Principles of Network Security

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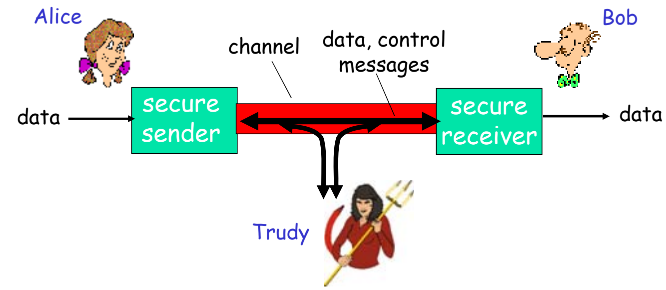
The Network Security Model

- 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: fake (spoof) identity
- 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).

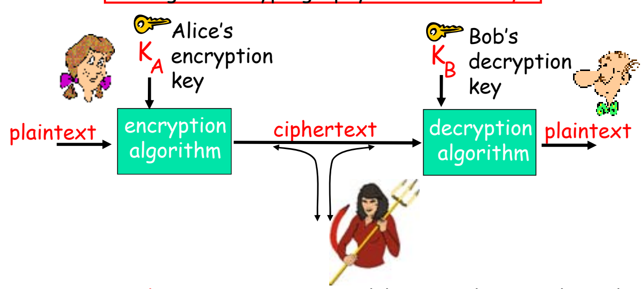
Access and Availability: services must be accessible and available to (and only to) legitimate users.

Principles of Network Security

- Confidentiality: cryptography
- Authentication
- Integrity
- Key distribution and certification

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:

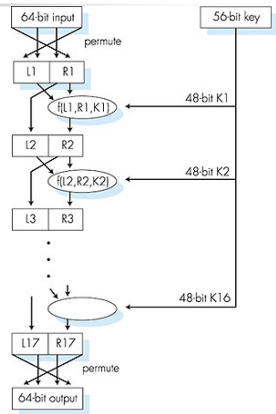
```
Plaintext: bob. i love you. alice
ciphertext: nkn. s gktc wky. mgsbc
```

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



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AES: Advanced Encryption Standard

- Newer (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

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Public Key Cryptography

Symmetric key cryptography

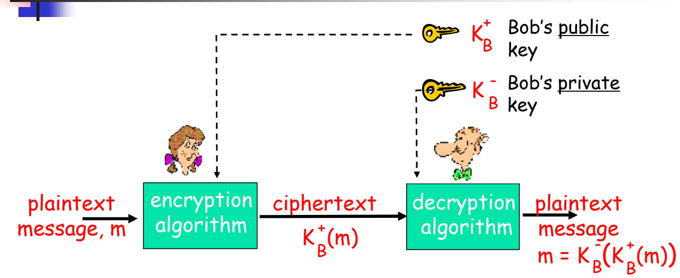
- requires sender, receiver know shared secret key
- Q: how to agree on key in the first place? (particularly difficult if Trudy is eavesdropping on all communication)

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

4/22/2013 CSC 257/457 - Spring 2013 11

Public Key Cryptography



Principle for choosing the public/private key pair:
One should not be able to derive the private key from the public key.

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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<n) 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 $c = m^e \bmod n$
- To decrypt a received ciphertext, c: do $m = c^d \bmod n$
- Reason: for any m (relatively prime with n)
  - $m^z \bmod n = 1$; therefore $m^{ed-1} \bmod n = 1$
- Another property: $(m^d \bmod n)^e \bmod n = m$
- RSA is much slower than the symmetric key cryptos

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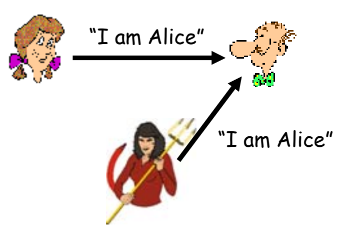
Authentication: version 1.0

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

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

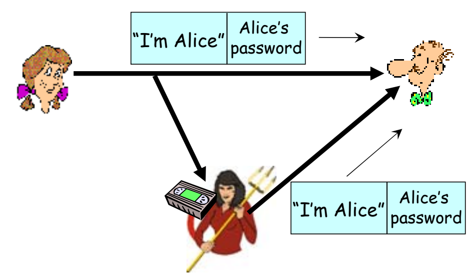


Failure scenario??

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.



Failure scenario??

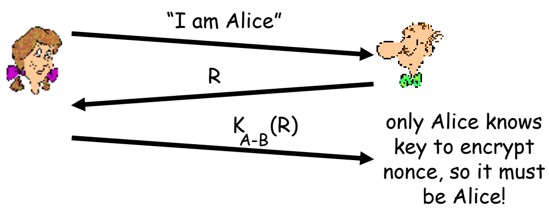
playback attack: Trudy records Alice's packet and later plays it back to Bob

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



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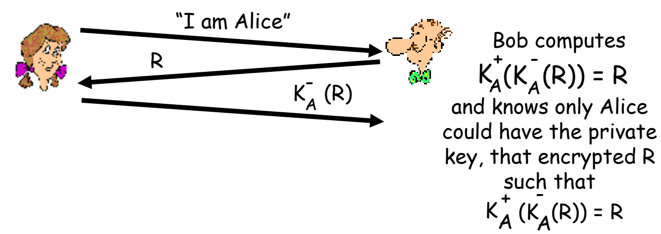
Authentication: version 4.0

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

ap4.0: use nonce, public key cryptography.



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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 signature.
- 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.

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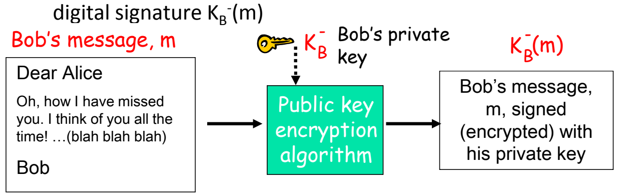
Digital Signatures

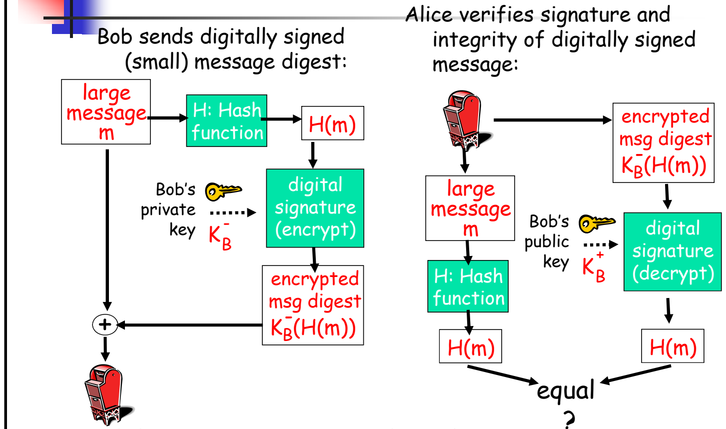
- Bob signs m by encrypting with his private key, creating a digital signature $K_B^-(m)$



- Suppose Alice receives msg m and its digital signature $K_B^-(m)$
- Alice applies Bob's public key K_B^+ to $K_B^-(m)$ then checks whether $K_B^+(K_B^-(m)) = m$.
- If so, whoever signed m must have used Bob's private key.

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

Signed Message Digest



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 $K_B^-(H(m))$.

Good/bad hash functions?

- Hint: given a hash function, 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.

message	ASCII format	message	ASCII format
I O U 1	49 4F 55 31	I O U 9	49 4F 55 39
0 0 . 9	30 30 2E 39	0 0 . 1	30 30 2E 31
9 B O B	39 42 D2 42	9 B O B	39 42 D2 42
	B2 C1 D2 AC		B2 C1 D2 AC

different messages but identical checksums!

Hash function property: given digest x for message m, computationally infeasible to find another message m' that shares the same digest.

Good Hash Functions for Generating Message Digests

- MD5
  - computes 128-bit message digest in 4-step process.
  - appears difficult to construct message m whose MD5 hash is equal to x.
- SHA-1
  - [NIST, FIPS PUB 180-1]
  - 160-bit message digest

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Key Distribution and Certification

Symmetric key distribution problem:

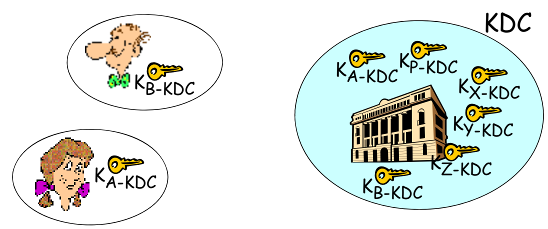
- How do Alice and Bob establish shared secret key over network without Trudy's knowledge?

Public key distribution problem:

- When Alice obtains Bob's public key (from web site, e-mail, diskette), how does she know it is Bob's public key, not Trudy's?

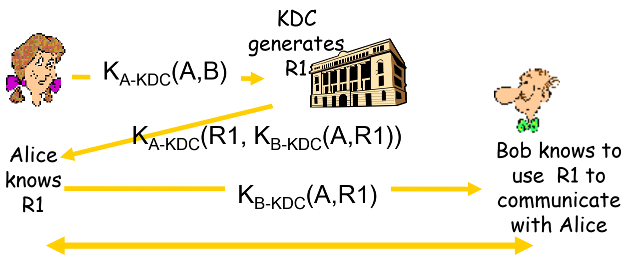
Secret Key Distribution: Key Distribution Center (KDC)

- KDC: server shares different secret key with *each* registered user (many users).
- Alice, Bob know own symmetric keys, $K_{A\text{-}KDC}$ $K_{B\text{-}KDC}$, for communicating with KDC.



Key Distribution using KDC

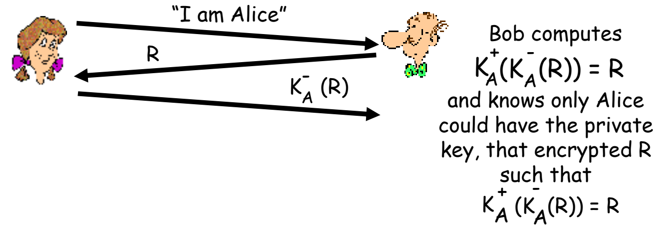
Q: How does KDC allow Bob, Alice to determine shared symmetric secret key to communicate with each other?



Alice and Bob communicate: using R1 as session key for shared symmetric encryption

Security Vulnerability with Public Key Distribution

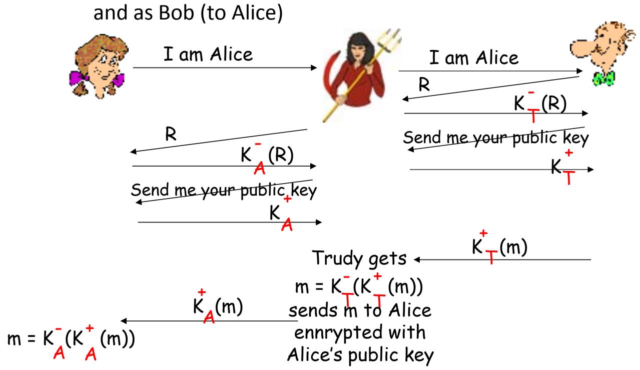
A case example for public key-based authentication.



What if Bob doesn't know Alice's public key ahead of time?

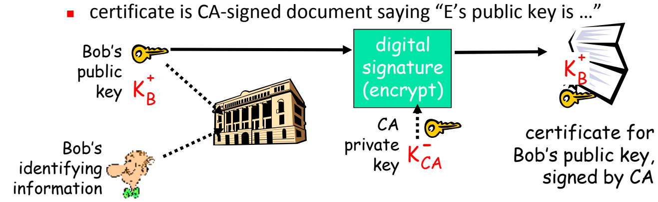
Security vulnerability when public keys are not well known

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



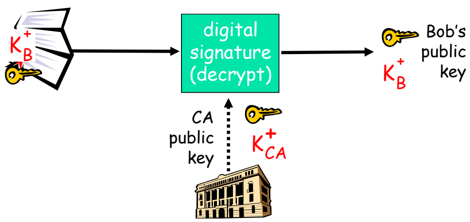
Public Key Distribution: Certification Authorities

- Certification authority (CA): trustable by everyone; every one knows its public key.
- E (person, router) registers its public key with CA.
  - E provides "proof of identity" to CA.
  - CA creates certificate binding E to its public key.
  - certificate is CA-signed document saying "E's public key is ..."



Certification Authorities (cont.)

When Alice wants to verify Bob's public key:
- gets Bob's certificate (Bob or elsewhere).
- apply CA's public key to Bob's certificate, verify Bob's public key.



Key Certification Methods

- Public key certificate signed by a certification authority
- Peer certification:
  - If A knows B personally, they can verify each other's public keys using offline means and sign them;
- Certificate chain leading to a certificate authority
  - CA signs A's public key certificate
  - A signs B's public key certificate
  - B signs C's public key certificate

Summary: Principles of Network Security

Cryptography:
- symmetric keys: protocols? weakness?
- public keys: protocol? weakness?

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)

Key distribution?

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