Real-Time Communication Security: SSL, IPSEC

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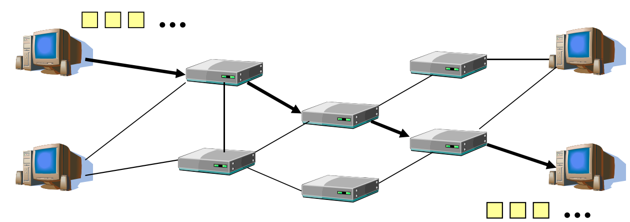
The Internet

A packet-switched network:

- Data to be transmitted is divided into "packets"
- Each packet is forwarded by "routers" towards the destination



TCP/IP Reference Model

Application Layer (HTTP, FTP, SMTP, etc.)
Transport Layer (TCP, UDP)
Network Layer (IP)
Data Link Layer (PPP, Ethernet, etc.)
Physical Layer

- IP: delivery of packets to the destination
- TCP: reliability of the communication
  - ordering the packets
  - error detection & recovery
  - congestion control
- UDP: basic transport protocol

Securing TCP/IP Communications

	Application L.
Layer 4 (SSL/TLS) →	Transport L.
Layer 3 (IPsec) →	Network L.
	Data Link L.
	Physical L.

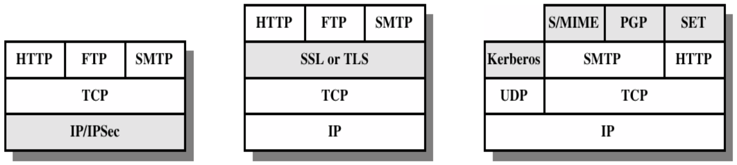
Layer 3:

- can secure all IP communication transparent to applications
- must be built into the OS

Layer 4:

- doesn't require OS modification; deployment easy

Different Security Models in TCP/IP



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

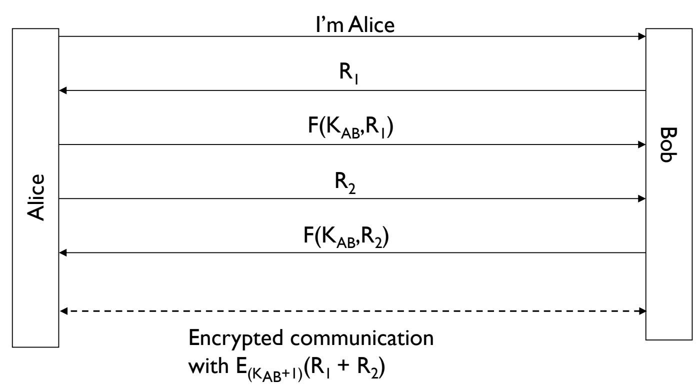
Real-Time Protocol Security Issues

- Interactive session security (unlike e-mail)
- Layer 4 (SSL)
  - Implemented on top of layer 4, between TCP & application
  - Doesn't require any modifications to OS (deployment made easy!)
- Layer 3 (IPsec)
  - Implemented between IP & TCP
  - Each IP packet authenticated separately
  - Built in the OS
  - Can secure all IP communication
  - Host-to-host application is common. Process-to-process also possible

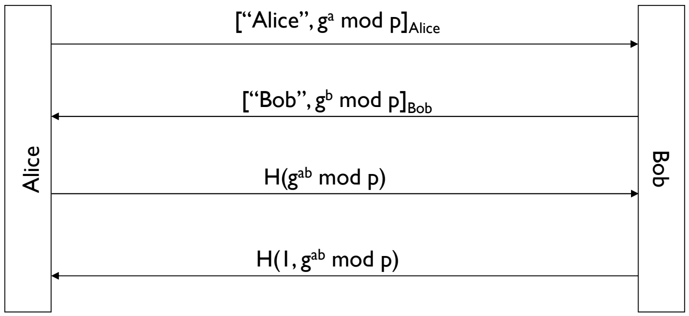
Perfect Forward Secrecy

- PFS: Compromise of long-term secrets doesn't compromise session keys
- Example: Diffie-Hellman with RSA authentication
- Non-PFS examples:
  - Kerberos
  - Session key transport with RSA encryption
- By-product: Escrow foilage
  Conversations can't be decrypted by authorities holding copies of long-term private keys

A non-PFS Protocol Example



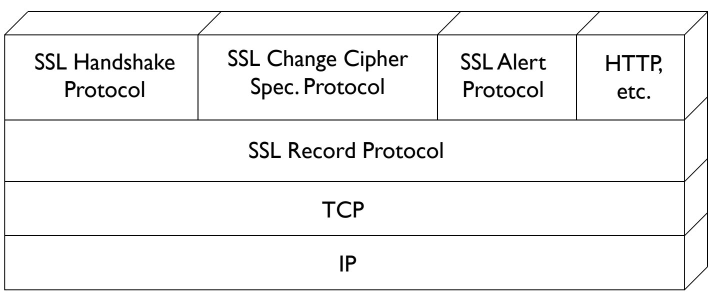
A PFS Protocol Example: Diffie-Hellman with RSA signature



SSL/TLS

- SSLv2
  - Released in 1995 with Netscape 1.1
  - Key generation algorithm kept secret
  - Reverse engineered & broken by Wagner & Goldberg
- SSLv3
  - Fixed and improved, released in 1996
  - Public design process
- PCT: Microsoft’s version of SSL
- TLS: IETF’s version

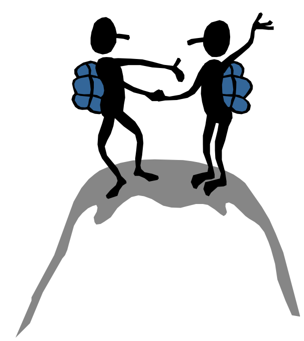
SSL Architecture



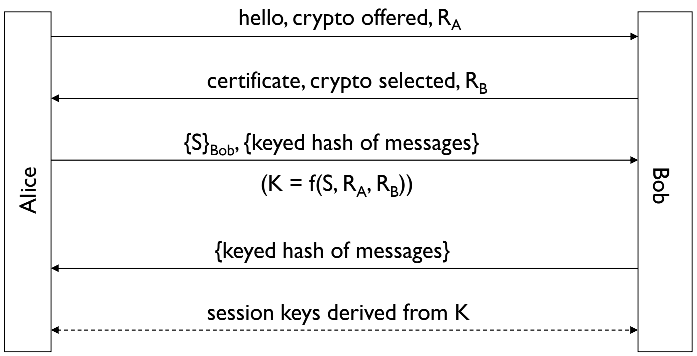
- Record Protocol: Message encryption/authentication
- Handshake Protocol: Identity authentication & key exchange
- Alert Protocol: Error notification (cryptographic or otherwise)
- Change Cipher P.: Activate the pending crypto suite

Handshake Protocol

- Negotiate Cipher-Suite Algorithms
  - Symmetric cipher to use
  - Key exchange method
  - Message digest function
- Establish the shared master secret
- Optionally authenticate server and/or client



Basic SSL/TLS Handshake Protocol



Key Computation

- "pre-master key": S
- "master key": $K = f(S, R_A, R_B)$
- For each connection, 6 keys are generated from K and the nonces. (3 keys for each direction: encryption, authentication/integrity, IV)

Session and Connection

- Session:
  - association between a client and a server;
  - created by the Handshake Protocol;
  - defines secure cryptographic parameters that can be shared by multiple connections.
- Connection:
  - end-to-end reliable secure communication;
  - every connection is associated with a session.

SSL Session Establishment

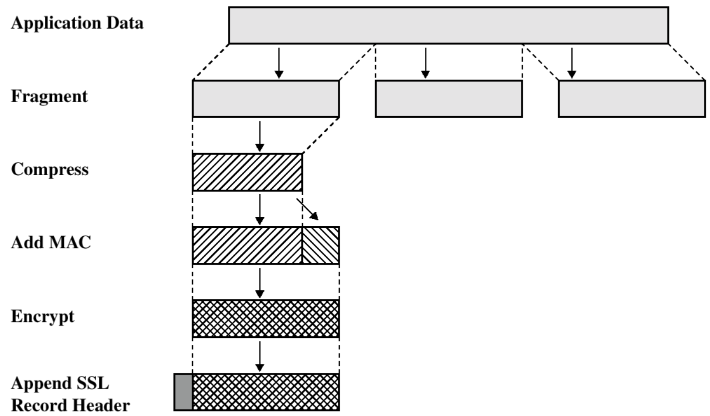
- Client authentication: Bob can optionally send "certificate request" in message 2.
- Session vs. Connection: "Sessions" are relatively long-lived. Multiple "connections" (TCP) can be supported under the same SSL session. (designed for HTTP 1.0)
- To start a connection, Alice can send an existing session ID.
- If Bob doesn't remember the session ID Alice sent, he responds with a different value.

Negotiating Crypto Suites

- Crypto suite: A complete package specifying the crypto to be used. (encryption algorithm, key length, integrity algorithm, etc.)
  - ~30 predefined standard cipher suites.
  - Confidentiality: Achieved by encryption using DES, 3DES, RC2, RC4, IDEA.
  - Integrity: Achieved by computing a MAC and send it with the message; MD5, SHA1.
  - Key exchange: relies on public key encryption.
- Selection:
  - v2: Alice proposes a set of suites; Bob returns a subset of them; Alice selects one. (which doesn't make much sense)
  - v3: Alice proposes a set of suites; Bob selects one.

SSL Record Protocol

- Provides confidentiality and message integrity using shared keys established by the Handshake Protocol



IPsec

- Cryptographic protection of the IP traffic, transparent to the user
- Main components:
  - Internet Key Exchange (IKE): IPsec key exchange protocol
  - Authentication Header (AH): Authentication of the IP packet
  - Encapsulating Security Payload (ESP): Encryption/authentication of the IP packet

Uses of IPsec

- Can be used to provide user-, host-, or network-level protection (the granularity)
- Protocol modes:
  - Transport mode: Host applies IPsec to transport layer packet
  - Tunnel mode: Gateway applies IPsec to the IP packet of a host from the network (IP in IP tunnel)
- Typical uses:
  - Remote access to network (host-to-gateway)
  - Virtual private networks (gateway-to-gateway)

Security Association & Policy

- Security Policy Database
  Specifies what kind of protection should be applied to packets (according to source-destination address, port numbers, UserID, data sensitivity level, etc.)
- Security Association (SA)
  - An IPsec-protected connection (one-way)
  - Specifies the encryption/auth. algorithm, key, etc.
  - Identified by
    - security parameter index (SPI)
    - destination IP address
    - protocol identifier (AH or ESP)
  - SAs are stored in SA databases
    - AH information (auth. algorithm, key, key lifetime, etc.)
    - ESP information (auth./encryption algorithm, key, key lifetime, etc.)
    - Lifetime of the SA

IPsec Packet Processing

Outbound packets:

- The proper SA is chosen from the security policy database
- From the SA database, the SPI and SA parameters are retrieved
- The IPsec protection is performed; packet passed to IP

Inbound packets:

- By the SPI, the SA is found
- IPsec auth./decryption is performed
- Packet passed to upper layer protocol

History of IKE

- Early contenders:
  - Photuris: Authenticated DH with cookies & identity hiding
  - SKIP: Authenticated DH with long-term exponents
- ISAKMP:
  - A protocol specifying only payload formats & exchanges (i.e., an empty protocol)
  - Adopted by the IPsec working group
- Oakley: Modified Photuris; can work with ISAKMP
- IKE: A particular Oakley-ISAKMP combination

Authentication Header (AH)

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Next Header   |  Payload Len  |          RESERVED             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                 Security Parameters Index (SPI)               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Sequence Number Field                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                Authentication Data (variable)                 |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

- Auth. alg.: HMAC (with MD5, SHA1, etc.)
  CBC-MAC (3DES, RC5, AES, etc.)
- Typically, IV is included in the payload
- Authentication covers immutable fields of IP header as well as the payload.

AH with IPv4

```
                  BEFORE APPLYING AH
            ----------------------------
      IPv4  |orig IP hdr  |     |      |
            |(any options)| TCP | Data |
            ----------------------------

                  AFTER APPLYING AH
            ---------------------------------
      IPv4  |orig IP hdr  |    |     |      |
            |(any options)| AH | TCP | Data |
            ---------------------------------
            |<------- authenticated ------->|
                 except for mutable fields
```


Encapsulating Security Payload (ESP)

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+ ----
|               Security Parameters Index (SPI)                 | ^Authentication
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+ |Coverage
|                      Sequence Number                          | |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+ | ----
|                    Payload Data (variable)                    | |   ^
~                                                               ~ |   |
|                                                               | |Encryption
+               +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+ |Coverage
|               |     Padding (0-255 bytes)                     | |   |
+-+-+-+-+-+-+-+-+               +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+ |   |
|                               |  Pad Length   | Next Header   | v   v
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+ ------
|                 Authentication Data (variable)                |
~                                                               ~
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

- Encryption: usually a block cipher in CBC mode
- IV is typically included in the payload (not encrypted)

ESP with IPv4

```
              BEFORE APPLYING ESP
            ----------------------------
      IPv4  |orig IP hdr  |     |      |
            |(any options)| TCP | Data |
            ----------------------------

                AFTER APPLYING ESP
            -------------------------------------------------
      IPv4  |orig IP hdr  | ESP |     |      |   ESP   | ESP|
            |(any options)| Hdr | TCP | Data | Trailer |Auth|
            -------------------------------------------------
                                |<----- encrypted ---->|
                          |<------ authenticated ----->|
```