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Network Security Basics

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Importance of Network Security?

- Think about…
  - The most private, embarrassing or valuable piece of information you've ever stored on a computer
  - How much you rely on computer systems to be available when you need them
  - The degree to which you question whether a piece of email really came from the person listed in the From field
  - How convenient it is to be able to access private information online (e.g. buy without entering all data, look up your transcript without requesting a copy,…)

Importance of Network Security

- Society is becoming increasingly reliant on the correct and secure functioning of computer systems
  - Medical records, financial transactions, etc.
- It is our jobs as professional computer scientists:
  - To evaluate the systems we use to understand their weaknesses
  - To educate ourselves and others to be wise network consumers
  - To design networked systems that are secure

Types of attacks

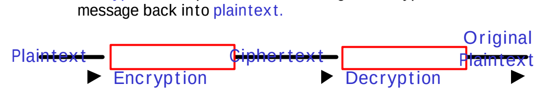
- What are we worried about?
- Passive:
  - **Interception**: attacks confidentiality.
    a.k.a., eavesdropping, "man-in-the-middle" attacks.
  - **Traffic Analysis:** attacks confidentiality, or anonymity.
    Can include traceback on a network, CRT radiation.
- Active:
  - **Interruption**: attacks availability.
    (a.k.a., denial-of-service attacks
  - **Modification**: attacks integrity.
  - **Fabrication**: attacks authenticity.

Fundamentals of Defense

- What can we do about it?
- Restricted Access
  - Restrict physical access, close network ports, isolate from the Internet, firewalls, NAT gateways, switched networks
- Monitoring
  - Know what normal is and watch for deviations
- Heterogeneity/Randomness
  - Variety of Implementations, Random sequence numbers, Random port numbers
- Cryptography……

Cryptography

- The most widely used tool for securing information and services is cryptography.
- Cryptography relies on ciphers: *mathematical functions used for encryption and decryption of a message.*
  - *Encryption*: the process of disguising a message in such a way as to hide its substance.
  - Ciphertext: an encrypted message
  - Decryption: the process of returning an encrypted message back into plaintext.



What makes a good cipher?

substitution cipher: substituting one thing for another

- monoalphabetic cipher: substitute one letter for another

```
    plaintext:  abcdefghijklmnopqrstuvwxyz

   ciphertext:  mnbvcxzasdfghjklpoiuytrewq
```

E.g.: **Plaintext: bob. i love you. alice**
ciphertext: nkn. s gktc wky. mgsbc

Q: How hard to break this simple cipher?:

- brute force (how hard?)
- other?

Ciphers

- The security of a cipher (like a substitution cipher) may rest in the secrecy of its *restricted* algorithm.
  - Whenever a user leaves a group, the algorithm must change.
  - Can't be scrutinized by people smarter than you.
  - But, secrecy is a popular approach :(
- Modern cryptography relies on secret *keys, a selected value from a large set (a keyspace),* e.g., a 1024-bit number. 2^{1024} values!
  - Security is based on secrecy of the key, not the details of the algorithm.
  - Change of authorized participants requires only a change in key.

Keys: Symmetric vs Assymetric

- The most common cryptographic tools are
  - Symmetric key ciphers
    - Use same key to encrypt and decrypt
    - One key shared and kept secret
    - DES, 3DES, AES, Blowfish, Twofish, IDEA
    - Fast and simple (based on addition, masks, and shifts)
    - Typical key lengths are 40, 128, 256, 512
  - Asymmetric key ciphers
    - Pair of keys: one encrypts and another decrpyts
    - One key (the private key) must be kept secret; the other key (the public key) can be freely disclosed
    - RSA, El Gamal
    - Slow, but versatile (usually requires exponentiation)
    - Typical key lengths are 512, 1024, 2048

Session Keys

- Symmetric key algorithms are faster than asymmetric key algorithms
- Often asymmetric key cryptography used to exchange a shared secret key
- This key called a symmetric session key is then used to encrypt this conversation with symmetric key cryptograhy
- Each new conversation would use a different session key
- Other benefits (In addition to efficiency)
  - session keys also reduce the key exposure or amount of encrypted text that could be collected to aid in analysis
  - If session key compromised only get info in the last session

Symmetric key crypto: DES

DES: Data Encryption Standard

- US encryption standard [NIST 1993]
- 56-bit symmetric key, 64 bit plaintext input
  - initial permutation
  - 16 identical "rounds" of function application, each using different 48 bits of key
  - final permutation
- How secure is DES?
  - DES Challenge: 56-bit-key-encrypted phrase decrypted (brute force) in a little over 22 hours (1999 DES Challenge III)
  - no known "backdoor" decryption approach
- making DES more secure
  - use three keys sequentially (3-DES) on each datum
  - use cipher-block chaining

Public key encryption algorithms

Two inter-related requirements:

1. need a decryption function d_B ( ) and an encryption function e_B ( ) such that

$d_B(e_B(m)) = m$ $e_B(d_B(m)) = m$

2. need public and private keys for d_B ( ) and e_B ( )

RSA

- Ronald L. Rivest, Adi Shamir and Leonard M. Adleman
  - Won 2002 Turing award for this work!
- Want a function e_B that is easy to do, but hard to undo without a special decryption key
- Based on the difficulty of factoring large numbers (especially ones that have only large prime factors)

RSA in a nutshell

1. Choose two large prime numbers p, q. (e.g., 1024 bits each)
2. Compute $n = pq$, $z = (p-1)(q-1)$
3. Choose e (with $e < n$) that has no common factors with z. (e, z are "relatively prime").
4. Choose d such that $ed-1$ is exactly divisible by z. (in other words: $ed \bmod z = 1$).
5. *Public* key is (n,e). *Private* key is (n,d).

Why? (Will hint at)
How? (Won't discuss)

RSA: Encryption, decryption

0. Given (n,e) and (n,d) as computed above
1. To encrypt bit pattern (message), m, compute
   $c = m^e \bmod n$ (i.e., remainder when m^e is divided by n)
2. To decrypt received bit pattern, c, compute
   $m = c^d \bmod n$ (i.e., remainder when c^d is divided by n)

Magic happens! $m = (m^e \bmod n)^d \bmod n$

RSA: small example

Bob chooses $p=5$, $q=7$. Then $n=35$, $z=24$.
$e=5$ (so e, z relatively prime).
$d=29$ (so $ed-1$ exactly divisible by z.

	letter	m	m^e	$c = m^e \bmod n$
encrypt:	l	12	1524832	17

	c	c^d	$m = c^d \bmod n$	letter
decrypt:	17	481968572106750915091411825223072000	12	l

RSA: Why? $m = (m^e)^d \bmod n$

Number theory result: If p,q prime, $n = pq$, then

$$x^y \bmod n = x^{y \bmod (p-1)(q-1)} \bmod n$$

$$(m^e)^d \bmod n = m^{ed} \bmod n$$

$$= m^{ed \bmod (p-1)(q-1)} \bmod n$$

(using number theory result above)

$$= m^1 \bmod n$$

(since we chose ed to be divisible by $(p-1)(q-1)$ with remainder 1)

$$= m$$

If it were easy to factor n into p and q then we would be in trouble!

Reversible

- What the private key encrypts the public key decrypts
- What the public key encrypts the private key decrypts

Practical matters

- Big primes like 5 and 7 (☺) already generated big numbers like 481968572106750915091411825223072000
  - What would happen with 1024 bit keys?
  - Costly operations!
- Finding big primes?

Storing your keys

- For both symmetric and asymmetric cryptography how do you store the keys?
  - Typical key lengths are 512, 1024, 2048
- Can't exactly memorize it
- Ok to store in on your computer? In a shared file system? No!
- Normally stored in a file encrypted with a pass phrase
- Pass phrase != your key

Using Cryptography

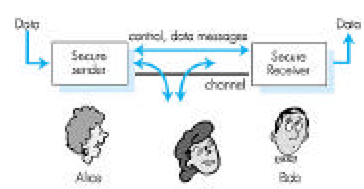
Uses of Cryptography

- Secrecy/Confidentiality : ensuring information is accessible only by authorized persons
  - Traditionally, the primary objective of cryptography.
  - E.g. encrypting a message
- Authentication : corroboration of the identity of an entity
  - allows receivers of a message to identify its origin
  - makes it difficult for third parties to masquerade as someone else
  - e.g., your driver's license and photo authenticates your image to a name, address, and birth date.

Uses of Cryptography

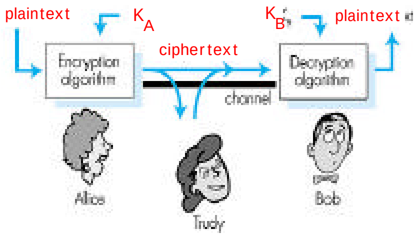
- Integrity : ensuring information has not been altered by unauthorized or unknown means
  - Integrity makes it difficult for a third party to substitute one message for another.
  - It allows the recipient of a message to verify it has not been modified in transit.
- Nonrepudiation : preventing the denial of previous commitments or actions
  - makes it difficult for the originator of a message to falsely deny later that they were the party that sent the message.
  - E.g., your signature on a document.

Friends and enemies: Alice, Bob, Trudy



- well-known in network security world
- Bob, Alice want to communicate "securely"
- Trudy, the "intruder" may intercept, delete, add messages

The language of cryptography



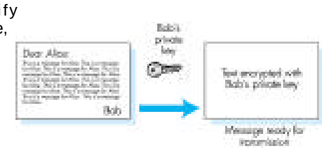
Digital Signatures

Cryptographic technique analogous to hand-written signatures.

- Sender (Bob) digitally signs document, establishing he is document owner/creator.
- Verifiable, nonforgeable: recipient (Alice) can verify that Bob, and no one else, signed document.

Simple digital signature for message m:

- Bob encrypts m with his private key d_B, creating signed message, $d_B(m)$.
- Bob sends m and $d_B(m)$ to Alice.



Digital Signatures (more)

- Suppose Alice receives msg *m*, and digital signature $d_B(m)$
- Alice verifies *m* signed by Bob by applying Bob's public key e_B to $d_B(m)$ then checks $e_B(d_B(m)) = m$.
- If $e_B(d_B(m)) = m$, whoever signed *m* must have used Bob's private key.

Alice thus verifies that:

- Bob signed *m*.
- No one else signed *m*.
- Bob signed m and not *m'*.

Non-repudiation:

- Alice can take *m*, and signature $d_B(m)$ to court and prove that Bob signed *m*.

Message Digests

Computationally expensive to public-key-encrypt long messages

Goal: fixed-length,easy to compute digital signature, "fingerprint"

- apply hash function H to *m*, get fixed size message digest, *H(m)*.

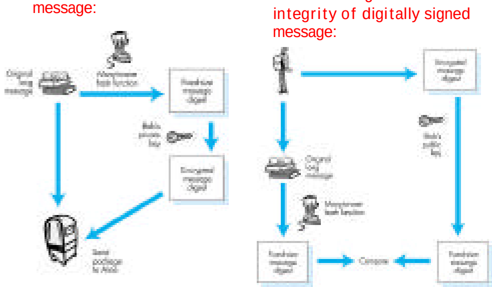
Hash function properties:

- Many-to-1
- Produces fixed-size msg digest (fingerprint)
- Given message digest x, computationally infeasible to find m such that x = H(m)
- computationally infeasible to find any two messages m and m' such that H(m) = H(m').

Digital signature = Signed message digest

Bob sends digitally signed message:

Alice verifies signature and integrity of digitally signed message:



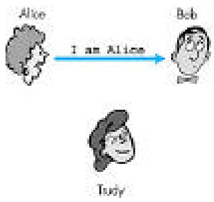
Hash Function Algorithms

- Internet checksum would make a poor message digest.
  - Too easy to find two messages with same checksum.
- MD5 hash function widely used.
  - Computes 128-bit message digest in 4-step process.
  - arbitrary 128-bit string x, appears difficult to construct msg m whose MD5 hash is equal to x.
- SHA-1 is also used.
  - US standard
  - 160-bit message digest

Authentication

Goal: Bob wants Alice to “prove” her identity to him

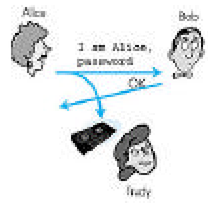
Protocol ap1.0: Alice says “I am Alice”



Failure scenario??

Authentication: another try

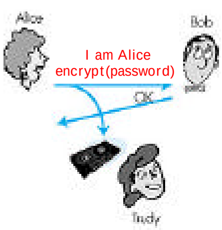
Protocol ap3.0: Alice says “I am Alice” and sends her secret password to “prove” it.



Failure scenario?

Authentication: yet another try

Protocol ap3.1: Alice says “I am Alice” and sends her *encrypted* secret password to “prove” it.



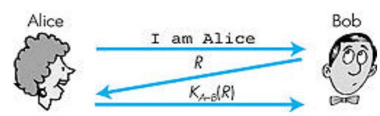
Failure scenario?
Trudy can’t decrypt password
But can still replay it

ap4.0: Authentication: yet another try

Goal: avoid playback attack

Nonce: number (R) used onlyonce in a lifetime

ap4.0: to prove Alice “live”, Bob sends Alice nonce, R. Alice must return R, encrypted with shared secret key

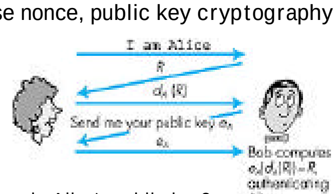


Failures, drawbacks?

Authentication: ap5.0

ap4.0 requires shared symmetric key
- problem: how do Bob, Alice agree on key?
- are public key techniques any better?

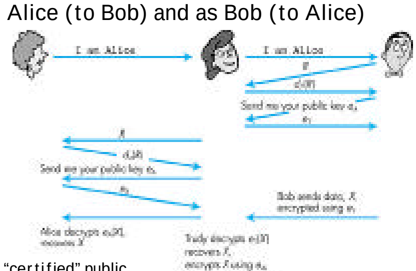
ap5.0: use nonce, public key cryptography



What proves e_A is Alice’s public key?

ap5.0: security hole

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



Need “certified” public keys

Trusted Intermediaries

Problem:
- How do two entities establish shared secret key over network?

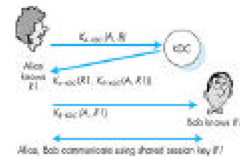
Solution:
- trusted key distribution center (KDC) acting as intermediary between entities

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?

Solution:
- trusted certification authority (CA)

Key Distribution Center (KDC)

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



- Alice communicates with KDC, gets session key R1, and $K_{B\text{-}KDC}(A,R1)$
- Alice sends Bob $K_{B\text{-}KDC}(A,R1)$, Bob extracts R1
- Alice, Bob now share the symmetric key R1.

Certification Authorities

- Certification authority (CA) binds public key to particular entity.
- Entity (person, router, etc.) can register its public key with CA.
  - Entity provides "proof of identity" to CA.
  - CA creates certificate binding entity to public key.
  - Certificate digitally signed by CA.
  - Public key of CA can be universally known (on billboard, embedded in software) - unless have to change because private key compromised

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

Establishing Trust

- Is the problem of establishing "trust" with a key authority or certification authority the same as establishing "trust" with anyone else?
  - Private Key: How do you agree on a shared secret key with the key authority?
  - Public Key: CA can put their public key on a bulletin board but how do you convince them that your public key really is your public key?
- Problem is the same!!
  - Use out of band means
- BUT!!!! Once you establish trust with them you can use that to bootstrap trust with others