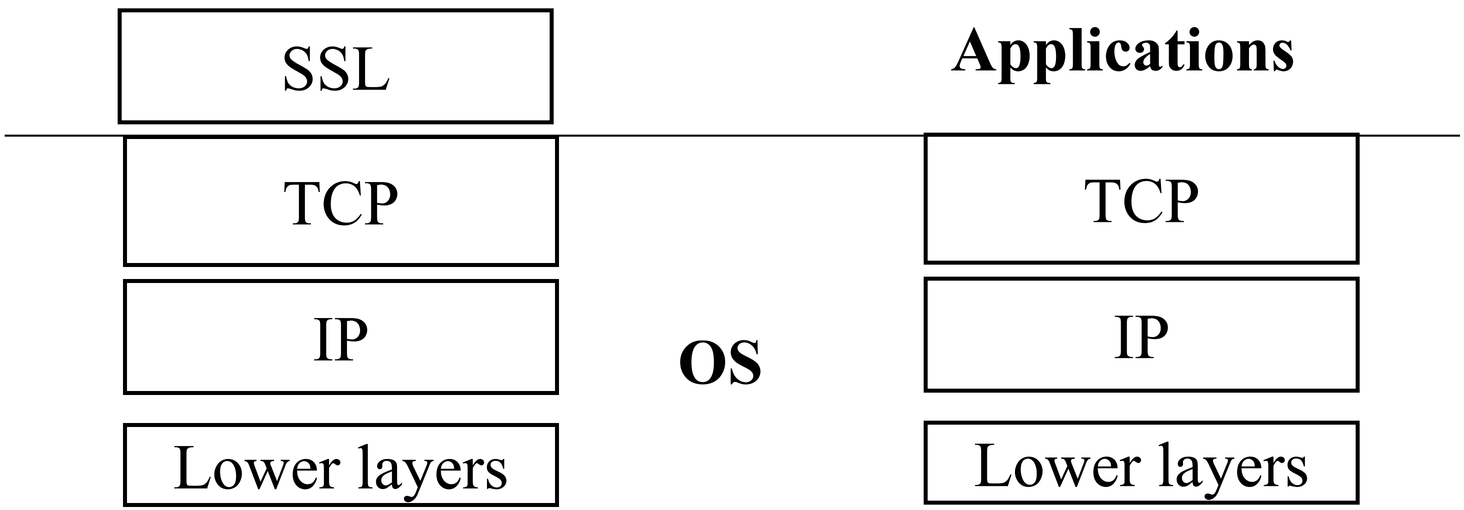
SSL, SSH and IPSec

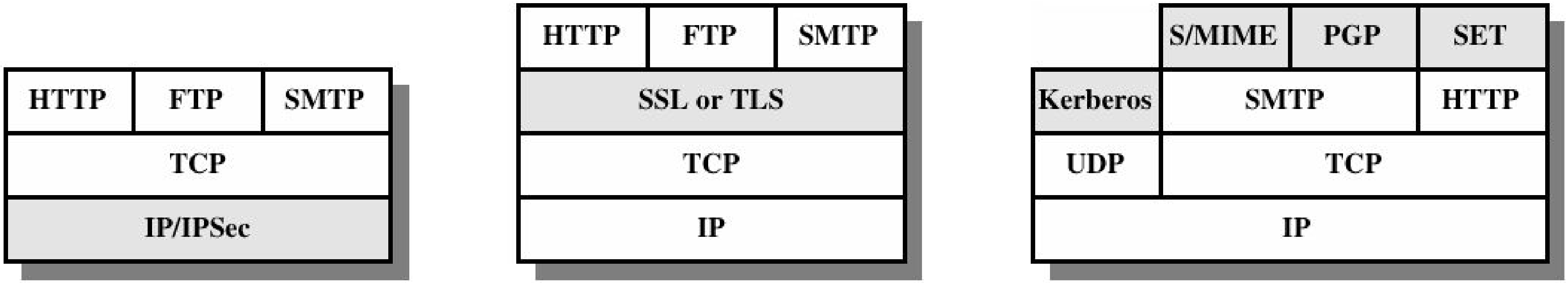
Overview of things to come

- Security can be implemented at many levels
  - Kerberos, SSL and SSH are implemented at the application level
  - No need to change the OS
  - Applications must be specially designed to work with Kerberos, SSL or SSH

  - IPSec is implemented at the transport level
  - Inside the OS
  - More transparent to user



Security facilities in the TCP/IP protocol stack



(a) Network Level (b) Transport Level (c) Application Level

SSL and TLS

- SSL provides a secure transport connection between applications
  - Usually client and server
- SSL (Secure Socket Layer) was originally proposed by Netscape
- SSL v3.0 was specified in an Internet Draft (1996)
  - http://tools.ietf.org/html/draft-ietf-tls-ssl-version3-00
  - has been widely implemented in web browsers and web servers
    - e.g., Netscape Navigator and MS Internet Explorer
- TLS (Transport Layer Security) --1999
  - http://tools.ietf.org/html/rfc2246
  - TLS can be viewed as SSL v3.1
    - TLS is not interoperable with SSL v3 (slightly different crypto)
  - TLSv1.2 (2008): crypto update

Components

- SSL Handshake Protocol
  - negotiation of security algorithms and parameters
  - key exchange
  - server authentication -- optionally client authentication
- SSL Change Cipher Spec Protocol
  - a single byte message-- indicates end of the SSL handshake
- SSL Record Protocol
  - fragmentation
  - compression
  - message authentication and integrity protection
  - encryption
- SSL Alert Protocol
  - error messages (fatal alerts and warnings)

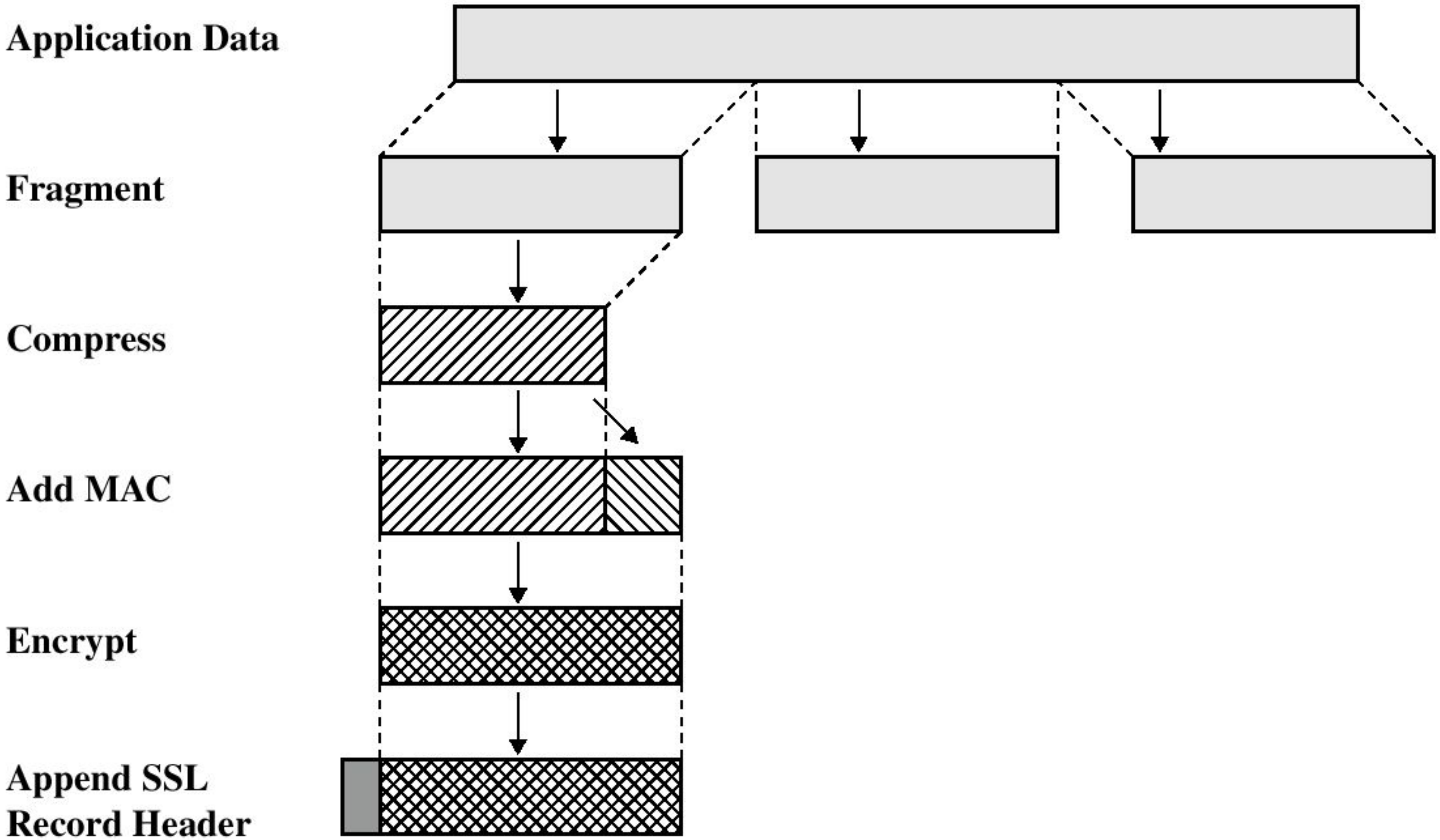
Important Concepts

- SSL works in terms of connection and sessions between client and server:
  - SSL Session:
    - An association between a server and a client
    - Stateful
      - cryptographic security parameters
    - Can be multiple sessions between parties (but not common)
    - Sessions are created by the handshake protocol
  - SSL Connection:
    - Peer-to-peer relationship, transient
    - Every connection is associated with a session
    - A session can have multiple connection

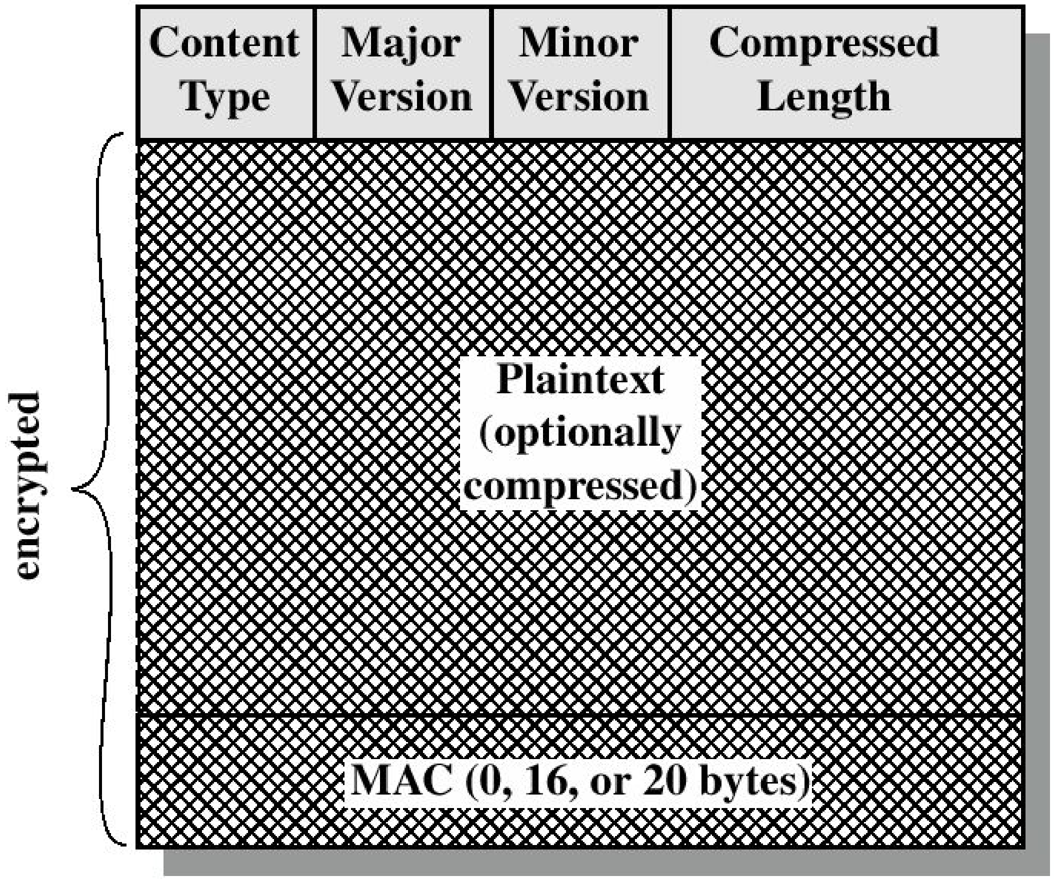
Lower Layer: SSL Record Protocol

- Receive messages from upper layer
- Breaks messages into blocks
- Compresses blocks
- Computes MAC for each block
  - Each block has implicit sequence number to prevent reordering
- Encrypts blocks
  - Note: if encryption and MAC key not selected then no encryption or MAC used
- Adds header

SSL Record Protocol Operation



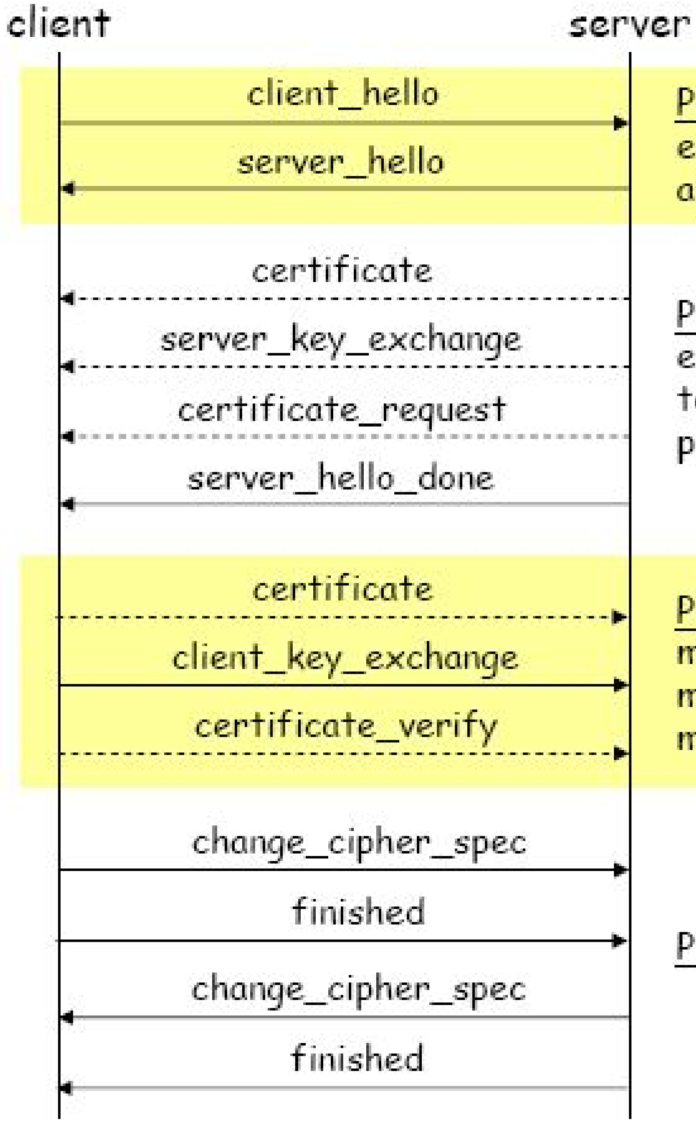
SSL Record Format



Handshake Protocol

- The most complex part of SSL.
- Authenticate both server and client
- Negotiate encryption, MAC algorithm and cryptographic keys.
- Used before any application data are transmitted.

SSL Handshake Protocol



Phase 1: Negotiation of the session ID, key exchange algorithm, MAC algorithm, encryption algorithm, and exchange of initial random numbers

Phase 2: Server may send its certificate and key exchange message, and it may request the client to send a certificate. Server signals end of hello phase.

Phase 3: Client sends certificate if requested and may send an explicit certificate verification message. Client always sends its key exchange message.

Phase 4: Change cipher spec and finish handshake

Certificate

- **Serial Number**: Used to uniquely identify the certificate.
- **Subject**: The person, or entity identified.
- **Signature Algorithm**: The algorithm used to create the signature.
- **Signature**: The actual signature to verify that it came from the issuer.
- **Issuer**: The entity that verified the information and issued the certificate.
- **Valid-From**: The date the certificate is first valid from.
- **Valid-To**: The expiration date.
- **Key-Usage**: Purpose of the public key (e.g. encipherment, signature, certificate signing...).
- **Public Key**: The public key.
- **Thumbprint Algorithm**: The algorithm used to hash the public key certificate.
- **Thumbprint** (also known as fingerprint): The hash itself, used as an abbreviated form of the public key certificate.

Change Cipher Spec Protocol

- Sent by both the client and server to notify the other party that the following records will be protected using the just-negotiated CipherSpec and keys.

- Consists of single message -- a single byte with the value 1.

- The purpose of the message is to updates the cipher suite to be used on the connection.

Alert Protocol

- Used to convey SSL-related alerts to the peer entity.
- Alert messages are compressed and encrypted.
- The message is two bytes:
  - 1 byte: warning (1) or fatal (2)
  - 1 byte: status of the certificate & other specific alerts

Second byte

- fatal
  - unexpected_message
  - bad_record_MAC
  - decompression_failure
  - handshake_failure
  - illegal_parameter
- warning
  - no_certificate
  - bad_certificate
  - unsupported_certificate
  - certificate_revoked
  - certificate_expired
  - certificate_unknown…..

- in case of a fatal alert
  - connection is terminated
  - session ID is invalidated
    - no new connection can be established within this session

Attacks on SSL

- SSL is claimed to protects against MITM attack using
  - End point authentication
  - Encryption
  - Attacks are even more dangerous because of perceived security.
- MITM attacks rely on spoofing ARP and DNS.
- Causes of reported attack
  - Improper use of cryptography
  - Mis-configured clients
  - Bad implementation
- Crypto 2009: use weakness in MD5 to forge a ‘rogue’ certificate
- Lack of user awareness and education.
  - Users click-through on certificate warnings.

Flaws in SSL v2

- Same key used for encryption and MAC
- Weak keys due to old export restrictions in US
- Weak MAC based on MD5 only
- Weakness in handshake can allow for MITM attack
- Uses TCP close to indicate end of data (can lead to truncation attack)
- SSL v2 now disabled by default in IE v7, Firefox v2

SSL-TLS

- Version number
  - TLS 1.1 is the SSL version 3.2
- Cipher suites
  - TLS doesn’t support Fortezza key exchange and encryption
- Padding
  - variable length padding is allowed (max 255 padding bytes)
- MAC
  - TLS uses the latest version of HMAC
  - the MAC covers the version field of the record header too
- certificate_verify message
  - the hash is computed only over the handshake messages
  - in SSL, the hash contained the master_secret and pads
- More alert codes

SSL-TLS

- TLS v1.2 (2008)
  - MD5-SHA1 based MAC replaced by cipher-based MAC
  - Added AES-based ciphers to list
  - Slight modifications about how hashes are used

OpenSSL Project

- A collaborative effort to develop a robust, commercial-grade, full-featured, and Open Source toolkit.

- It implements:
  - Secure Sockets Layer (SSL v2/v3)
  - Transport Layer Security (TLS v1) protocols
  - A full-strength general purpose cryptography library.

http://www.openssl.org/

Secure Shell (SSH)

(teaser)

SSH

- Started as secure replacement for *telnet.*
  - SSH-1 Tatu Ylönen(1995)
  - SSH -2, Proprietary (SSH Comm Security) (1996)
  - SSH -3 (1999) OSSH→ OpenSSH
  - SSH-2 became IETF standard (2006)

- Provides confidentiality
  - Credential used for login
  - Content of the remote login session

- SSH provides security at <u>Application Layer</u>.
  - Secure copying of files between client and server
  - Also can be used for tunnelling other protocols
  - <u>Transport layer</u> security for those protocol

SSH

- SSH authenticates both the client and the server.
- Authentication:
  - Server: Public/Private key pair
    - Client uses a locally stored PK of the server to verify the server's signature
  - Client:
    - Username/password
    - Asymmetric key pair– the server need to know the PK

Applications

- Anonymous ftp for software updates, patches...
  - client authentication not needed
  - clients want to be sure of origin and integrity of software

- Secure ftp.
  - e.g. upload of webpages to webserver using sftp
  - Server needs to authenticate clients
  - Username and password sufficient
  - transmission over secure SSH transport layer protocol

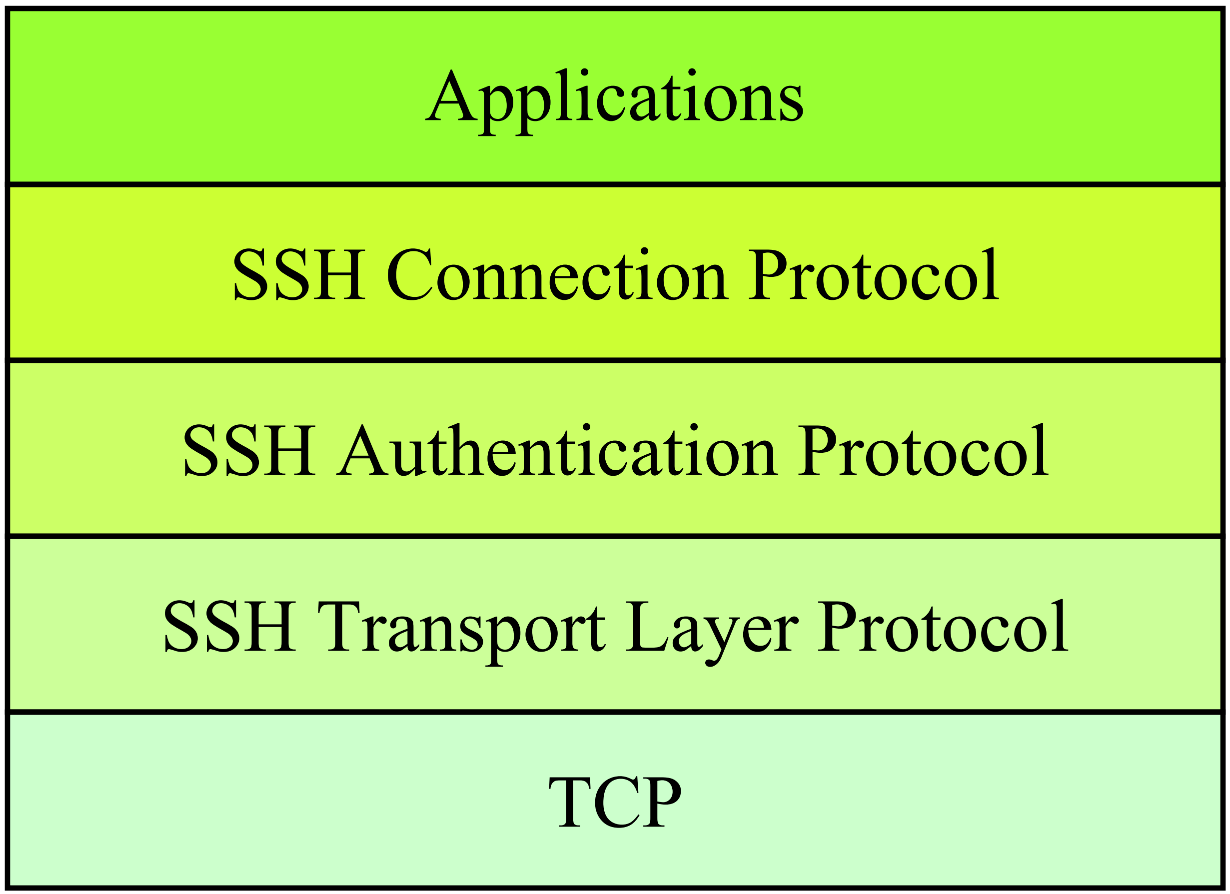
- Secure remote administration
  - SysAdmin (client) sets up terminal on remote machine
  - SysAdmin password protected by SSH transport layer protocol

- Secure remote login

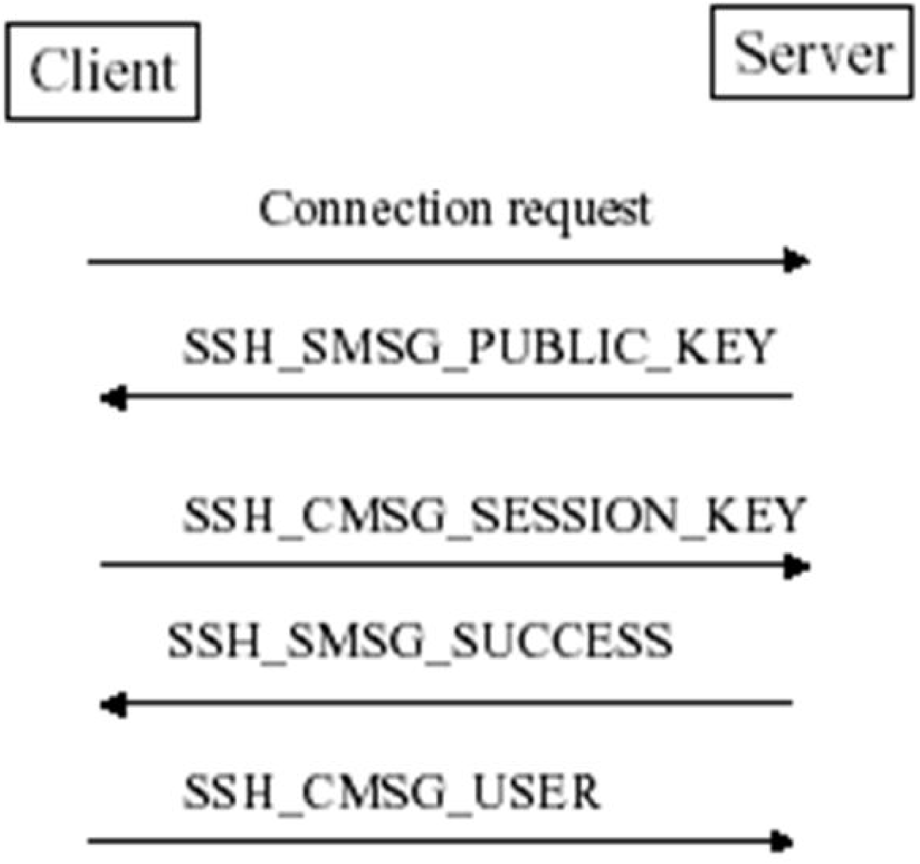
SSH-2 Architecture

- Three layer architecture: http://www.ietf.org/rfc/rfc4251.txt
- Transport Layer Protocol: provides
  - Initial connection
  - server authentication,
  - confidentiality, and integrity with perfect forward secrecy
  - Key re-exchange after 1Gb of data transmitted or after 1 hour
- User Authentication Protocol
  - Authenticates client to the serve
- Connection Protocol
  - Supports multiple connections (channels) over a single transport layer protocol secure channel.

SSH-2 Architecture



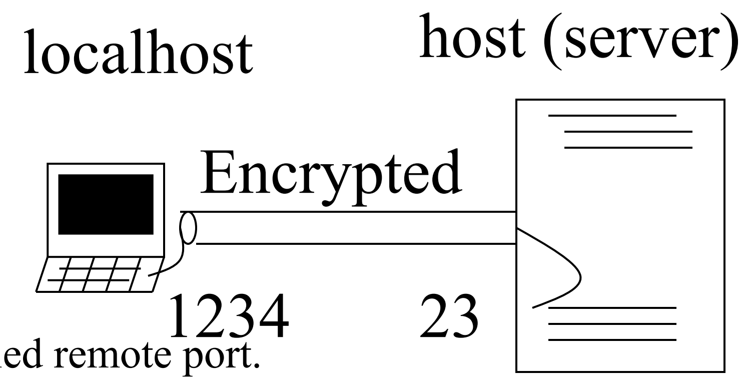
Key Exchange and Authentication



- Server listens to port 22

Port forwarding

- Also tunneling: a way to forward TCP traffic through SSH.
  - e.g securing POP3, SMTP and HTTP connections
    - insecure connections
  - The client-server applications will run their normal authentication over the encrypted tunnel.



- There are two types of port forwarding:
  - local (outgoing tunnel)
  - remote forwarding. (incoming tunnel)
- Local port forwarding:
  - forwards traffic coming to a local port to a specified remote port.
  - E.e. the command,

    ssh2 -L 1234:localhost:23 username@host

  - traffic to port 1234 on the client will be forwarded to port 23 on the server (host).

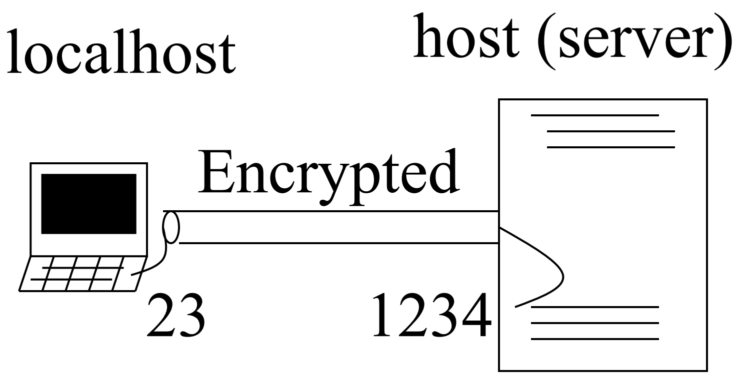
Remote port forwarding

- Does the opposite:
  - forwards traffic coming to a remote port to a specified local port.

- For example, the command

```
ssh2 -R 1234:localhost:23 username@host
```

  - traffic that comes from port 1234 on the server (host) will be forwarded to port 23 on the client (localhost).



Causes of Insecurity

- Implementation weaknesses (e.g. plaintext recovery attack 2008)
- Does not use very standard crypto (attack in 2004)
- Weak server platform security
  - Worms, malicious code, rootkits,…
- Weak user platform security
  - Keystroke loggers, malware,…
- Absence of use of certificates for public key (rely on user)
- Lack of user awareness and education.
  - Users click-through on warnings.

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IPSec

History

- In 1994, the Internet Architecture Board (IAB) issued a report entitled *Security in the Internet Architecture* (RFC 1636).
  - Many incidents that affected many sites, IP spoofing attacks, packet sniffing, etc.
  - General consensus: the Internet needed better security.
- Internet Protocol Security (IPsec): a suite of protocols for securing IP communications. (approx Layer 3)
- IPsec is specified by the Internet Engineering Task Force (IETF)

http://www.networksorcery.com/enp/topic/ipsecsuite.htm

Internet Protocol Security (IPsec)

- Protection of communication between,
  - hosts
  - gateways
  - a host and a gateway

  Packet-oriented security

- Comparison with SSL, TLS, SSH:
  - These are at higher level of OSI stack
  - Applications must be altered to incorporate these

- IPsec provides application-transparent Security
  - Network services that use IP (e.g. telnet, FTP) or user application that uses IP (TCP BSD Socket) can use IPSec without modification.

Components

- ISAKMP (Internet Security Association and Key Management Protocol)
  - Security association
  - IKE (Internet key exchange) for establishing security association
  - a collection of algorithms and parameters, keys, etc to encrypt and authenticate a data flow *in one direction*.

- Security protocols:
  1. Authentication Header (AH)
  2. Encapsulating Security Payload (ESP)

- Databases
  - Security Association Database (SADb)
  - Policy Database

IPSec Architecture

- Security Policy Database (SPD)
  - Given source and destination IP addresses, determines which if packets are kept or discarded, and whether IPSec is applied or bypassed
- Security Association (SA)
  - Association between peers for security services
  - Unidirectional
  - Defined uniquely by destination address, security protocol (AH or ESP) and security parameter index (SPI)
  - Contains only one security protocol (if both AH and ESP are used, there will be two SAs)

IPSec Architecture

- Security Association bundle
  - Sequence of SAs that IPSec applies to packets
- Security Association Database (SADb)
  - Indexed by destination (or incoming) address and SPI
  - Its key fields are
    - Crypto algorithm identifier and keys
    - Lifetime of the SA
    - Whether in tunnel mode or transport mode

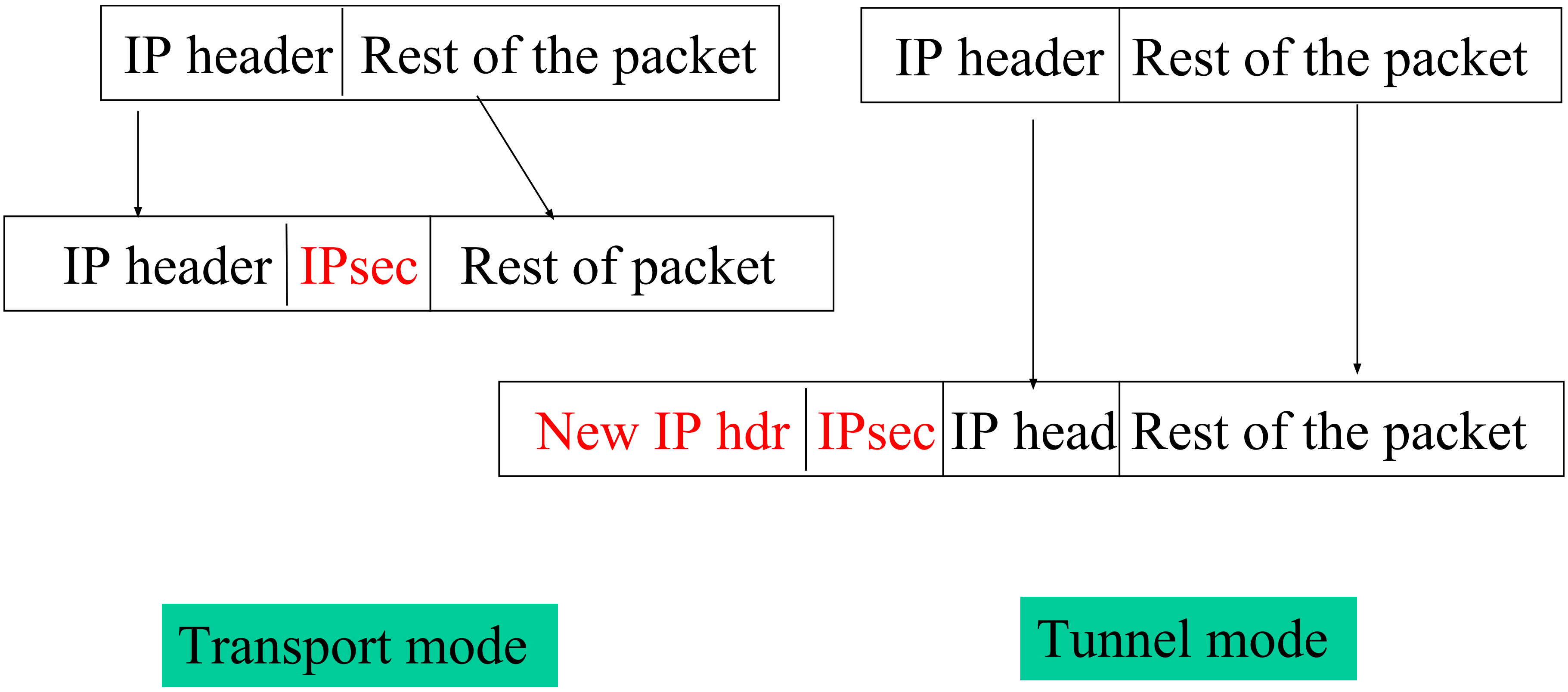
Modes

- Two modes of applying IPsec protection
- Both modes are applicable to both security protocols (AH and ESP)

1. Transport mode
   - Default mode for end-to-end security
     - Client-server communication
   - IPsec information is added between IP header and the rest of the packet

2. Tunnel modes
   - used for protecting traffic between two networks when packets have to pass through an untrusted network
   - Whole IP packet becomes payload to a new IP packet protected by IPSec

Modes


IP header
Rest of the packet
IP header
IPsec
Rest of packet
Transport mode
IP header
Rest of the packet
New IP hdr
IPsec
IP head
Rest of the packet
Tunnel mode

Modes

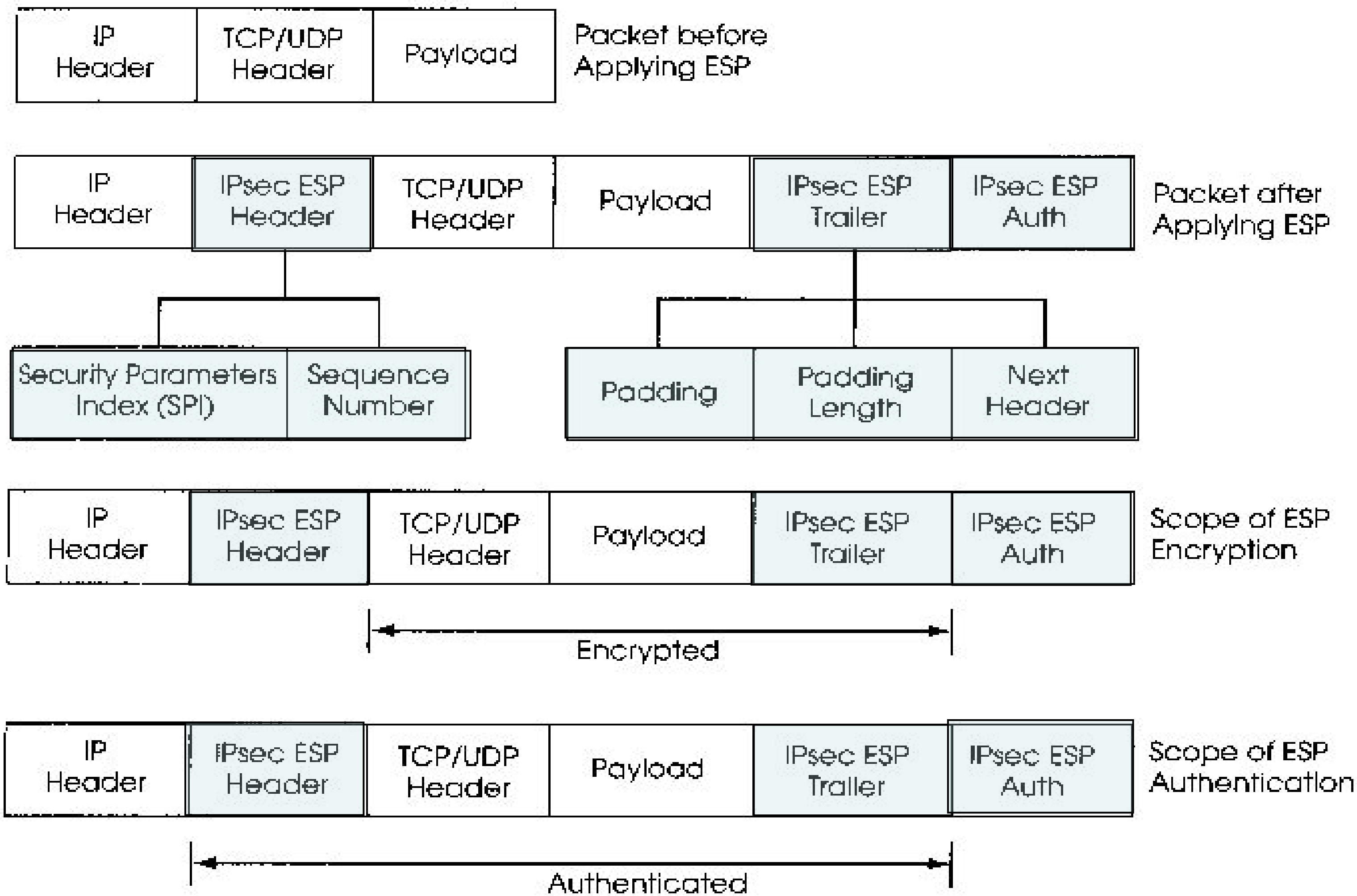
- In transport mode, IP datagram contains only *one* IP header,
  - specifies the source address and the ultimate destination
- In tunnel mode, an IP datagram contains two IP headers:
  - an outer IP header: specifies the IPSec processing destination
  - an inner IP header: contains the source and the ultimate destination of the packet
  - the inner packet is usually encrypted

Encapsulating Security Payload (ESP)

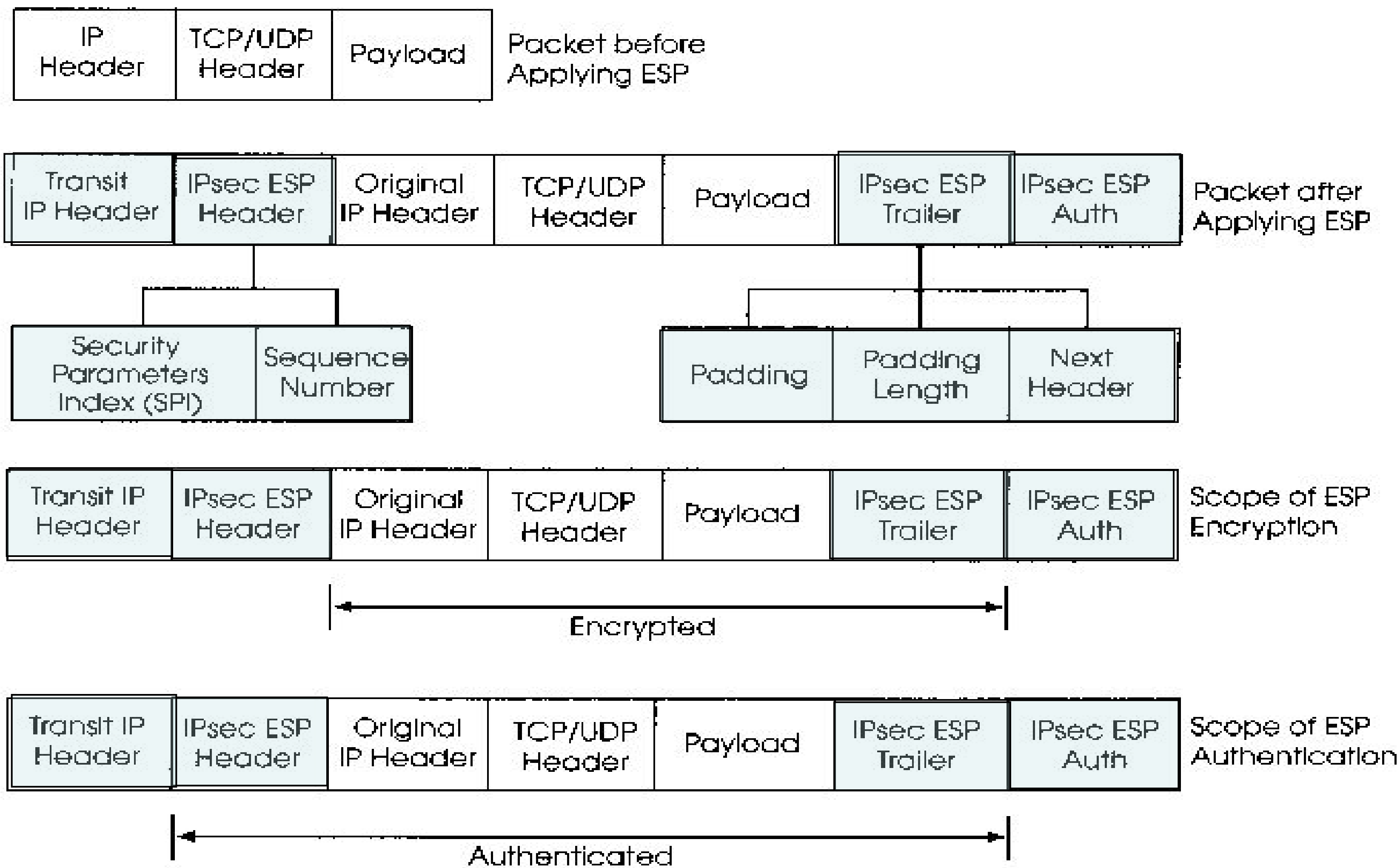
- The Encapsulating Security Payload protocol provides
  - confidentiality service
  - limited traffic-flow confidentiality
  - authentication service
    - Applied to payload only

- In transport mode, ESP secures upper-layer protocols.
- In tunnel mode, ESP extends protection to the inner IP header.

ESP Protocol in Transport Mode



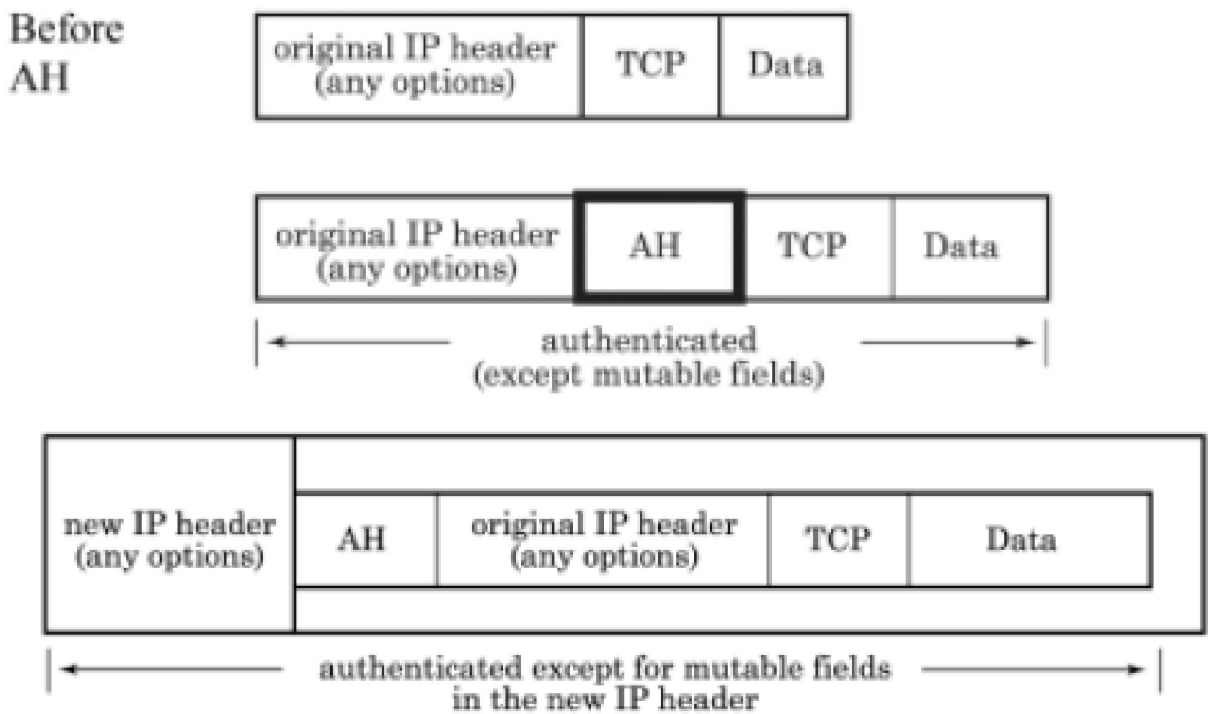
ESP Protocol in Tunnel Mode



Authentication Header (AH) Protocol

- Authentication Header protocol provides an authentication service for
  - data origin authentication
  - connectionless integrity
  - an optional anti-replay service
  - Applied to both payload and IP header

AH Modes



Transport Mode

Tunnel Mode

Mutable & Immutable

- Some fields of IP header can be modified in transit,
  - the value of the field is set to zero for purposes of the MAC computation.
    - TTL , must be decremented by every router
    - Hop counts.

- If a field is mutable, but its value at the (IPsec) receiver is predictable, then that value is inserted into the field for purposes of the MAC calculation.
  - Destination address in “source routing”
    - Source specifies the route - so the address changes but the destination address is known

Internet Security Association and Key Management Protocol (ISAKMP)

- ISAKMP defines procedures and packet formats to establish, negotiate, modify and delete Security Associations (SA).

- ISAKMP supports the negotiation of SAs for security protocols at all layers of the network stack (e.g., IPSEC, TLS (etc.).

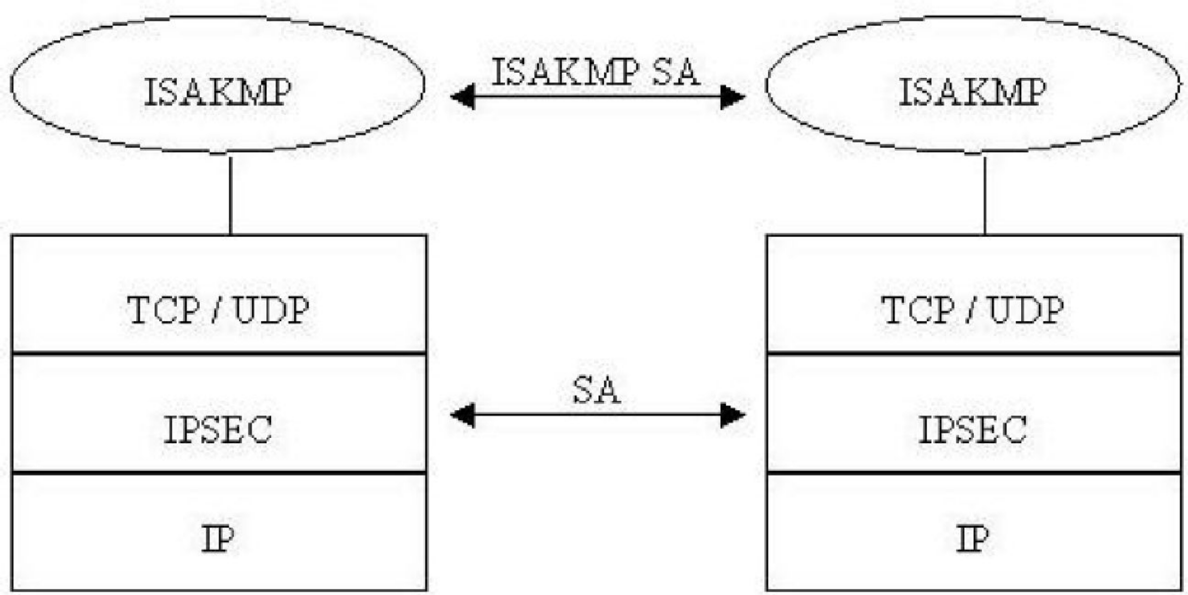
- ISAKMP is distinct from key exchange protocols
  - separating the details of security association management (and key management) from the details of key exchange.

- Better security requires authentication and key exchanges to be combined

Negotiation phases

- Phase 1: two entities such as ISAKMP servers agree on how to protect further negotiation traffic.
  ➔ establishing ISAKMP SA .

- Phase 2: ISAKMP SA is used for security associations for other protocols such as IPSEC



Internet Key Exchange (IKE)

- A protocol for mutual authentication and establishing shared key for IPsec SA
- Two phases:
  - Phase 1: Mutual authentication and establishment of session keys between two identities
    - It’s known as the ISAKMP SA, or IKE SA.
  - Phase 2: using the keys from phase 1, multiple phase 2 SA between the two identities

IKE Phase 1

- Phase-1 can be two types, called *modes*:
  - Main mode:
    - six messages
    - mutual authentication and session key establishment
    - additional functionalities
      - e.g. hide endpoint identifiers
  - Aggressive mode:
    - three messages
    - mutual authentication and session key establishment

IKE Phase 1 – Main Mode

1. Alice → Bob: C1, *Crypto suites I support*
2. Bob → Alice:C1,C2, *Crypto suite I choose*
3. Alice → Bob: C1,C2, g^a *mod p*
4. Bob → Alice: C1,C2, g^b *mod p* ➔ *Alice and Bab have K=* g^{ab}
5. Alice → Bob: C1,C2, *Enc(Alice, "Proof" Alice; K)*
6. Bob → Alice: C1,C2, *Enc(Bob, "Proof" Bob; K)*

All cryptographic algorithms can be negotiated.

IKE Phase 1 – Aggressive Mode

1. Alice → Bob: *Alice,* g^a *mod p, crypto proposal*
2. Bob → Alice: g^b *mod p, crypto choice, "proof" I'm Bob*
3. Alice → Bob: *proof I'm Alice*

- Alice proposes the security parameter, and use them in message 1.
  - Unclear what if Bob refuse
- Message 2 and 3 is to show DH value is known, the secret identifying Alice (or Bob) is known

Key Types

- Three types of keys:
  - Pre-shared
  - Public key pairs - encryption
  - Public key pairs- signature
- Proof of identity is different for each key type
  - Proving the sender knows the key associated with an identity
  - A ‘proof’ is some hash of the key, DH values, nonces, crypto choices offered and cookies

Which to Choose

We described three protocols that add security to network communication. Which is ‘the best’?

- Depends on situation
- Use application-level security (SSL or SSH) when
  - Few applications require security
  - Environment doesn’t provide security
  - Application needs to be authenticated

Which to Choose

- Use IPSec when
  - Many applications require security
  - Application itself doesn't provide it
  - Protect packet itself
  - Hide destination (tunnel mode)

➢ Often used for VPN