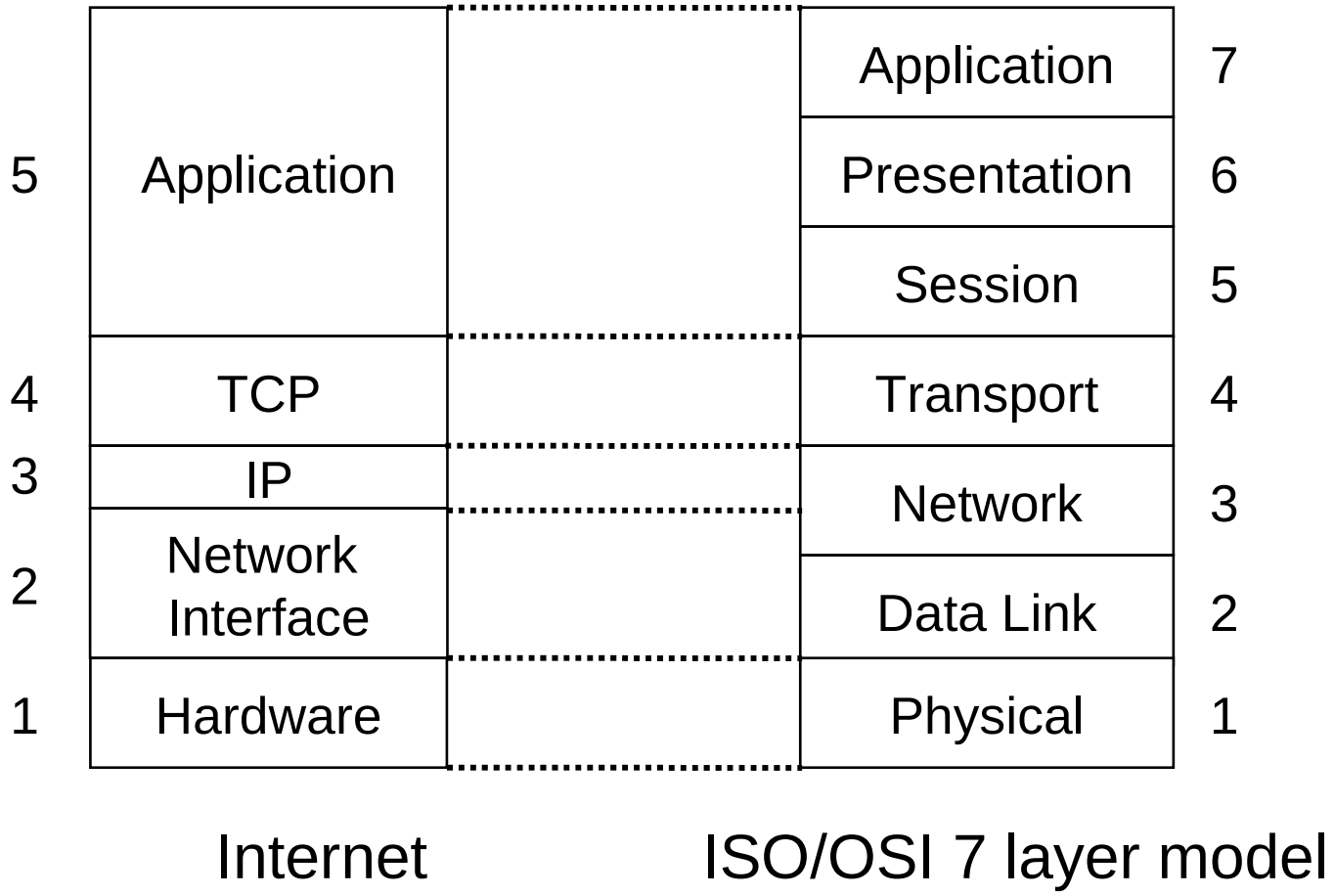
Secure Tunnels

- Secure tunnel (channel): secure logical connection between two end points across an insecure network.
- Typical security guarantees are data integrity, confidentiality, and data origin authentication.
- End points might be machines named by domain names or IP addresses; end points might be specific software components hosted at a client or a server.
- Confusion about the precise nature of the end point authenticated can lead to “security services that do not provide any security at all”.
  - If the tunnel does not end where the user expects, the attacker may wait at the other side of the tunnel.
- Secure tunnels do not provide security services once data are received.

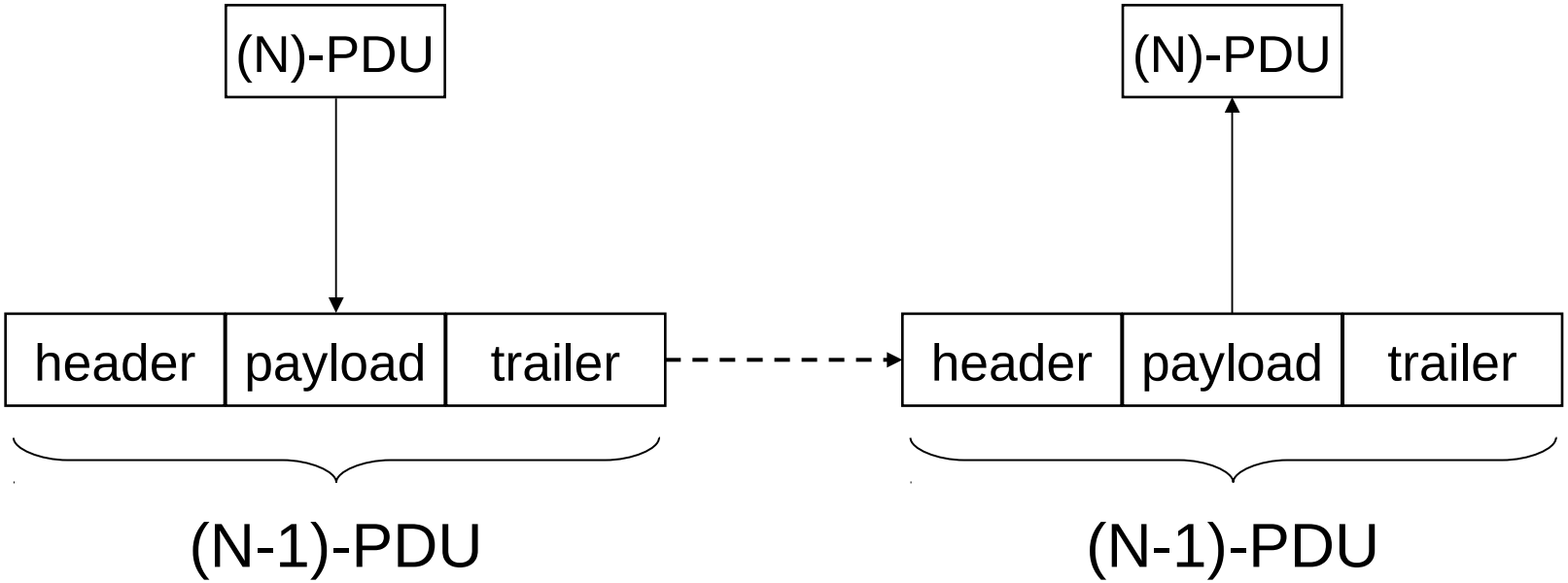
Typical Cryptographic Primitives

- ‘Expensive’ asymmetric encryption and signature algorithms, Diffie-Hellman (still to come), only for entity authentication and key exchange.
- Symmetric encryption algorithms, for speed.
- ‘Cheap’ MAC algorithms, usually built from hash functions.
- (Keyed) pseudo-random functions for key derivation.
- Sequence numbers to prevent replay attacks.
- Nonces and timestamps for freshness in entity authentication.

Protocol Layering



Protocol Layering



PDU … Protocol Data Unit

Implementing Security Services

- Header in (*N*-1)-PDU is convenient location for storing security relevant data.
- Upper layer protocol can be aware of lower layer security services:
  - Upper layer protocol has to change its calls so that they refer to the security facilities provided.
- Lower layer security services can be transparent to upper layer protocol:
  - Upper layer protocol need not be changed at all.

Security & Network Layers

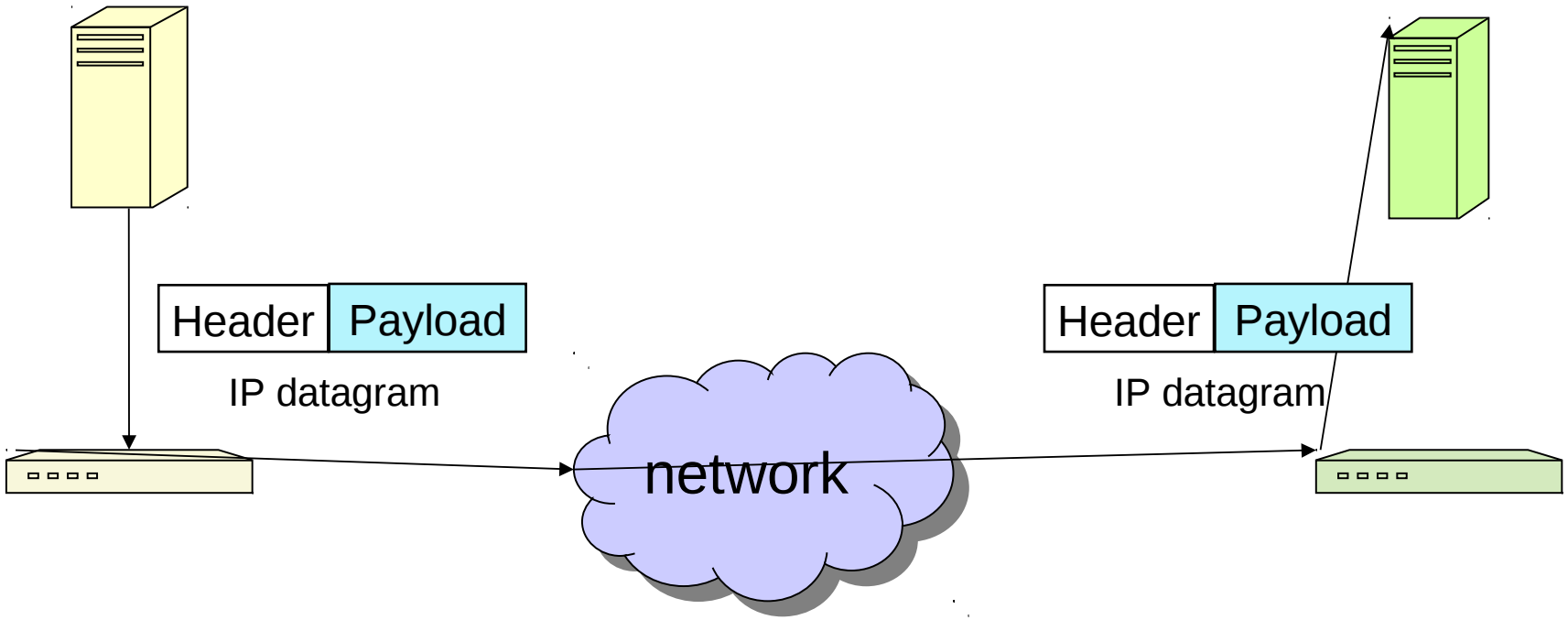
- Security can be applied at any of the network layers except layer 1 (physical layer).
  - Even this is sometimes possible, e.g. spread spectrum techniques for limited privacy.
- In general, the lower the layer the more generic but the less specific the protection.
- Endpoints of security channels differ between layers.
- End-to-end or hop-by-hop security?
- Example: protection at Data Link (Network Interface) layer, e.g. link level encryptor.
  - Advantage: covers all traffic on that link, independent of protocols above.
  - Disadvantage: protection only for one ‘hop’.

IPsec

- Defined in RFCs 4301 – 4309 (obsolete 2401-2412).
- Provides security at network (Internet) layer.
  - All IP datagrams covered.
  - No re-engineering of applications.
  - Transparent to upper layer.
- Mandatory for next generation IPv6, optional for IPv4.
- Two basic modes of use:
  - Transport mode: IPsec-aware hosts as endpoints.
  - Tunnel mode: for IPsec-unaware hosts, tunnel established by intermediate gateways or host OS.

IPsec Transport Mode

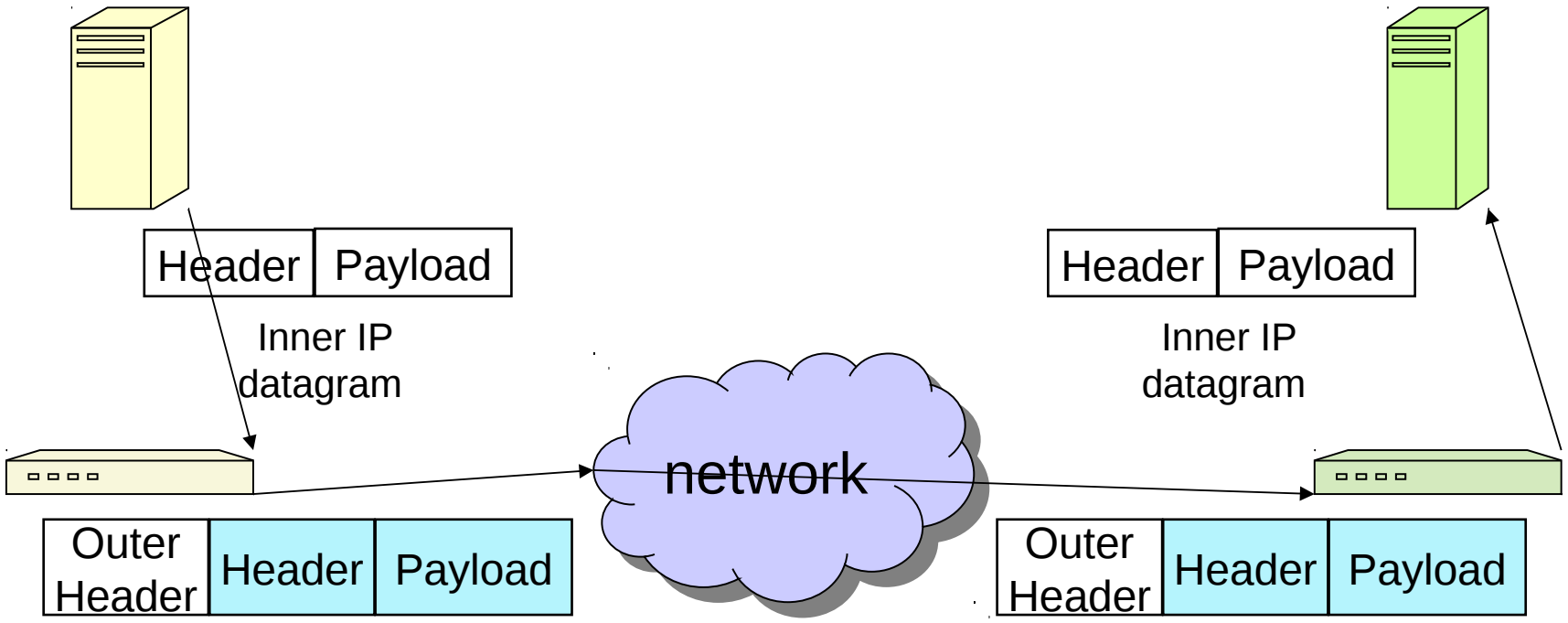
- Host-to-host (end-to-end) security:
  - IPsec processing performed at endpoints of secure channel.
  - Endpoint hosts must be IPsec-aware.



IPsec Tunnel Mode

- Entire IP datagram plus security fields treated as new payload of ‘outer’ IP datagram.
  - Original ‘inner’ IP datagram encapsulated within ‘outer’ IP datagram.
- IPsec processing performed at security gateways on behalf of endpoint hosts.
  - Gateway could be perimeter firewall or router.
  - Gateway-to-gateway but not end-to-end security.
  - Hosts need not be IPsec-aware.
- Encrypted inner IP datagram, including original source and destination addresses, not visible to intermediate routers.

IPsec Tunnel Mode



IPsec

- Authentication and/or confidentiality services for data:
  - AH protocol [RFC 4302]
  - ESP protocol [RFC 4303]
- Use of AH being deprecated in favour of ESP.
  - Political reasons for introducing an authentication-only protocol in the 1990s have faded.
- (Too?) flexible set of key establishment methods (covered later in the course): IKE, IKEv2.

AH Protocol [RFC 4302]

- AH = Authentication Header: provides connectionless data integrity and data origin authentication.
  - Authenticates whole payload and most of header.
- Prevents IP address spoofing: source IP address is authenticated.
- Creates stateful channel using sequence numbers. Heresy!
- Prevents replay of old datagrams: AH sequence number is authenticated.
- Uses MAC and secret key shared between endpoints.

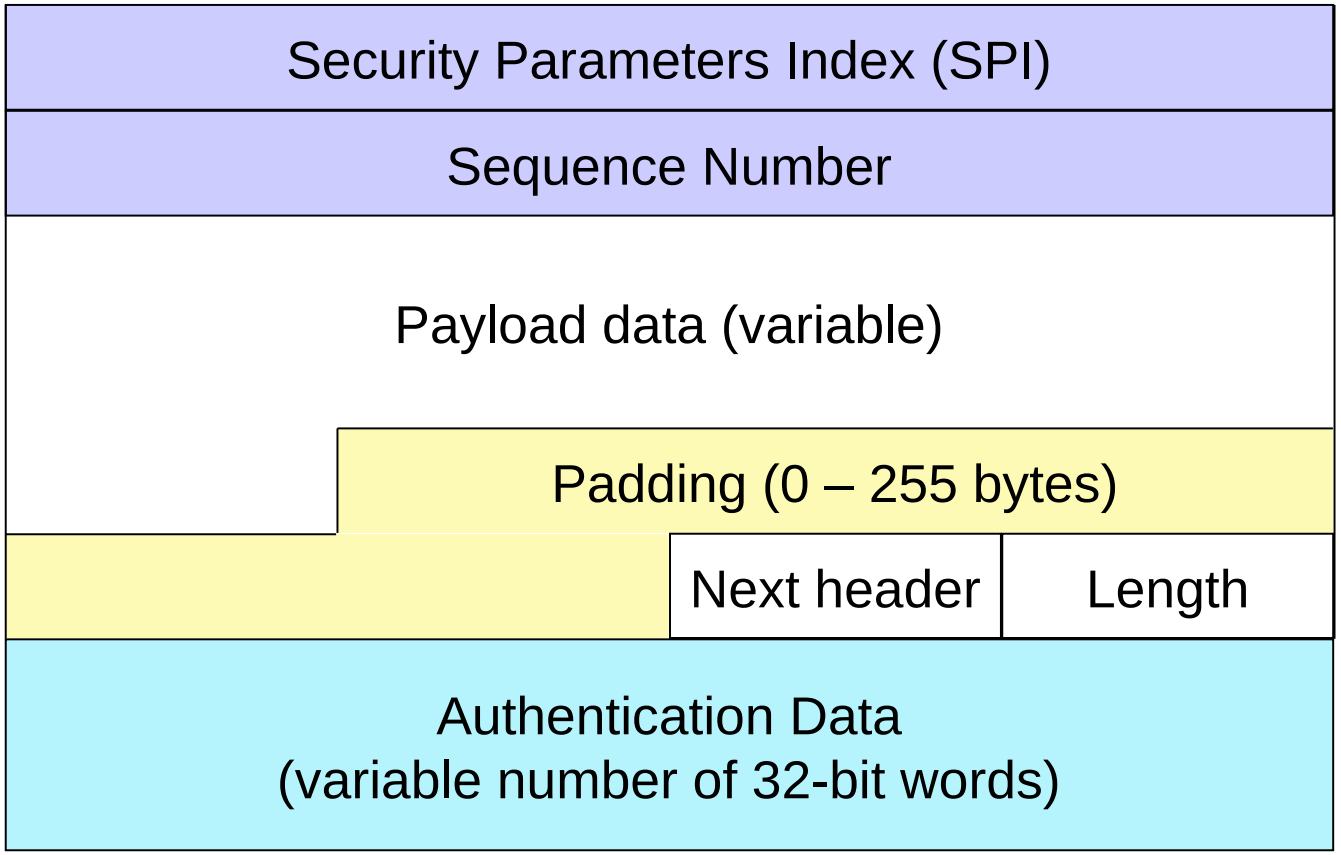
ESP Protocol

- Encapsulating Security Payload [RFC 4303].
- Provides one or both of:
  - Confidentiality for payload/inner datagram; sequence number not protected by encryption.
  - Authentication of payload/inner datagram, but not of outer IP header.
- Traffic-flow confidentiality in tunnel mode.
- Symmetric encryption and MACs based on secret keys shared between endpoints.

ESP Headers

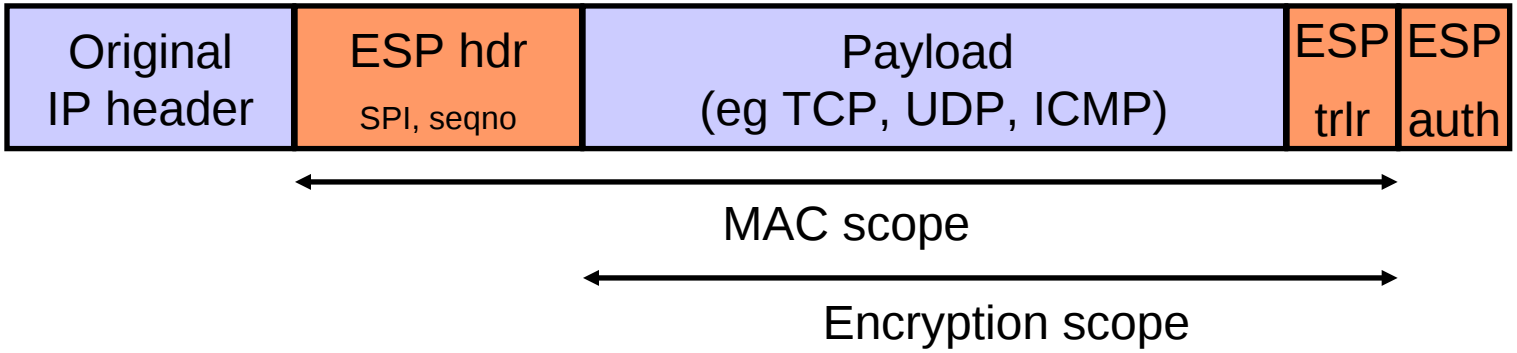
- ESP specifies header and trailer to be added to IP datagrams.
- Header fields include:
  - SPI (Security Parameters Index): identifies which algorithms and keys are to be used for IPsec processing (more later).
  - Sequence number.
- Trailer fields include:
  - Any padding needed for encryption algorithm (may also help disguise payload length).
  - Padding length.
  - Authentication data (if any), i.e. the MAC value.

ESP Header (RFC 2406)

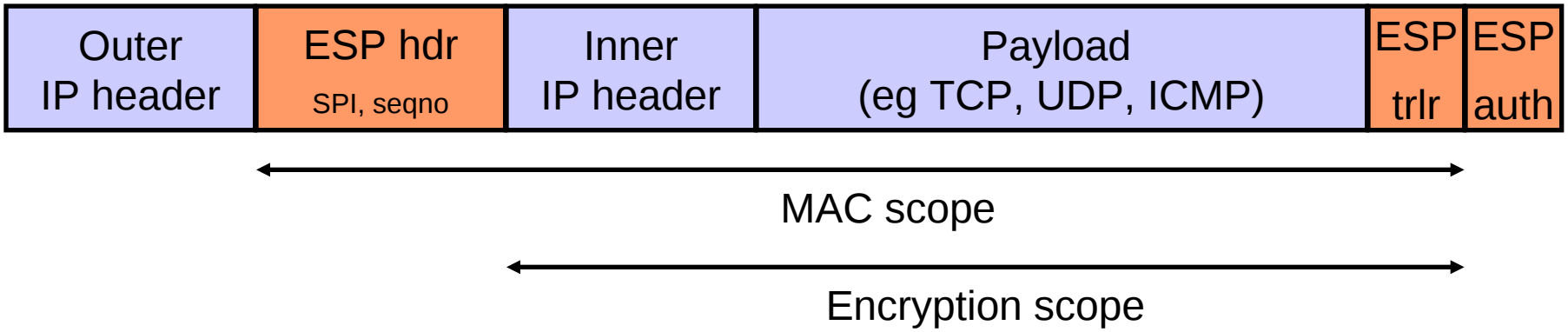


ESP Protocol – Transport & Tunnel

ESP in transport mode:



ESP in tunnel mode:



IPsec Security Association (SA)

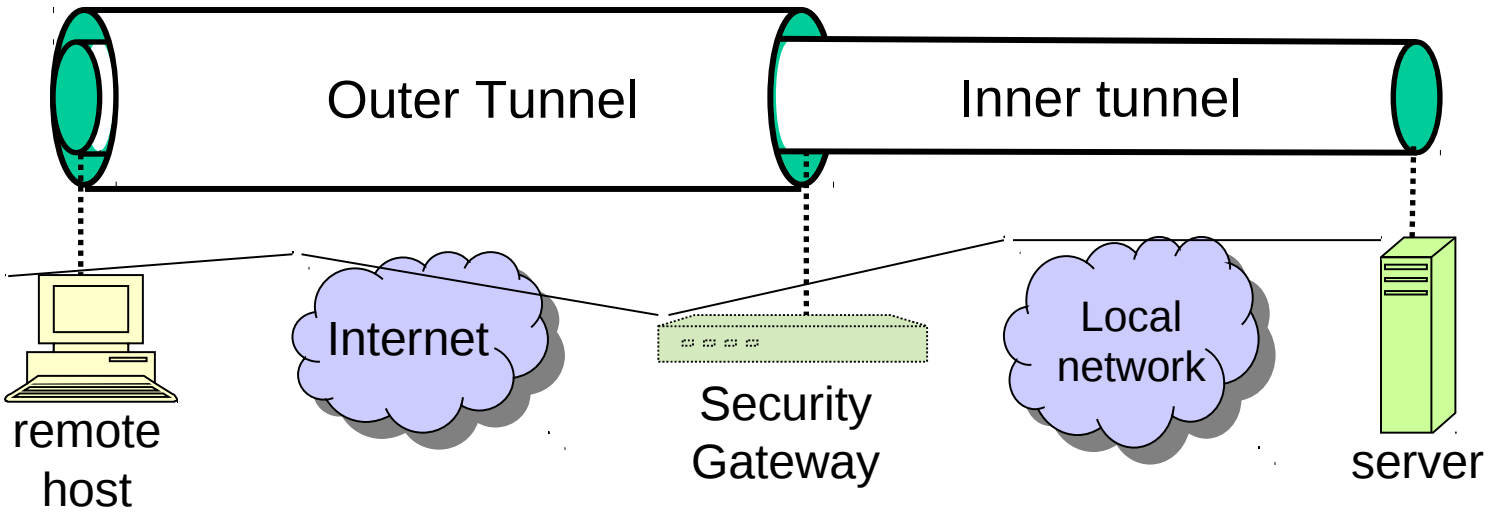
- A SA is a one-way (simplex) relationship between sender and receiver.
  - Specifies processing to be applied to *this* datagram from *this* sender to *this* receiver.
- List of active SAs held in SA database (SAD).
- Each SA identified by SPI, source address, destination address; contains:
  - Sequence number counter and anti-replay window.
  - AH/ESP info: algorithms, IVs, keys, key lifetimes.
  - SA lifetime.
  - Protocol mode: tunnel or transport.
  - …

Combining SAs

- IPsec security services may be provided at different points in network.
  - Host-to-host.
  - Gateway-to-gateway for Virtual Private Network (VPN).
- SAs can be combined using:
  - Transport adjacency: more than one SA applied to same IP datagram without tunnelling.
  - Iterated tunnelling: multiple levels of nesting of IPsec tunnels; each level has its own SA; each tunnel can begin/end at different IPsec site along route.

Remote Host to Internal Server

- Remote host has Internet access to gateway, then gains access to server behind gateway.
- Traffic to server protected in inner tunnel.
- Outer tunnel protects inner traffic over Internet.



IPsec Key Management

- IPsec needs a lot of symmetric keys:
  - One key for each SA.
  - Different SA for each combination of {ESP,AH} $\times$ {tunnel,transport} $\times$ {sender, receiver}.
- Two sources for SAs and keys:
  - Manual keying: works for small number of nodes but hopeless for reasonably sized networks of IPsec-aware hosts; requires manual re-keying.
  - IKE: Internet Key Exchange [RFC 2409, 4306]; many options and parameters.

IKE Security Goals

- Entity authentication of participating parties.
- Establish fresh shared secret, to derive further keys:
  - for protecting IKE management channel,
  - for SAs for general use.
- Secure negotiation of all algorithms.
  - Authentication method, key exchange method, encryption and MAC algorithms, hash algorithms.
- Resistance to Denial-of-Service attacks.
- Options for perfect forward secrecy, deniable authentication and identity protection.

IKE v2

- RFC 4306, December 2005.
- Two phases, three message exchanges.
  - IKE_SA_INIT
  - IKE_AUTH
  - CREATE_CHILD_SA
- Establishes an IKE SA and a variable number of child SAs.
- Diffie-Hellman as the only key establishment method; various groups supported.

IKE_SA_INIT exchange

- Messages between initiator and responder:
  1. I→R: HDR, SAi1, KEi, Ni
  2. R→I: HDR, SAr1, KEr, Nr, [CERTREQ]
- Parameters:
  - HDR: SPI, version number, various flags, …
  - SA: security associations
  - KEi, KEr: Diffie-Hellman values g^i, g^r mod p.
  - Ni, Nr: nonces
  - [CERTREQ]: optional certificate request
- Algorithm negotiation: Initiator states which cryptographic algorithms are supported (SAi1), responder picks a suite (SAr1).

IKE_SA_INIT: Effect

- Initiator and responder have negotiated a shared but unauthenticated SA (SAr1).
- Initiator and responder can compute a shared but unauthenticated key SKEYSEED.
- The shared suite of cryptographic algorithms and the shared key(s) are used to protect the messages in the next exchange.
- No identities disclosed in IKE_SA_INIT exchange, other than the IP addresses in the IP headers.

Keying Material

- Both parties derive joint key SKEYSEED from KEi, KEr using a pseudo-random function prf.

  SKEYSEED = prf(Ni | Nr, g^{ir})

- Further keys derived from master key:

  {SK_d | SK_ai | SK_ar | SK_ei | SK_er | SK_pi | SK_pr } = prf+(SKEYSEED, Ni | Nr | SPIi | SPIr)

  - SK_e for encryption,
  - SK_a for integrity, message authentication,
  - SK_d for deriving keys for child SAs,
  - SK_p for creating AUTH payload in 2nd exchange.

IKE_AUTH Exchange

- Messages cryptographically protected under keys derived after the first exchange; denoted by SK {…}:
  1. I→R: HDR, SK {IDi, [CERT,] [CERTREQ,] [IDr,] AUTH, SAi2, TSi, TSr}
  2. R→I: HDR, SK {IDr, [CERT,] AUTH, SAr2, TSi, TSr}
- Parameters:
  - IDi, IDr: identity of initiator and responder
  - AUTH: authenticator
  - TS: traffic selectors (not discussed further in this lecture)

IKE_AUTH: Effect

- Authenticator: Digital signature or MAC over message; details defined in the RFC.
- Authenticators MUST be verified.
- A new authenticated SA (SAr2) is negotiated.
- The shared suite of cryptographic algorithms from SAr2 and the shared keys are used to protect the messages in a third exchange.
- Identities only included in encrypted messages.

CREATE_CHILD_SA

- Messages cryptographically protected with keys derived after the first phase;
  1. I→R: HDR, SK {[N], SA, Ni, [KEi], [TSi, TSr]}
  2. R→I: HDR, SK {SA, Nr, [KEr], [TSi, TSr]}
- Parameters:
  - [N]: “Notify”; used e.g. to indicate the SA when an SA is being rekeyed.
- Negotiates SAs for AH, ESP; option to establish new keys for a CHILD_SA.

Denial-of-Service (DoS) Attacks

- Strong cryptography can be a weakness.
- DoS: attacker sends bogus message to the victim, who performs “expensive” crypto operation, e.g. signature verification.
- Defence: DoS attacks cannot be prevented.
- To mitigate the effect of DoS attacks, design protocols in a way that the attacker’s cost is comparable to the victim’s cost.

DoS Attacks on IKEv2

- Attack against initiator: during IKE_SA_INIT reply to first message with bogus response.
- If the initiator uses the first response received to set up a connection, no usable SA and key will be established and IKE fails.
- Countermeasure: initiator accepts multiple responses to its first message, continues the protocol, and discards all invalid half-open connections when a valid cryptographically protected response is received to any one of its requests.

DoS Attacks on IKEv2

- Attack against responder: responder flooded with session initiation requests from forged IP addresses.
- Effect: State and CPU exhausted at the responder.
- Countermeasure: check that requests come from claimed source address (authentication).
- Mechanism: to counter state exhaustion, use a stateless mechanism; solution: “cookies”.
  - Cookie MUST depend on the specific parties.
  - MUST NOT be possible for anyone other than the issuer to generate cookies that will be accepted by the issuer.
  - Issuer uses local secret information in the generation and later verification of a cookie.
  - Fast cookie generation and verification.

IPsec Security Policy

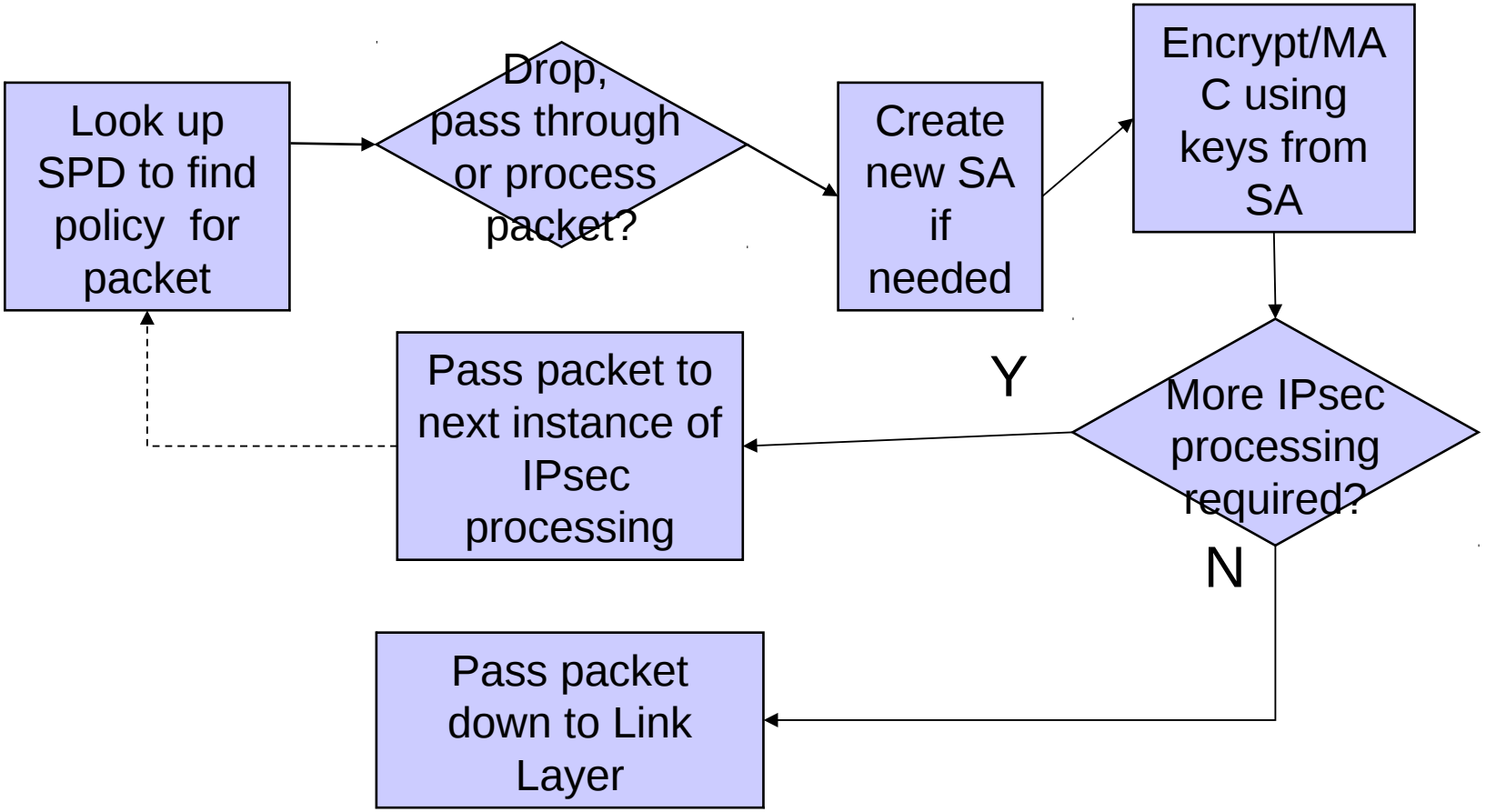
- IPsec aware host needs rules for processing packets.
  - Should packet be dropped, passed through, encrypted, MACed?
  - Which key and algorithm to apply?
- Rules stored in a Security Policy Database (SPD).
- SPD consulted for each outbound & inbound packet.
- Fields in IP datagram compared to fields in SPD entries to find matches.
  - Match can be based on source and destination addresses (ranges of addresses), transport layer protocol, transport layer port numbers,…
- Match identifies a Security Association (SA) or group of SAs (or the need for new SA).

Finding the ‘Right’ SA

- Each entry in the Security Association Database (SAD) must indicate whether the SA lookup makes use of the destination, or destination and source IP addresses in addition to the SPI.
- For each inbound IPsec-protected packet, search the SAD such that the entry that matches the “longest” SA identifier is found.

1. Search the SAD for a match on {SPI, destination address, source address}; if an SAD entry matches, then process the inbound packet with that entry.
2. Otherwise, search the SAD for a match on {SPI, destination address}; if an SAD entry matches, then process the inbound packet with that entry.
3. Otherwise, search the SAD for a match on only {SPI} if the receiver has chosen to maintain a single SPI space for AH and ESP, or on {SPI, protocol} otherwise; if an SAD entry matches, then process the inbound packet with that entry.
4. Otherwise, discard the packet and log an auditable event.

IPsec Outbound Processing



AH, ESP and NAT

- Network Address Translation (NAT) invented for coping with IPv4 address shortage.
  - Maps private IP addresses to routable addresses in the public network.
- NAT supposed to be transparent to all applications; not true when used in conjunction with IPsec.
- AH in tunnel or transport mode incompatible with NAT; may only be employed when source and destination networks are reachable without translation.
- ESP works with NAT; outer IP header is not included in hash value computation for authentication.

IKE and NAT/PAT

- IKE has problems when NAT devices transparently modify outgoing packets.
- If incoming packets in IKE negotiation are expected from UDP port 500 and if a NAT device is introduced, the final packet port may not be the expected port; thus IKE negotiation will not even begin.
- When IKE includes IP addresses as part of the authentication process, changes made by a NAT device will cause IKE negotiation to fail.
- NAT-firewall security issues: draft-fessi-nsis-natfw-threats-00.

TCP Checksum & NAT

- TCP checksum calculation includes IP addresses (given in the pseudo header).
  - Heresy: integrity check breaks the layered architecture.
  - Pseudo header not transmitted; reconstructed by receiver.
- NAT changes source IP address.
- When receiver processes TCP packet, the TCP integrity check will use a ‘wrong’ IP address, and checksum verification will fail.
- Receiver needs to be given correct source address.
- NAT Traversal (NAT-T) [RFC 3947 and 3948] adds a UDP header that encapsulates the ESP header (sits between ESP header and outer IP header).

SSL/TLS

SSL/TLS Overview

- SSL = Secure Sockets Layer.
  - Unreleased v1, flawed but useful v2, good v3.
- TLS = Transport Layer Security Protocol.
  - TLS1.0 = SSL3.0 with minor modifications
  - Version 1.2 defined in RFC 5246 (October 2008)
  - Open-source implementation at www.openssl.org/
- Widely used in Web browsers and servers to support ‘secure e-commerce’ over HTTP.
  - HTTPS sessions indicated by browser lock.

SSL/TLS Basic Features

- Security at session layer.
  - ‘Thin layer’ between TCP and, e.g., HTTP.
  - TCP provides reliable, end-to-end transport.
  - Applications must be aware of SSL, need some modification.
- Two layer architecture:
  - SSL Record Protocol: provides secure, reliable channel to second layer.
  - Upper layer carries SSL Handshake Protocol, Change Cipher Specification Protocol, Alert Protocol, HTTP, any other application protocols.

SSL/TLS Handshake – Goals

- Entity authentication of participants.
  - Participants are ‘client’ and ‘server’.
  - Server nearly always authenticated, client more rarely.
  - Appropriate for most e-commerce applications.
- Establish a fresh, shared secret.
  - Shared secret used to derive further keys.
  - For confidentiality and authentication in SSL Record Protocol.
- Secure ciphersuite negotiation.
  - Encryption and hash algorithms
  - Authentication and key establishment methods.

Sessions & Connections

- Session:
  - Created by handshake protocol.
  - Defines set of cryptographic parameters (encryption and hash algorithm, master secret, certificates).
  - Carries multiple connections to avoid repeated use of expensive handshake protocol.
- Connection:
  - State defined by nonces, secret keys for MAC and encryption, IVs, sequence numbers.
  - Keys for many connections derived from single master secret created during handshake protocol.

SSL Handshake Protocol: Run

- We sketch the most common use of SSL:
  - No client authentication.
  - Client sends **`pre_master_secret`** using Server's public encryption key from Server certificate.
  - Server authenticated by ability to decrypt to obtain **`pre_master_secret`**, and construct correct **`finished`** message.
- Other protocol runs are similar.

SSL Handshake Protocol Run

M1: `ClientHello`

- Client initiates connection.
- Sends client version number.
  - 3.1 for TLS.
- Sends **`ClientNonce`**.
  - 28 random bytes plus 4 bytes of time.
- Offers list of ciphersuites:
  - Key exchange and authentication options, encryption algorithms, hash functions.
  - E.g. **`TLS_RSA_WITH_3DES_EDE_CBC_SHA`**.

M2: `ServerHello, …`

- Sends server version number.
- Sends **`ServerNonce`** and **`SessionID`**.
- Selects single ciphersuite from list offered by client.
- Sends **`ServerCertChain`** message.
  - Allows client to validate server's public key back to acceptable root of trust.
- (optional) **`CertRequest`** message.
  - Omitted in this protocol run – no client authentication.
- Finally, **`ServerHelloDone`**.

M3: `ClientKeyExchange`, …

- **`ClientKeyExchange`** contains encryption of **`pre_master_secret`** under server's public key.
- **`ChangeCipherSpec`** indicates that client is updating cipher suite to be used on this session.
  - Sent using SSL Change Cipher Spec. Protocol.
- Optional (only when client is authenticated): **`ClientCertificate`**, **`ClientCertificateVerify`** messages.
- Finally, **`ClientFinished`** message.
  - MAC on all messages sent so far (both sides).
  - MAC computed using **`master_secret`**.

M4: `ChangeCipherSpec, …`

- **`ChangeCipherSpec`** indicates that server is updating cipher suite to be used on this session.
  - Sent using SSL Change Cipher Spec. Protocol.
- Finally, **`ServerFinished`** message.
  - MAC on all messages sent so far (both sides).
  - MAC computed using **`master_secret`**.
  - Server can only compute MAC if it can decrypt **`pre_master_secret`** in M3.

SSL Handshake Protocol Run

1. Is the client authenticated to the server in this protocol run?
   - No!
1. Can adversary learn value of **`pre_master_secret`**?
   - No! Client has validated server's public key; To learn **`pre_master_secret`** the server's private key is needed to decrypt ClientKeyExchange
1. Is the server authenticated to the client?
   - Yes! ServerFinished includes MAC on nonces computed using key derived from **`pre_master_secret`**.

SSL/TLS Applications

- Secure e-commerce using SSL/TLS.
- Client authentication not needed until client decides to buy something.
- SSL provides secure channel for sending credit card information.
- Client authenticated using credit card information, merchant bears (most of) risk.
- Widely deployed (de-facto standard).

EAP

EAP

- Extensible Authentication Protocol
- Specified in IEEE 802.1X and RFC 3748 for entity authentication.
- Defines general message flow; can be implemented using a variety of underlying mechanisms.
- Application:
  - WLAN authentication (802.1X); Cisco wireless equipment implements EAP.
  - EAPOL: EAP over LAN; just a delivery mechanism; for authentication, an EAP method such as EAP-TLS or EAP-TTLS has to be defined.
  - 3GPP WLAN interworking, e.g. EAP-AKA
  - Windows supports various EAP methods for remote access.

Design Principle

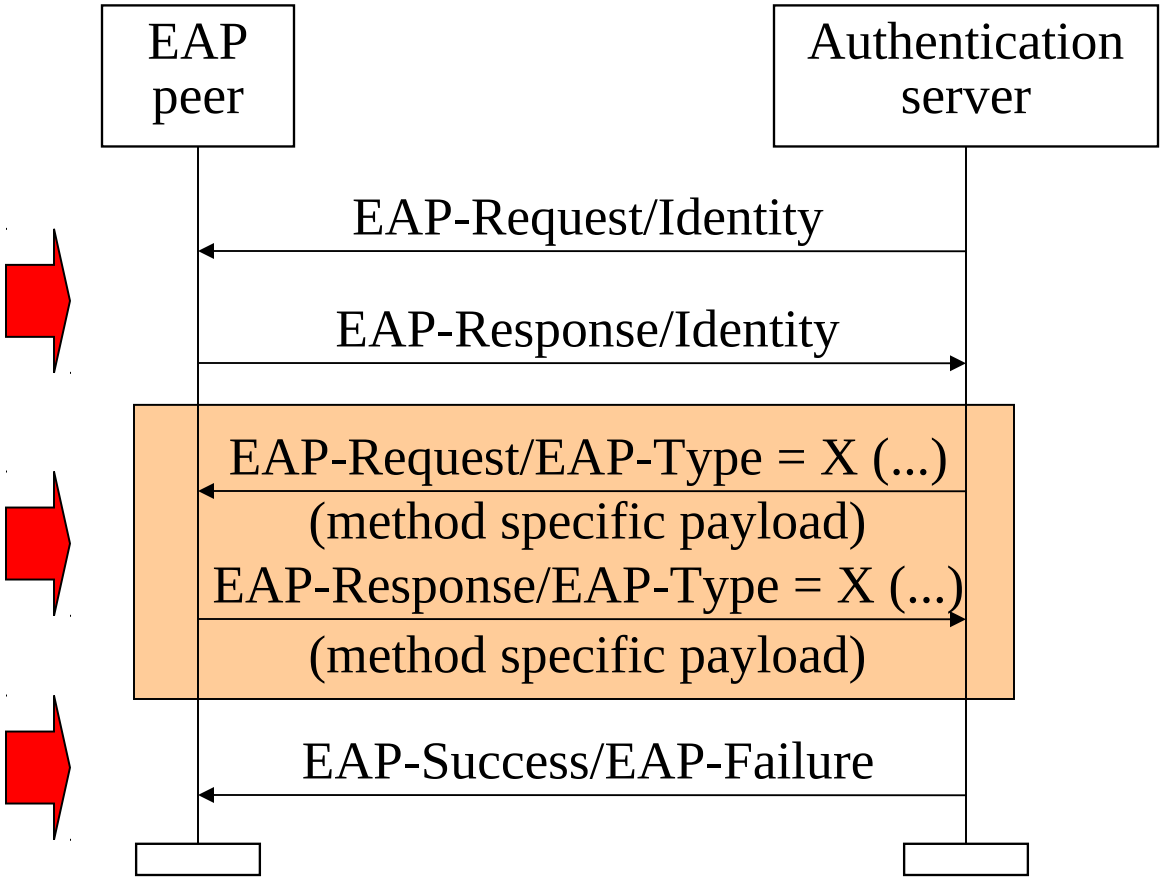
- Applications calling an authentication protocol just see an abstract message flow.
- Thus, authentication mechanism can be chosen independent of application.
- Authentication mechanism can be changed without having to rewrite application.
- Other examples: GSS-API, SAML profiles for web services.

EAP Generic Message Flow

Identity exchange message (can be skipped).

Repeat as many rounds as needed to complete EAP-methods

Success/Failure message



EAP methods

- Generic EAP messages exchange identities, encapsulate authentication protocol messages.
- These protocols are called methods.
- Users identified by Network Access Identifier (NAI); specified in RFC 4282.
- EAP methods provide at least one way authentication (EAP peer $\rightarrow$ EAP server).
- Many existing or proposed EAP methods that differ in their characteristics & security levels.

EAP-TTLS v0 (with CHAP)