Security Engineering
Fall 2015

Lecture 11 – Cryptography

(or 2000 years in 2 hours)

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Agenda

- ***Topic***
  - Introduction
  - Symmetric key cryptography
  - Hash (one-way) functions
  - Public key cryptography
  - Digital signatures
  - Authentication – key establishment
- ***Disclaimer***
  - This is a quick summary to provide an introduction to people who have no crypto background. For the real thing attend the Crypto course.

Terminology

- ***Cryptography***
  - the science of designing methods "secret writing".
- ***Cryptanalysis***
  - The science of methods for analysing and breaking ciphers.
- ***Cryptology = cryptography & cryptanalysis.***
- ***Cryptography today***
  - the study of mathematical techniques related to aspects of information security, such as confidentiality, data integrity, entity authentication, and data origin authentication.
- ***Why do we need it?***

Why do we need cryptgrpahy?

- ***Because we want to talk over a channel that only process bits***
- ***Do bits have colors?***
  - Alice sends Bob a stream of "green" bits b1…bn
  - Charlie sends Bob the same stream of "red" bits.
  - If bits had colors Alice could tell them apart
- ***Are bits invisible?***
  - Alice sends Bob a stream of "invisible" bits b1..bn
  - Charlie can read the stream b1…bn
  - If bits were invisible only Bob could read them

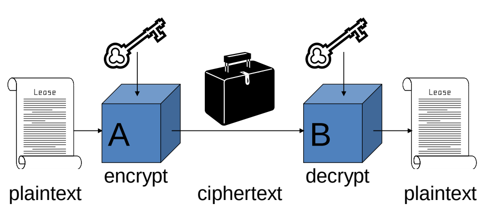
Security services

- ***Data confidentiality*: *encryption* hides the content of messages.**
- ***Data integrity*: integrity check functions (*hash functions*) detect changes to documents.**
- ***Data origin authentication*: *digital signatures* and *message authentication codes* verify the source and integrity of documents**
- ***More services may mean authentication against a third party vs authentication for yourself only***

Encryption

- ***Encryption algorithms (ciphers) protect the confidentiality of data.***
  - Some (but not all) encryption algorithms can also be used for integrity checks.
- ***A plaintext (clear text) x is converted into a ciphertext eK(x) under the control of a key K.***
- ***Decryption with an appropriate key K' computes the plaintext from the ciphertext dK'(eK(x))=x***
- ***Properties***
  - If you don't know K' the message should look random.
  - Relation between K and K' determines type of crypto

Symmetric key encryption



Symmetric Key Cryptography

- ***Properties***
  - Symmetric ciphers (secret key cryptography): same key used for encryption & decryption.
  - Encryption protects documents on the way fromAtoB.
  - A and B have to share a key and keep their keys secret.
  - A procedure is required for A and B to obtain their shared key.
  - For n parties to communicate directly, about n^2keys are needed.
- ***Example***
  - SWIFT (the network used for international bank transfers) use symmetric keys to encrypt data in transit
  - Long ago people with a suitcase full of key material (a tape) had to physically bring the key material across the world.

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Block ciphers & stream ciphers

- ***Block ciphers: encrypt sequences of "long" data blocks without changing the key.***
  - Security relies on design of encryption function.
  - Typical block length: 64 bits, 128 bits.
- ***Stream ciphers: encrypt sequences of "short" data blocks under a changing key stream.***
  - Security relies on design of key stream generator.
  - Encryption can be quite simple, e.g. XOR.
  - Typical block length: 1 bit, 1 byte, 8-bit word
- ***Typical usage***
  - Stream cipher → streaming data (eg phone conversation)
  - Block cipher → data at rest (eg image)

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One time pad

- ***Very simple algorithm***
  - Given a streaming sequence of N message bits p_i
  - Take a sequence of N truly random bits k_i
  - To encrypt → c_i=k_i xor m_i
  - Decrypt → m_i = m_i xor k_1
- ***Properties***
  - Perfect confidentiality in information theoretic sense
    - BUT only if you use the key only ONCE
  - Zero integrity protection
    - (so good only if integrity protected otherwise)
  - Hugely expensive: truly random sequence are difficult to generate

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Sorry man, I have a 1GB file…

- ***If your file is large and your block ciphers only do 128B how do you do encrypt the whole?***
  - "chain" the result of the first encryption to encrypt the data of the second and so on
  - Basically generalize the idea of the one-time pad
- ***Key-only chaining (stream ciphers style)***
  - K_i+1 = enc(K,K_i)
- ***Text and Key chaining (many variants)***
  - C_i+1 = P_i+1 xor enc(K,C_i)
- ***Advantage:***
  - if touch a bit decryption fails → can spot manipulation
- ***Disadvantage:***
  - if you touch a bit decryption fails → can't recover the plaintex

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Block Ciphers

- ***Algorithms: AES (Rijndael), DES, 3DES, …***
- ***Typical block sizes: 64, 128, 256 bits.***
- ***No provable security.***
- ***Algorithms designed to resist known attacks: e.g. differential & linear cryptanalysis.***
- ***Recommended key length: 80-90 bits.***
- ***DES: 56-bit keys vulnerable to brute-force key search.***

Key Size (bits)	Number of Alternative Keys	Time Required at 1 Decryption/μs	Time Required at 10^6 Decryptions/μs
32	$2^{32} = 4.3 \times 10^9$	$2^{31}\ \mu s = 35.8$ minutes	2.15 milliseconds
56	$2^{56} = 7.2 \times 10^{16}$	$2^{55}\ \mu s = 1142$ years	10.01 hours
128	$2^{128} = 3.4 \times 10^{38}$	$2^{127}\ \mu s = 5.4 \times 10^{24}$ years	5.4×10^{18} years
168	$2^{168} = 3.7 \times 10^{50}$	$2^{167}\ \mu s = 5.9 \times 10^{36}$ years	5.9×10^{30} years
26 characters (permutation)	$26! = 4 \times 10^{26}$	$2 \times 10^{26}\ \mu s = 6.4 \times 10^{12}$ years	6.4×10^6 years

Cryptographic hash functions

- ***Cryptographic hash functions are used for integrity checks.***
- ***Apply a hash function h to a document x and store the result h(x) in a secure place.***
- ***The result h(x) is called "hash value", "message digest", or "checksum".***
- ***Changes to x detected by re-computing the hash of x and comparing the result with the stored value.***

Security properties

- ***Ease of computation: it is easy to compute h(x).***
- ***Compression: the hash function maps inputs of arbitrary length to fixed length results.***
- ***Pre-image resistance (one-way): given y, it is computationally infeasible to find x so that h(x)=y.***
- ***More properties***
  - weak collision resistance
    - computationally infeasible given x to find $y \neq x$ such that $H(y) = H(x)$
  - strong collision resistance
    - computationally infeasible to find any pair (x, y) such that $H(x) = H(y)$
- ***Many hash functions: SHA,RIPEMD-160, MD5 (dubious)***
- ***As of now no proof that they always work***
  - *Actually their existence is at the core of P vs NP question*

Message authentication codes

- ***Hash functions do not need keys.***
- ***For integrity checks, hash values have to be protected: keys for cryptographic protection.***
- ***Message authentication code (MAC): keyed hash function for data origin authentication.***
- ***HMAC construction: take a hash function h, for a key kand a document x, compute***
- ***$HMAC(x) = h(k||p_1||h(k||p_2||x)$***

(p_1, p_2 are padding fields, || is concatentation)

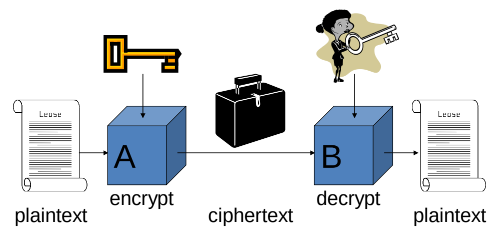
Back to square one?

- ***Symmetric key encryption:***
  - sender and receiver have to share a key.
- ***Keyed Hash:***
  - sender and receiver have to share a key
- ***To send a secret message from A to B, or to verify the integrity of a message from A to B we have to get a secret key to A and B first.***
  - To solve the problem of sending secret messages, we have to solve the problem of sending secret keys.
- ***Are we moving in circles?***

Public key encryption

- ***Proposed in the open literature by Diffie & Hellman in 1976.***
  - Arguably invented by British Secret Service some year earlier
- ***Each party has a public encryption key and a private decryption key.***
- ***Computing the private key from the public key should be computationally infeasible.***
- ***The public key need not be kept secret but it is not necessarily known to everyone.***
- ***There exist applications where access to public keys is restricted.***

Encryption with public keys



Basic idea

Protocol for A

- ***A and B share off line***
  - common parameters Pab
- ***A computes***
  - random number Xa
- ***A sends***
  - 1-way-A(Pab,Xa)
- ***A computes***
  - Combine-A(1-way-B(Pab,Xb),Xa)
- ***If the math commutes A and B share a secret***

Protocol for B

- ***A and B share off line***
  - common parameters Pab
- ***B computes***
  - random number Xb
- ***B sends***
  - 1-way-B(Pab,Xb)
- ***B computes***
  - Combine-B(1-way-A(Pab,Xa),Xb)
- ***If the math commutes A and B share a secret***

Diffie Hellman

- ***Based on the discrete log problem***
- ***Given***
  - p is prime number
  - g is a primitive root of p (generator)
    - powers of g generate all integers from 1 to p-1
  - m any integer < p
- ***Compute discrete logarithm a***
  - $m = g^a \bmod p$ for $0 \le l \le p-1$
- ***Computationally untractable (as of now)***
- ***However something commutes***
  - $(g^a)^b=(g^b)^a$

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Diffie-Hellman Example

- ***Have***
  - prime number q = 353
  - primitive root g = 3
- ***A and B each compute their private secrete (Xa,Xb) and public keys (Ya,Yb)***
  - A computes Ya = 3^{97}mod 353 = 397 mod 353 = 40
  - B computes Yb = 3^{233}mod 353 = 3233 mod 353 = 248
- ***then exchange (Ya,Yb) and compute shared secret***
  - for A: K = $(Yb)^{Xa}$ mod 353 = 24897 mod 353 = 160
  - for B: K = $(Ya)^{Xb}$ mod 353 = 40233 mod 353 = 160
  - Math (modulo p): $(Yb)^{Xa} = (g^{Xb})^{Xa} = g^{Xb*Xa} =(g^{Xa})^{Xb} =(Ya)^{Xb}$
- ***attacker must***
  - Solve 3^X mod 353 = 40 to find Y which is hard
  - desired answer is 97, then compute key as B does

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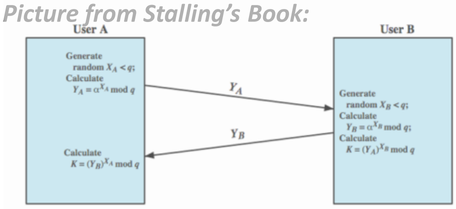
Key Exchange Protocols

- *Picture from Stalling's Book:*



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Some complications…

- ***What if messages can be changed in transit?***
- ***How do you beat a Chess Master?***
  - Have another chess master playing against him
- ***DH can be attacked because it only guarantee confidentiality but not integrity***
- ***Attack***
  - A send YA to B and C intercepts it
  - C sends YC to B claiming to be A
  - B sends YB to A and C intercepts it
  - C sends YC to B claiming to be B
  - What has A? What has B? What has C?

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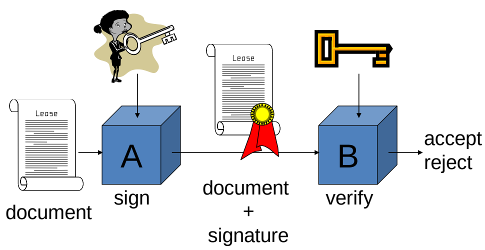
Digital signature mechanisms

- ***Used for non-repudiation, origin authentication and data integrity services.***
- ***Used in some authentication exchange mechanisms.***
- ***Digital signature mechanisms have three components:***
  - key generation
  - signing procedure (private)
  - verification procedure (public)

Digital signatures



Digital Signatures

- ***A* has a *public verification key* and a *private signature key*(→ public key cryptography).**
- ***A* uses her private key to compute her signature on document *m*.**
- ***B* uses a public verification key to check the signature on a document *m* he receives.**
- ***At this technical level, digital signatures are a cryptographic mechanism for associating documents with verification keys.***

Digital Signatures continued

- ***To get an authentication service that links a document to A's name (identity) and not just a verification key, we require a procedure for B to get an authentic copy of A'spublic key.***
- ***Only then do we have a service that proves the authenticity of documents 'signed by A'.***
- ***Yet even such a service does not provide non-repudiation at the level of persons.***

Electronic signatures

- ***Digital signatures: mathematical evidence linking a document to a public key.***
- ***Electronic signatures: a security service for associating documents with legal persons.***
- ***The link between a public key and a person has to be established by procedural means.***
- ***This link can be recorded in a certificate.***
- ***Certificates are not necessary for verifying digital signatures, verification keys are.***

Certificates

- ***How do you get a verification key?***
  - Public key cryptosystems often assume there is a public directory of user names and keys.
  - But a "Global PK directory" does not exists
- ***Kohnfelder [1978]: implement the directory as a set of digitally signed data records containing a name and a public key; he coined the term certificate for these records.***
- ***Today: a certificate is a signed document binding a subject to other information; subjects can be people, keys, names, …***

Certification Authorities

- ***Certificates are signed by an Issuer.***
- ***Certification Authority (CA) is just another name for Issuer.***
- ***Sometimes CA is used more narrowly for organizations issuing ID certificates [PKIX].***
- ***The application determines the technical and procedural 'trust' requirements a CA has to meet.***
- ***Sometimes Trusted Third Party (TTP) is used as a synonym for CA.***

Public Key Infrastructures

- ***The protocols, services and standards that facilitate the use of public-key cryptography by allowing the secure distribution of public keys between communicating parties.***
- ***PKI standards: X.509 [ISO/IEC 9594-8], PKIX [RFC 2459], PKCS.***
- ***X.509 certificates were intended to bind public keys [originally passwords] to X.500 path names (Distinguished Names) who has permission to modify X.500 directory nodes.***

X.509 certificates

- ***User certificate (public key certificate, certificate): the public key of a user, together with some information, rendered unforgeable by encipherment with the secret key of the certification authority which issued it.***
- ***Attribute certificate: a set of attributes of a user together with some other information, digitally signed under the private key of the CA.***
- ***Certification authority: an authority trusted by one or more users to create and assign certificates.***

X.509v3 certificate format

version (v3)
serial number
signature algorithm id
issuer name
validity period
subject name
subject public key info
issuer unique identifier
subject unique identifier
extensions

Extensions: added to increase flexibility.

Critical extensions: if a critical extension cannot be processed, the certificate must be rejected.

Critical extensions are also used to standardize policy.

extensionID
critical: YES/NO
extensionValue

Revocation

- ***Certificates may have to be revoked***
  - if a corresponding private key is compromised.
  - if a fact the certificate vouches for no longer is valid.
- ***Certification Revocation Lists (CRLs):***
  - Distributed in regular intervals or on demand.
  - Make sense if on-line checks are not possible or too expensive.
- ***When on-line checks are feasible, certificate status can be queried on-line:***
  - Online Certificate Status Protocol – OCSP.
  - Positive lists in the German signature infrastructure.

Question….

- ***In order to verify a certificate you need a verification key.***
- – If you get a verification key from a certificate, how do you get a certificate?
- ***Ask a certificate server to send you a signed certificate***
- – How do you get the verification key to check the key that signed the certificate?
- ***Ask a certificate server to send you a signed certificate certifiying the certificate server…***
- – Spot a certain loop here?
- ***Need a root of trust***
- – How many people trust

How to bootstrap trust?

- ***Do you trust…***
  - TÜRKTRUST Bilgi İletişim ve Bilişim Güvenliği Hizmetleri A.Ş.
  - A-Trust Ges. f. Sicherheitssysteme im elektr. Datenverkehr GmbH
  - Go Daddy Root Certificate Authority - G2
  - CA 沃通根证书
  - XRamp Security Services Inc
- ***How many of you actually trusted in the last month…***
  - GeoTrust Universal CA

Oh man but I have still my 1GB…

- ***How do you sign a 1GB file?***
- ***The mathematician's correct answer***
  - I just use elliptic curve over a field of "1GB" instead of 512Bits
  - You'll die before the algorithm calculates that
- ***The computer scientist's hack***
  - Let m be very large
  - Compute hash(m) – now this is small
  - Compute sign(privK,hash(m))
  - If hash is broken → digital signature down the pipe

Sorry man, I also need encrypting my 1GB

- ***How do you encrypt a 1GB file?***
- ***The dumb CS hack***
  - Let m be very large
  - Compute hash(m) – now this is small
  - Compute enc(pubK,hash(m))
- ***The smart CS's hack***
  - Let m be very large
  - Generate a random symmetric key sessionK
  - Compute enc(sessionK,m), enc(pubK,sessionK)
  - Send both
  - If symmetric encryption broken → security broken

Key exchange and distribution

- ***Crypto transforms (communications) security problems into key management problems.***
- ***To use encryption, digital signatures, or MACs, the parties involved have to hold the "right" cryptographic keys.***
- ***With public key algorithms, parties need authentic public keys.***
- ***With symmetric key algorithms, parties need shared secret keys.***

Key usage

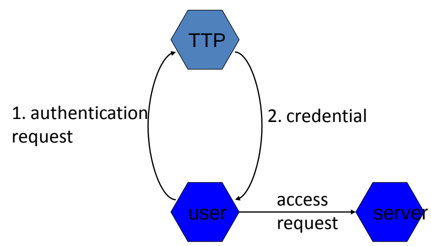
- ***It is good cryptographic practice to restrict the use of keys to a specific purpose.***
- ***In key management, we may use key encrypting keys and data encrypting keys.***
- ***Examples for key usages:***

  Encryption Decryption
  Signature Non-repudiation
  Master key Transaction key …
- ***With RSA, don't use a single key pair both for encryption and for digital signatures.***

Key establishment & TTPs

- ***In a protocol like TLS where key authentication is based on digital signatures, we may need a Trusted Third Party (TTP) to vouch for the authenticity of verification keys.***
- ***In a protocol where authentication is based on symmetric cryptographic algorithms, a TTP may serve as a key distribution centre (KDC) supplying parties with session keys.***

Key distribution



Key distribution

- ***Advantage: scalability – a single authentication server can support many servers and users.***
- ***The credential tells the server that the user has been authenticated.***
- ***The credential could contain a session key to be shared between user and server so that the server can authenticate further requests.***
- ***The TTP would also serve as Key Distribution Centre (KDC).***

Kerberos

- ***Kerberos was developed at MIT for user authentication in a distributed system.***
- ***The parties involved are client A, server B, and Kerberos authentication server (KAS) S.***
- ***Based on the Needham-Schroeder key establishment ("authentication")protocol: the server provides A and B with a session key.***
- ***Uses a symmetric encryption algorithm.***
- ***More of this in the network security lectures***

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Cryptographic keys

- *Most cryptographic algorithms take a **key** as one of their inputs.*
- ***Kerckhoffs' principle**: Do not rely on the secrecy of cryptographic algorithms; only the keys have to be kept secret.*
- ***State of the art: Standardized algorithms that have been examined quite intensively and are often the strongest part in a security architecture.***
- ***Good key management practices are required to reap the benefits of strong cryptography.***

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Key management questions

- ***Where are keys generated?***
- ***How are keys generated?***
- ***Where are keys stored?***
- ***How do they get there?***
- ***Where are the keys actually used?***
- ***How are keys revoked and replaced?***

- ***When keys are stored on a computer, cryptography relies on strong computer security.***
- ***If the keys are computer generated (and not truly random numbers) cryptography rely on strong random number generators***

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The DigiNotar CA Break

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The DigiNotar CA Break

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Resources

- ***Chapters 2,19, 20 and 21. Stallings & Brown. Computer Security Principles and Practice.***
- ***Chapter 14,15. Dieter Gollmann. Computer Security***
- ***Alfred Menezes, Paul van Oorschot, Scott Vanstone: Handbook of Applied Cryptography http://www.cacr.math.uwaterloo.ca/hac/***
- ***Bruce Schneier: Applied Cryptography***