Principles of Network Security

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The Network Security Model

- Bob and Alice want to communicate “securely”.
- Trudy (the adversary) has access to the channel.

Who might Bob and Alice be?

- Web browser/server for electronic transactions (e.g., on-line purchases/banking)
- DNS servers
- routers exchanging routing table updates
- ... well, real-life Bobs and Alices!

What can an adversary do?

- eavesdrop: understand the content of messages
- actively changing messages
- impersonation: can fake (spoof) source address in packet (or any field in packet)
- denial of service: prevent service from being used by others (e.g., by overloading resources)
What is Network Security?

Confidentiality: only sender, intended receiver should "understand" message contents

Authentication: sender, receiver want to confirm identity of each other

Message Integrity: sender, receiver want to ensure message not altered (in transit, or afterwards)

Access and Availability: services must be accessible and available to (and only to) legitimate users.

Outline

- What is network security?
- Confidentiality: cryptography
- Authentication
- Integrity

The Language of Cryptography

First goal of cryptography: confidentiality.

- Symmetric key crypto: encryption and decryption keys are identical. (both are secret)
- Public key crypto: encryption key is public, decryption key is secret.

Symmetric Key Cryptography: Monoalphabetic Cipher

Monoalphabetic cipher: substitute one letter for another.

Plaintext: abcdefghijklmnopqrstuvwxyz

Ciphertext: mnbvcxzasdfghjklpoiuytrewq

Example: Plaintext: bob. i love you. alice
Ciphertext: nkn. s gktc wky. mgsbc

Q1: How hard to break this simple cipher?
- brute force?
- other?

Q2: How to make it more difficult to break?
Symmetric Key Cryptography: DES

- DES: Data Encryption Standard
  - US encryption standard [NIST 1993]
  - 56-bit symmetric key, 64-bit plaintext input
  - encryption: initial permutation ⇒ 16 "rounds", each using different 48 bits of key ⇒ final permutation
  - decryption: reverse operation using the same key

- How secure is DES?
  - DES Challenge (1999): 56-bit-key-encrypted phrase decrypted (brute force) in 22 hours 15 minutes

- Making DES more secure:
  - use three keys sequentially (3-DES)
  - use more bits

AES: Advanced Encryption Standard

- new (Nov. 2001) symmetric-key NIST standard, replacing DES
- processes data in 128 bit blocks
- 128, 192, or 256 bit keys
- brute force decryption (try each key) taking 1 sec on DES, takes 149 trillion years for 128-bit AES

Public Key Cryptography

- symmetric key cryptography
  - requires sender, receiver know shared secret key
  - Q: how to agree on key in first place? (particularly difficult if Trudy is eavesdropping on all communication)

- public key cryptography
  - encryption key is different from decryption key
  - encryption key is public, known to everyone, also called public key
  - decryption key is secret, known only to receiver, also called private key

Principle for choosing the public/private key pair:
One should not be able to derive the private key from the public key.
Public Key Cryptography: RSA
(Ron Rivest, Adi Shamir and Len Adleman)

- Choosing keys:
  - Choose two large prime numbers p, q. (e.g., 1024 bits each)
  - Compute \( n = pq, \, z = (p-1)(q-1) \)
  - Choose e (with e\(\equiv 1\) mod z) that has no common factors with z.
  - Choose d such that ed - 1 is exactly divisible by z.
  - Public key is (n,e). Private key is (n,d).
- To encrypt a message, m (< n): do \( c = m^e \mod n \)
- To decrypt a received ciphertext, c: do \( m = c^d \mod n \)
- Reason: for any m (relatively prime with n)
  - \( m^z \mod n = 1 \); therefore \( m^{ed-1} \mod n = 1 \)
- Another property: \((m^d \mod n)^e \mod n = m \)
- RSA is much slower than the symmetric key cryptos.

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Authentication: version 1.0

Authentication: Bob wants Alice to "prove" her identity to him.

Protocol ap1.0: Alice says "I am Alice".

"I am Alice" → Alice
Failure scenario??
"I am Alice" → Trudy can simply declare herself to be Alice

Authentication: version 2.0

Protocol ap2.0: Alice says "I am Alice" and sends her secret password to "prove" it.

"I am Alice" → Alice
"I am Alice" → Alice's password
"I am Alice" → Alice's password
playback attack: Trudy records Alice's packet and later plays it back to Bob

Failure scenario??
Authentication: version 3.0

**Goal:** avoid playback attack

**Nonce:** number (R) used only once-in-a-lifetime

**ap3.0:** Bob sends Alice a nonce, R. Alice must return R, encrypted with shared secret key

"I am Alice"

\[ R \]

\[ K_{A-B}(R) \]

only Alice knows key to encrypt nonce, so it must be Alice!

Authentication: version 4.0

**ap3.0** requires shared symmetric key. Key distribution can be a problem.

**ap4.0:** use nonce, public key cryptography.

"I am Alice"

\[ R \]

\[ K_A(R) \]

Bob computes \( K_A(K_A(R)) = R \) and knows only Alice could have the private key, that encrypted R such that \( K_A(K_A(R)) = R \)

Security hole when public keys are not well known

**Man (woman) in the middle attack:** Trudy poses as Alice (to Bob) and as Bob (to Alice)

I am Alice

\[ R \]

\[ K_A(R) \]

Send me your public key

Send me your public key

Trudy gets

\[ K_A^*(m) \]

\[ m = K_A^*(m) \]

\[ K_A(m) \]

\[ K_A(m) \]

m = \( K_A^*(m) \) sends m to Alice encrypted with Alice's public key

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Integrity

- Digital Signatures:
  - Cryptographic technique to ensure document integrity.
  - Analogous to hand-written signatures.
  - Sender (Bob) digitally signs document, establishing he is document owner/creator.
  - The recipient (Alice) receives the document and the digital signatures.
  - The recipient can be sure that the document is:
    - Verifiable: Bob signed the document.
    - Nonforgeable: the document hasn't been changed since Bob signed it.

Digital Signatures

- Bob signs m by encrypting with his private key, creating a digital signature $K_B(m)$.

Bob's message, m

%Public key encryption algorithm%

Dear Alice
Oh, how I have missed you. I think of you all the time! ... (blah blah blah)
Bob

Bob's private key

Problem: computationally expensive to public-key-encrypt long messages.

Message Digests

- Apply a hash function H to m, get a much smaller message digest H(m).
- Public-key-encrypt the message digest to generate the digital signature $K_B(H(m))$.

Digital signature = signed message digest

- Bob sends digitally signed message digest:
  - Large message m
  - H-Hash function
  - H(m)
  - Digital signature (encrypt)

- Alice verifies signature and integrity of digitally signed message:
  - Large message m
  - H-Hash function
  - H(m)
  - Encrypted msg digest $K_B(H(m))$
  - Digital signature (decrypt)
Message Digests:
good/bad hash function

- apply a hash function \( H \) to \( m \), get a much smaller message digest \( H(m) \).
- public-key-encrypt the message digest to generate the digital signature \( K_B(H(m)) \).

Note: it is possible for many messages sharing the same digest.

Internet Checksum: Poor Hash Function for Generating Message Digests

Given a message and its Internet checksum, it is easy to find another message with same checksum.

<table>
<thead>
<tr>
<th>message</th>
<th>ASCII format</th>
</tr>
</thead>
<tbody>
<tr>
<td>I O U 1</td>
<td>49 4F 55 31</td>
</tr>
<tr>
<td>0 0 . 9</td>
<td>30 30 2E 39</td>
</tr>
<tr>
<td>9 B O B</td>
<td>39 42 D2 42</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>message</th>
<th>ASCII format</th>
</tr>
</thead>
<tbody>
<tr>
<td>I O U 2</td>
<td>49 4F 55 39</td>
</tr>
<tr>
<td>0 0 . 1</td>
<td>30 30 2E 31</td>
</tr>
<tr>
<td>9 B O B</td>
<td>39 42 D2 42</td>
</tr>
</tbody>
</table>

Message: I O U 1
Checksum: 49 4F 55 31
Different message: I O U 2
Checksum: 49 4F 55 39

Different messages but identical checksums!

Hash function property: given message digest \( x \) for message \( m \), computationally infeasible to find another message \( m' \) such that \( x = H(m') \).

Good Hash Functions for Generating Message Digests

- MD5 hash function widely used
  - computes 128-bit message digest in 4-step process.
  - appears difficult to construct message \( m \) whose MD5 hash is equal to \( x \).
- SHA-1 is also used
  - US standard [NIST, FIPS PUB 180-1]
  - 160-bit message digest

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