Security

Use these slides in conjunction with the material from 2004.

Some parts based on or inspired by the slides from
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Past contributions by
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- Background and security properties
- Cryptographic algorithms
- Security mechanisms
- Security protocols and systems
- Security Devices
Motivation for Security in Communications

- Pretty much common sense today

- Open communications
  - Global access to information resources
  - Ubiquitous availability of communication networks

- Protection
  - Assets (information, other valuables)
  - Privacy of persons
  - Transactions in critical communications

- “Electronic business”
  - Authentication, Authorization, and Accounting (AAA)
  - Offer (digital) services to known (and unknown) customers

- (Legal) requirements

Some Terms in Brief

- (Communication) protocols / systems may have weaknesses

- A weakness may (but need not) cause a vulnerability

- A vulnerability can be exploited.

- Threats may makes use of one or more vulnerabilities.

- Attacks may result from threats to the system.

- Attacks may result in damage to the system.

- Risk = probability of an attack × amount of damage
Security is Risk Management

Some Sources of Attacks

- 50% of all attacks from the inside (employees)
  - Laziness, personal gain, frustration
  - May be triggered by third parties: social engineering!

- Hacker, “script kiddies”
  - Curiosity, thrill, addiction
  - Experiencing how far they can get
  - Most important: peer recognition in the community!

- “Professional”: industry espionage, secret service

- (Organized) crime
  - Blackmailing: e.g., for online gambling sites
  - Competitive edge: DoS against your opponent
Some Security Threats

- Connection / session hijacking
- Masquerading / impersonation / identity spoofing
- Man-in-the-middle (MITM) attacks
- Theft of service
- Connection / session disruption or termination
- Replay
- Eavesdropping
  - Content sniffing, traffic analyses
- Denial-of-service
- Break in

Solutions

- Achieving security goals
  - Preventing attacks
  - Noticing attacks (e.g., monitoring, intrusion detection)
  - Limiting damage from attacks (e.g., isolation)
- Management aspects (planning, training, guidelines, policy, etc.)
- Technical measures
  - Overall system design
  - Protection of hosts and other devices
    - Physical; OS & software (e.g., regular updates)
  - Secure algorithms and protocols
  - Security devices (e.g., firewalls)
Security Properties

- Confidentiality of messages
  - Protection against eavesdropping

- Authentication of peers, messages
  - Protection against masquerading of senders
  - Prerequisite for authorization of actions

- Integrity of messages
  - Protection against modification in transit

- Non-repudiation of actions (accountability)
  - Message origin
  - Reception of messages

Related Properties

- Availability of systems and services
  - Protection against maliciously caused overload
    - E.g., denial-of-service attacks
  - Distinction from dependability and safety
    - Different background
    - Ensure correctness, protect against malfunctioning

- Privacy of (personal) information
  - Partially in competition with authentication
Security

- Background and security properties
- Cryptographic algorithms
  - Security mechanisms
  - Security protocols and systems
  - Security Devices

Cryptographic Algorithms

- Cipher algorithms
  - Symmetric algorithms: DES (56-bit), AES (128-bit and more)
  - Asymmetric (public-key) algorithms: e.g., RSA, PGP

- Digest algorithms
  - Compute a digest ("finger-print") of a message: SHA-1, MD5
  - Basis for hashed message authentication code (HMACs)

- Pseudo random number generators
  - Generate keys for ciphers and HMAC generators
General

- Algorithms should be publicly known
  - No security by obscurity
  - Enables broad community review and attempts to break the algorithm
  - Strength should only depend on the strength of the chosen key

- Attacks against algorithms
  - Crypto-text only
  - Known plaintext attacks
  - Chosen plaintext attacks

- Algorithms should not reveal additional hints to the attacker
  - Allow for brute force searching of the entire key space as only resort
  - Large key space is important! (today: $\geq 2^{128}$ for symmetric, $\geq 2^{2048}$ for asymmetric)
  - Need to be computationally efficient; operate on blocks and (infinite) streams

General (2)

- Asymmetric ciphers usually rely on complexity of math operations
  - E.g., finding prime factors of a really large number
  - Issue: “really large” grows over time; keys need to get longer
    - Solely depends on computing power available
  - Economic aspect: effort invested vs. value gained

- One-way functions (message digests)
  - Map a large data portion onto a fixed length hash (or digest)
    - Many-to-one mapping, clashes possible
  - Needs to be defined so that it is not possible to construct a second (meaningful) messages that maps to the same output
    - Changing any bit in the input results in changing all the output
  - Need to be computationally efficient
    - If large amounts of data need to be handled
Symmetric Ciphers

- Encryption key = decryption key

A plaintext \( e(K) \) \rightarrow \text{ciphertext} \rightarrow d(K) \rightarrow \text{plaintext} \ B

- Transposition ciphers
  - Rearrange the occurrence of characters
  - HELLOWORLD \rightarrow HLOOL ELWRD \rightarrow HLOOLELWRD

- Substitution ciphers
  - Simple case: Caesar chiffre: \( A \rightarrow D, B \rightarrow E, \ldots, X \rightarrow A, Y \rightarrow B, Z \rightarrow C \)
  - HELLOWORLD \rightarrow KHOORZRUOG

Example: DES

- Block cipher
  - 64 bit block length, 56 bit key length
  - Three phases
    - 64 bits in block are permuted
    - 16 rounds of identical operations
    - Inverse of the original permutation

- Four modes of operation
  - Electronic Code Book (ECB)
    - Substitution cipher for 64 bit blocks
  - Cipher Block Chaining (CBC)
    - Link encryption of each code block to its predecessor (XOR)
  - Output Feedback (OFB) and Cipher Feedback (CFB)
    - Use DES as a stream cipher
    - (Parts of) encryption result XORed with continuous input stream
**DES Successors**

- Simple DES no longer considered secure
  - Can be “easily” broken with brute force

- Triple DES: Enhance the key space by running DES 3 times
  - DES-EEE₃: three different encryption keys
  - DES-EDE₃: three different keys: encryption, decryption, encryption
  - DES-EEE₂: two different keys: keys for first and third encryption identical
  - Effective key length up to 168 bits

- Official DES Successor: Advanced Encryption Standard (AES)
  - Multiple key lengths: 128, 192, 256 bits

- Other algorithms suitable for software: Twofish, Blowfish, RC5

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**Algorithms: Public-Key Cryptography**

- Two keys for each communication partner
  - Public key ➔ published
  - Private key ➔ kept secret

- Messages encrypted with the public key can only be decrypted with the private key (and vice versa)

- Can be used to provide different security services

  - Encryption:
    - A: plaintext \(\rightarrow\) ciphertext \(\rightarrow\) plaintext
    - B: plaintext \(\rightarrow\) ciphertext

  - Authentication:
    - A: plaintext \(\rightarrow\) authenticated text
    - B: plaintext \(\rightarrow\) authenticated text
RSA: Principle

- Rivest, Shamir, Adleman (1978)
- Background: complexity of prime factorization of large numbers
- Algorithm:
  - Choose two large numbers \( p \) and \( q \) and calculate \( n = p \times q \)
  - Calculate an encryption key \( e < n \) such that \( e \) and \( (p - 1) \times (q - 1) \) are relatively prime
  - Compute decryption key \( d \) as \( d = e^{-1} \times \text{mod} \ ((p - 1) \times (q - 1)) \)
  - Construct public key \( = (e, n) \) and private key \( = (d, n) \)

\[
\begin{align*}
\text{Encryption:} & \quad c = m^e \mod n \\
\text{Decryption:} & \quad m = c^d \mod n
\end{align*}
\]

RSA: Example

- Let \( p = 7 \) and \( q = 11 \) [everyone seems to be using these]
- We get \( n = p \times q = 7 \times 11 = 77 \) and \( (p - 1) \times (q - 1) = 6 \times 10 = 60 \)
- Pick \( e = 7 \) [7 and 60 are relatively prime]
- We get \( d = 7^{-1} \mod 60 \) or \( 7 \times d \mod 60 = 1 \) [\( 7 \times 43 = 301 \mod 60 = 1 \)]
- Public key \( (e, n) = (7, 77) \)
- Private key \( (d, n) = (43, 77) \)
- Message: 9 \[
\begin{align*}
\text{encryption:} & \quad c = m^e \mod n = 9^7 \mod 77 = 37 \\
\text{decryption:} & \quad m = c^d \mod n = 37^{43} \mod 77 = 9
\end{align*}
\]
Algorithms: Message Digest

- RSA computation is expensive
  - May be difficult to operate (imagine RSA key stored on a chipcard)
    - need to tunnel messages through card
- Seek representative for the full message
- Cryptographic checksum
  - Stronger than CRC (typically longer and more complex)
  - But: several messages map to the same checksum
- One-way function
  - Do not allow determining the original message based upon the digest
  - Do not allow determining another message that yields the same digest
- May be used for integrity protection
  - Encrypt the checksum with RSA or use a shared secret (later)

Message Digest Algorithms

- One-way function (examples: MD5, SHA-1)
  - Map a large data portion onto a fixed length hash (or digest)

```
<table>
<thead>
<tr>
<th>Initial value</th>
<th>Message (m)</th>
<th>Padding</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Transform</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transform</td>
<td></td>
</tr>
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<td>Transform</td>
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<td>Transform</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transform</td>
<td></td>
</tr>
<tr>
<td>MD5(m) =</td>
<td>Msg Digest</td>
<td></td>
</tr>
</tbody>
</table>
```

Note that there is no key involved at this point. Anyone can create the checksum from a message.
Message Authentication Code (MAC)

- Combine integrity protection and message authentication
  - Base the outcome of the digest function on a key

- Use DES in CBC mode with a key, last output block is digest

- Keyed MD5: Append keying material to the message
  - Shared key k: sender sends \( m + \text{MD5}(m+k) \)
  - Random key k: sender sends \( m + \text{MD5}(m+k) + \text{E}(k, \text{public_receiver}) \)

- Hashed Message Authentication Code (HMAC)
  - Use shared or random key to vary initial values
  - Important: no cryptography involved \( \Rightarrow \) no export regulations
  - \( \text{HMAC-H}(k, \text{text}) = H(k \text{ XOR } \text{opad} || H(k \text{ XOR } \text{ipad} || \text{text})) \)

HMAC Overview

- Hash function \( H \) takes blocks of size \( B \) as input

- Key \( K \)
  - Padding (0)
  - ipad: \( 0x36, 0x36, 0x36, \ldots, 0x36 \)
  - opad: \( 0x5C, 0x5C, 0x5C, \ldots, 0x5C \)

- Message (m)
  - \( H((K + \text{ipad}) || \text{m}) \)

- HMAC
Algorithms: Random Number Generation

- Random numbers: dynamically generated keys, challenges, etc.
  - Pseudo-random numbers are predictable and therefore not suitable

- Time of days, process id, etc. are also somewhat predictable
  - Also an attacker knows the time
  - The process id is usually drawn from a very limited space

- Use user “input” (mouse movements, key strokes)
  - But not necessarily reliable (and there may not be input devices)

- Use hardware input
  - Measure entropy of the environment
    - Radioactive sources, atmospheric noise from radio, other
    - Project example: lava lamp image
  - Nice reference: www.random.org

Security

- Background and security properties
- Cryptographic algorithms
- Security mechanisms
- Security protocols and systems
- Security Devices
Some Security Mechanisms

- Message integrity protection and authentication
  - (Hashed) Message authentication codes: (H)MACs
  - Digital signatures

- Key exchange/management
  - Obtain and validate public keys
  - Securely exchange keys between communication peers
  - Generate shared session keys
  - Usually address negotiation of algorithms and re-keying as well

- User Authentication
  - Establish the identity of communicating peers
  - Often prerequisite for (meaningful) key exchange

Digital Signatures

- An application of public-key cryptography (and message digests)
  - Main advantage of public-key cryptography
    - No need to transmit shared secrets (password, secret keys)
    - Private key does not have to be disclosed

- Simplest case: encrypt full message with private key: $E(m, \text{private})$
  - Provide identity along with message
  - Receiver can validate message origin by decrypting with public key

- Issues:
  - Replay attacks possible ➔ ensure message uniqueness (e.g., timestamp)
  - Computational overhead incurred by RSA ➔ sign message summary

- Sender sends: $m + E(\text{MD5}(m), \text{private})$
  - Includes information about digest algorithm, identity, timestamp, …
Issues with Public Key Cryptography

- **Problem:** Obtaining public keys of communication partners
  - Transmission over unsecured channels is not useful
  - Authentication (and integrity) is required

- **Solution:** *Certificates*
  - Certificates bind a public key to an entity
  - Digitally signed by a Certificate Authority (CA)
  - A CA can provide a certificate for its own public key
    - Signed by a well-known root CA
  - Hierarchy of CAs and corresponding directory services ➔ Public Key Infrastructure (PKI)
    - Important prerequisite for deploying public key cryptography

Sample Certificate

<table>
<thead>
<tr>
<th>Certificate Viewer: &quot;salomonruotta.juh.fi&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General</strong></td>
</tr>
<tr>
<td>This certificate has been verified for the following uses:</td>
</tr>
<tr>
<td>SSL Server Certificate</td>
</tr>
<tr>
<td><strong>Issued To</strong></td>
</tr>
<tr>
<td>Common Name (CN)</td>
</tr>
<tr>
<td>Organization (O)</td>
</tr>
<tr>
<td>Organizational Unit (OU)</td>
</tr>
<tr>
<td>Serial Number</td>
</tr>
<tr>
<td><strong>Issued By</strong></td>
</tr>
<tr>
<td>Common Name (CN)</td>
</tr>
<tr>
<td>Organization (O)</td>
</tr>
<tr>
<td>Organizational Unit (OU)</td>
</tr>
<tr>
<td><strong>Validity</strong></td>
</tr>
<tr>
<td>Valid On</td>
</tr>
<tr>
<td>Expires On</td>
</tr>
<tr>
<td><strong>Fingerprints</strong></td>
</tr>
<tr>
<td>MD5 Fingerprint</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Certificate Viewer: &quot;salomonruotta.juh.fi&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Certificate Hierarchy</strong></td>
</tr>
<tr>
<td>salomonruotta.juh.fi</td>
</tr>
<tr>
<td><strong>Certificate Fields</strong></td>
</tr>
<tr>
<td><strong>Issuer</strong></td>
</tr>
<tr>
<td>Certificate</td>
</tr>
<tr>
<td>Version</td>
</tr>
<tr>
<td>Serial Number</td>
</tr>
<tr>
<td>Subject</td>
</tr>
<tr>
<td>Certificate Signature Algorithm</td>
</tr>
<tr>
<td><strong>Field Value</strong></td>
</tr>
<tr>
<td>CA = CA for TLS Servers</td>
</tr>
<tr>
<td>OU = Certificate Services</td>
</tr>
<tr>
<td>OI = Helsinki University of Technology</td>
</tr>
<tr>
<td>C = FI</td>
</tr>
</tbody>
</table>
X.509 Certificates

TBSCertificate ::= SEQUENCE {
  version       [0]  EXPLICIT Version DEFAULT v1,
  serialNumber  CertificateSerialNumber,
  signature     AlgorithmIdentifier,
  issuer        Name,
  validity      Validity,
  subject       Name,
  subjectPublicKeyInfo SubjectPublicKeyInfo,
  issuerUniqueID [1]  IMPLICIT UniqueIdentifier OPTIONAL,
  subjectUniqueID [2] IMPLICIT UniqueIdentifier OPTIONAL,
  extensions    [3]  EXPLICIT Extensions OPTIONAL
                -- If present, version MUST be v3
}

Extensions:
  Subject Alternative Names
  Issuer Alternative Names

SubjectAltName ::= GeneralNames
IssuerAltName ::= GeneralNames

GeneralName ::= CHOICE {
  otherName            [0]   OtherName,
  rfc822Name           [1]   IA5String,
  dNSName              [2]   IA5String,
  x400Address          [3]   ORAddress,
  directoryName        [4]   Name,
  ediPartyName         [5]   EDIPartyName,
  uniformResourceIdentifier  [6]   IA5String,
  iPAddress            [7]   OCTET STRING,
  registeredID         [8]   OBJECT IDENTIFIER }

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Public Key Infrastructure (PKI)

- Have a (trusted) party certify the key’s correctness:
  - That the key belongs to a particular **subject** (person, device)
  - That the key is (still) valid

- Certification Authority (CA)
  - Asserts a an identity – public key mapping + validity period in a **certificate**
  - Digitally signs the certificate to ensure authenticity and integrity
  - Signature can be validated by another CA
  - Validation “hierarchy” or “path”

- Provide a repository to store all this information
  - Interaction between CAs
  - Register, publish, and revoke certificates

---

CA Hierarchy and Certificate Validation

- User certificate
  - User identity
  - Public key
  - Lifetime
  - Signature
  - Signer-ID

- CA-1 Certificate
  - User identity
  - Public key
  - Lifetime
  - Signature
  - Signer-ID

- CA-1.3 Certificate
  - User identity
  - Public key
  - Lifetime
  - Signature
  - Signer-ID

- Trusted Anchor

---
Public Key Infrastructure (PKI)

- Certification Authorities (CAs)
  - Optional: generate private – public key pairs
  - Validate a private–public key pair (authenticate subject)
  - Generate certificates
  - Publish certificates (to other CAs, to other entities for signature validation)
  - Revoke certificates (in case of compromise)
  - Management functions and inter-CA communications
  - Key pair management: update, recovery, …

- Registration Authorities (RAs)
  - Optional, for interaction with the user, key pair generation, etc.
  - Functionality may completely be integrated with CA (logical decomposition)

- End entity: acts on behalf of the user (user equipment)
  - Stores private keys “securely”, inquires certificates

- Certificate and CRL Repository
- RFC 2510, 2511, 2585, 3280(!)

Public Key Infrastructure
Self-Signed Certificates

- Certificates usually handed out by CA
  - Workable for servers
  - Impractical + expensive + hard to deal with for end users

- Alternative: self-signed certificate
  - Self-generated key pair
  - Self-created certificate
    - Signed with the own key
  - Sufficient to satisfy (syntactical) protocol requirements (e.g., TLS)
  - Semantics may suffice for certain applications, too
    - Certificates convey during initial contact
    - Stored at both peers
    - Allows to validate that the same peer was contacted before

Key Exchange Protocols

- Public-key cryptography not very efficient for encrypting larger messages
  - Often used to securely agree a session key (key exchange)
  - Session encryption is done with symmetric cryptography

Alternatives for key exchange:
- Pre-shared key
  - Offline agreement of a shared key for a symmetric algorithm
  - All the problems of shared keys that have to be configured on two systems...
- Exchange session key using public-key crypto
- Diffie-Hellman key generation
  - A key generation algorithm
  - Allows two partners to securely compute a common secret key
  - No eavesdropping possible → perfect forward secrecy
  - Preventing man-in-the-middle attacks requires authentication
    → combine with public-key crypto
Diffie-Hellman Key Generation

a) A and B agree on a large prime, $n$ and generator $g$, such that $g$ is primitive mod $n$.

Example: $g = 2$, $n = \text{FFFFFFFF FFFFFFFF C90FDAA2 2168C234 C4C6628B 80DC1CD1 29024E08 8A67CC74 020BBEA6 3B139B22 514A0879 8E3404DD EF9519B3 CD3A431B 302B0A6D F25F1437 4FE1356D 6D51C245 E485B576 625E7EC6 F44C42E9 A63A3620 FFFFFFFFF FFFFFFFFF (RFC2409)

One Moment – Primitive Root…?

- Just a quick note:

- $R$ is a primitive root of $P$ [$R = \text{prim\_root (P)}$]

  If $R^{P-1} \text{ mod } P = 0$

  AND

  If for all $k < P-1$ $R^k \text{ mod } P \neq 0$

- Now let’s do a little brain exercise…
Negotiation of parameters \( n \) and \( g \)

a) A computes a large integer \( x \)
   B computes a large integer \( y \)

b) A computes \( X = g^x \mod n \) and sends it to B,
   B computes \( Y = g^y \mod n \) and sends it to A.
Diffie-Hellman Key Generation

a) Negotiation of parameters $n$ and $g$

b) $X = g^x \mod n$

b) $Y = g^y \mod n$

c) $k = Y^x \mod n = g^{xy} \mod n$

d) $k = X^y \mod n = g^{xy} \mod n$

Both A and B can compute $k$, the shared secret key.

Issue: Man-in-the-middle attack!

User Authentication

- Establish the identity of one or both peers (client, server)
  - Three-way handshake
  - Trusted third party
  - Public key authentication
- Exchange (or generate) session key along with authentication

Related system aspects

- Backend protocols to access security databases
  - Authentication, Authorization, and Accounting (AAA)
  - RADIUS (widely deployed)
  - DIAMETER (more complete successor)
- Important aspect: Identity management
Three-way Handshake

- Assumption: Shared secret key
  - SHK = CHK = Server/client handshake key
- E (m, k): encrypt message m with key k
- Client chooses random number x
  - Sends encrypted with shared secret
- Server uses ClientId to determine key
  - Decrypts and returns x+1 encrypted
  - Also chooses random number y
  - Sends encrypted with shared secret
- Client decrypts x+1 and y
  - If x+1 decrypts correctly: server authenticated
  - Returns y+1 encrypted
- Server decrypts y+1
  - If y+1 decrypts correctly: client authenticated
  - Generated session key SK and sends encrypted

Trusted Third Party (Kerberos)

- Authentication server as trusted entity
  - Keys of A and B (KA and KB) are shared with the server
- A and B want to communicate securely (auth + encr)
- Server provides session K with lifetime L at time T
Simple Public Key Authentication

- No shared key necessary!
  - But a public key infrastructure of some sort
- A generates random number x
  - B decrypts and returns it → authenticated
- Different related approaches conceivable

\[ E(x, \text{Public B}) \]

Security

- Background and security properties
- Cryptographic algorithms
- Security mechanisms
  - Security protocols and systems
- Security Devices
Some Security Protocols

- **Link layer**
  - Link layer authentication: IEEE 802.1x
  - Wired Equivalent Privacy (WEP) for IEEE 802.11 Wireless LANs (insecure)
  - IEEE 802.11i as successor

- **IP layer**
  - IPsec
  - VPN tunneling alternatives: PPTP, L2TP

- **Transport layer**
  - Secure Shell (SSH) + associated protocols (file transfer, etc.)
  - Transport Layer Security (TLS)

- **Application layer**
  - HTTP digest authentication
  - Privacy enhanced mail (PEM)
  - Pretty good privacy (PGP)
  - S/MIME protection of message contents

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**IPSEC (1)**

- **Security Architecture for the Internet Protocol (RFC2401)**
  - Provide security services at the IP layer (network layer)
  - Protect one or more paths between a pair of hosts
    - Special case: protect path between gateways

- **Security Protocols**
  - Authentication Header (AH, RFC2402)
    - Authentication
    - Integrity
    - Usually used with HMAC-MD5-96 or HMAC-SHA-1-96
  - Encapsulating Security Payload (ESP, RFC2406)
    - Authentication
    - Integrity
    - Usually used with HMAC-MD5-96 or HMAC-SHA-1-96
    - Encryption
    - Default cipher: DES (insecure), ➔ 3DES, AES
**IPsec Authentication Header (Transport Mode)**

**IPv4**

IPv4-header + Options  | AH | Transport Header | Payload
---|---|---|---

authenticated
(except for modifiable fields)

**IPv6**

IPv6-Header  | Extensions  | AH  | Extensions  | Transport Header  | Payload
---|---|---|---|---|---

authenticated
(except for modifiable fields)

---

**IPsec Encapsulation Payload (Transport Mode)**

**IPv4**

IPv4-header + Options  | ESP Header  | Transport Header  | Payload  | ESP Trailer  | ESP Auth
---|---|---|---|---|---

encrypted
authenticated

**IPv6**

IPv6-Header  | Extensions  | ESP Header  | Extensions  | Transport Header  | Payload  | ESP Trailer  | ESP Auth
---|---|---|---|---|---|---|---

encrypted
authenticated
IPSEC (2)

- Security Associations (SAs)
  - Fundamental abstraction for IPsec
  - A unidirectional “connection” offering security services
  - One SA for each service and for each direction
  - Combining SAs, if more than one service is needed
  - Identified by SPI, IP destination addr, protocol ID (ESP or AH)

- Two Types of SAs
  - Transport Mode
    - SA between two hosts
    - Protection for upper layer protocols (UDP, TCP, ...)
  - Tunnel Mode
    - An SA applied to an IP tunnel
    - Tunnel IP packets on behalf of hosts (used by security gateways)

IPsec Tunnels
Key Management for IPsec

- Manual key management
  - Configure each system with keying material and SA parameters
  - Only feasible for static environments
  - A VPN tunnel between two sites in a common administrative domain

- Internet Security Association and Key Management Protocol (ISAKMP)
  - Generic key management framework defining procedures and Packet Format for SA management:
    - Establishment, negotiation, modification and deletion

- Internet Key Exchange (IKE)
  - Specialization of ISAKMP for IPsec
  - Two Phases:
    - Establishment of the ISAKMP SA (secure, authenticated bidirectional channel for SA negotiation)
    - SA negotiation for IPsec
  - Negotiable key exchange mechanisms

Security Protocols above IPsec

- IPsec deployment issues
  - IPsec between IP and transport layer
  - Need kernel support for IPsec
  - Most IPsec deployment so far in security gateways

Easier to deploy alternatives:

- TLS = Transport Layer Security
  - Standardized form of SSL (Secure Socket Layer, Netscape)
  - Once established, similar to TCP
  - Secures connection, not application semantics
  - In practical use, usually authenticates server, not client

- Application Layer Security Protocols
  - Part of the application layer signaling (e.g., HTTP)
  - Secure the application messages
  - If they are MIME-encoded: S/MIME (secure MIME)
    - Alternative: PGP, PEM
Transport Layer Security (TLS)

- Provide authentication, confidentiality and integrity between two communicating applications
  - Transparent to applications
  - Often used for client-server applications
  - Used for secure HTTP: https://
- Layered on top of a reliable transport protocol (e.g. TCP)
- Two layers:
  - TLS Record Protocol
    - Provides confidential and reliable (integrity) transport for higher layer protocols
    - Symmetric cryptography and HMACs
  - TLS Handshake Protocol
    - Allows for secure authentication of communication partners
    - Public key cryptography and certificates
    - Used on top of the TLS Record Protocol
**TLS Handshake Protocol Exchange**

- **ClientHello**
  - Offers set of ciphers
  - Includes random value
- **ServerHello**
  - Selects cipher
  - Includes random value
  - Provides certificate
- **Calculate master key**
- **Derive of session keys for the record layer**
- **Synchronize on new session key**

---

**TLS Real World Example**

(1)
Application Layer Security: HTTPS

- Web servers usually the “trusted” partners
  - Bank, government, insurance, etc.
- Web browsers (clients) usually the customers
  - “Few” web servers for “many” clients

- TLS for connection establishment
  - Web servers authenticated via certificates
  - Scales well as there are not so many
- HTTP Digest authentication via TLS connection
  - Server refuses request and challenges client
  - Client provides credentials typically based upon shared secret
    - Username, password
  - Response does not reveal secret
HTTP Digest Authentication

```
GET index.html
401 Unauthorized
GET index.html
200 OK
```

WWW-Authenticate: Digest realm="HUT", domain="netlab.hut.fi", nonce="qf73...", stale=FALSE, algorithm=MD5

Authorization: Digest username="jo", realm="HUT", nonce="qf73...", response="50c6a6071bc8..."

Secure/Multipurpose Internet Mail Extensions (S/MIME)

- Example for an application layer security mechanism.
- Security services for sending and receiving MIME data
  - Authentication, message integrity, non-Repudiation of origin, confidentiality
- Not restricted to e-mail
  - May be used with HTTP and other application protocols
- Relies on the Cryptographic Message Syntax (CMS)
  - Specification for authenticating, digitally signing and encrypting contents
  - Security functions are applied on envelopes containing message content (or other envelopes)
  - May embed certificates and other key management information
- Uses public key cryptography and certificates
  - Most useful with a PKI (e.g., CA hierarchy)
A Brief Excursion to MIME

- **Multipurpose Internet Mail Extensions**
  - Not just mail: used with HTTP and many other application protocols

- Define the purpose of a piece of content (in a message body)
  - Type, encodings
  - Intended interpretation
  - Specify additional parameters
  - Allow for references

- Allow for multipart contents
  - Arbitrarily nested pieces of contents
  - Specify the above for each part individually

---

**Example:**

- **Content-Type:** image/jpeg
- **Content-Length:** 5489
- **Content-Transfer-Encoding:** base64
- **Content-ID:** 42
- **Content-Description:** an image of a tree
- **Content-Disposition:** attachment; ...

- **Allow for multipart contents**
  - Content-Type: multipart/alternative
  - Content-Type: multipart/mixed
  - Context-Type: multipart/related
S/MIME Processing Steps

- S/MIME messages are combination of MIME bodies and CMS content types
  - Several MIME types as well as several CMS content types are used
- Data to be secured is always a canonical MIME entity
  - Secure MIME entity: sub-part, sub-parts, or an entire MIME entity
  - Canonicalization depends on the respective content type
- Optionally, apply transfer encoding
- MIME entity and security information as input to CMS processing
  - Will result in a CMS object
- CMS object is wrapped in MIME

Resulting S/MIME Messages

- Content-type: application/pkcs7-mime
  - PKCS#7: Cryptographic Message Syntax (CMS) Version 1.5 (RFC2315)
    - Current spec of CMS: RFC 3852; ASN.1-encoded cryptographic objects
  - ;smimetype= parameter to indicate what the object is used for
    - ensembled-data, signed-data, compressed-data
    - Concatenation possible: signed-encrypted-data
  - ;name=filename.suffix and ;filename=filename.suffix
    - application/pkcs7-mime: SignedData + EnvelopedData -> .p7m
    - application/pkcs7-mime: CompressedData -> .p7z
    - application/pkcs7-signature: SignedData -> .p7s
    - Filename is arbitrary; no longer than 8 characters
- Signing only: multipartscribed
  - Does not require S/MIME software on the receiver for viewing the contents
Sample Encoding: Encryption

Content-Type: application/pkcs7-mime; smime-type=enveloped-data; name=smime.p7m
Content-Transfer-Encoding: base64
Content-Disposition: attachment; filename=smime.p7m

rfvbnj756tbBghyHhHUujhJhjH77n8HHGT9HG4VQpfyF467GhIGfHfYT6
7n8HHGghyHhHUujhJh4VQpfyF467GhIGfHfYTfrvbnjT6jH7756tbB9H
f8HHGTfsvhJhjH776tbB9HG4VQbnj7567GhIGfHfYT6ghyHhHUujpfyF4
0GhIGfHfQbnj756YT64V

Sample Encoding: Signing

Content-Type: multipart/signed;
  protocol="application/pkcs7-signature";
  micalg=sha1; boundary=boundary42

--boundary42
Content-Type: text/plain

This is a clear-signed message.

--boundary42
Content-Type: application/pkcs7-signature; name=smime.p7s
Content-Transfer-Encoding: base64
Content-Disposition: attachment; filename=smime.p7s

ghyHhHUujhJhjH77n8HHGTfsvbnj756tbB9HG4VQpfyF467GhIGfHfYT6
4VQpfyF467GhIGfHfYT6jH77n8HHGghyHhHUujhJh756tbB9HGTrfsvbnj
8HHGTfsvhJhjH776tbB9HG4VQbnj7567GhIGfHfYT6ghyHhHUujpfyF4
7GhIGfHfYT64VQbnj756

--boundary42--
Security

- Background and security properties
- Cryptographic algorithms
- Security mechanisms
- Security protocols and systems
- Security Devices

“Security Devices” for IP Networks

- Some protection against attacks from the outside

- Packet Filter
  - (dis)allow forwarding of packets to/from certain addresses
  - Protect networks from stray traffic

- Application Layer Gateway (ALG) / Proxy
  - control (and police) communications at application layer

- Firewall
  - Combination of the above
  - protect internal resources against access from the outside

- Network Address Translator (NAT)
  - minimize required fraction of “Internet” address space
  - hide internal IP addresses
  - perform packet filtering for unknown traffic
Coupling Networks with Security in Mind

IP Layer: Router w/o Security
IP Layer: Packet Filter

Network protocol stack

IP

Network protocol stack

A
Corporate Network
R
Internet
B

Packet Filter

Corporate Network
R
Internet

Packet filter spec
• Source, destination IP address
• Protocol (UDP, TCP, ICMP)
• Source, destination port
• Direction of traffic
May be dynamically configured.
Stateful Packet Inspection

Application Layer Gateway
### Application Layer Gateway (Proxy)

- **Corporate Network**
- **Internet**
- **Access policies**

- ftp server → ftp proxy → ftp client
- Web browser → http proxy → http server
- client / server

### Firewalls

- Packet filters, enforcing packet altering/forwarding policies
  - Filter specification: Usually statically configured
  - Most configurations disallow packets for “non-standard ports”
- Stateful packet inspection
  - Detect transport or application context of packets
  - Dynamically adapt filter specification
- Application layer gateways
  - Terminate connections: act as transparent or explicitly visible proxies
  - Monitor connection: parse contents of application protocols
    - Functioning precludes end-to-end security!
  - Dynamically adapt filter specification
- Policies may be applied at all layers
Network Address Translators

- Intermediate systems that can translate addresses (and port numbers) in IP packets
  - Often used to map global addresses to address/port number combination of hosts in a corporate network

- Different motivations
  - Efficient usage of address space
    - Share one globally unique address
    - Use a private address space in the enterprise (10.x.x.x, 192.168.x.x, …)
  - Security
    - Make internal host inaccessible from the public Internet
    - Hide addresses / address structure

- Include dynamically configured packet filters, stateful packet inspection

Network (+Port) Address Translators (NAT)
Network Address Translators

Corporate Intranet

H1: ftp
H2: ftp
H2: telnet
H3: http

10.0.42.x
10.0.42.16
130.3.18.39

H1: ftp
H2: ftp
H2: telnet
H3: http

10.0.42.1:16587
10.0.42.2:17202
10.0.42.2:19001
10.0.42.3:32006

130.3.18.39:20001
130.3.18.39:20002
130.3.18.39:20003
130.3.18.39:20004

ftp server
ftp server
telnetd
web server

Firewall Applicability

- Firewalls and NATs help against unwanted traffic from the outside
  - Denial-of-Service attacks, port scans, break-in attacks, worms
  - ALGs against viruses

- But: Firewalls and NATs may also prevent legitimate traffic
  - Evil to IP communications: Break end-to-end model
  - Have many implicit assumptions about protocols
  - Do not work well with a number of protocols
    - Including their security features

- Just one piece in a security portfolio, to be applied wisely
- Applications and protocols still need security
- Users and their behavior still pose a significant risk