

Lecture 4

Cryptography



Mobile Business II (SS 2023)

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Introduction

- Symmetric Cryptosystems
- Public Key Cryptography



Cryptographic Systems

- Intention
 - Confidentiality (secrecy of messages): encryption systems
 - Integrity (protection from undetected manipulation) and accountability: authentication systems and digital signature systems
- Key distribution
 - Symmetric:

Both partners have the same key.

- Asymmetric: Different (but related) keys for encryption and decryption
- In practice mostly hybrid systems



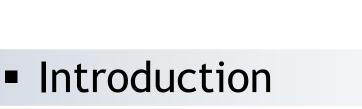


- Introduction
- Symmetric Cryptosystems
 - General Concept
 - Caesar Cipher
 - AES
 - Advantages and Problems
- Public Key Cryptography



Symmetric Encryption Systems

- Classical cryptosystems are usually based on symmetric encryption systems.
- Typical applications
 - confidential storage of user data
 - transfer of data between 2 users who negotiate a key via a secure channel
- Examples
 - Vernam-Code (one-time pad, Gilbert Vernam)
 - key length = length of the plaintext (information theoretically secure)
 - DES: Data Encryption Standard
 - key length 56 bit, so 2⁵⁶ different keys
 - AES: Advanced Encryption Standard (Rijndael, [NIST])
 - 3 alternatives for key length: 128, 192 und 256 bit

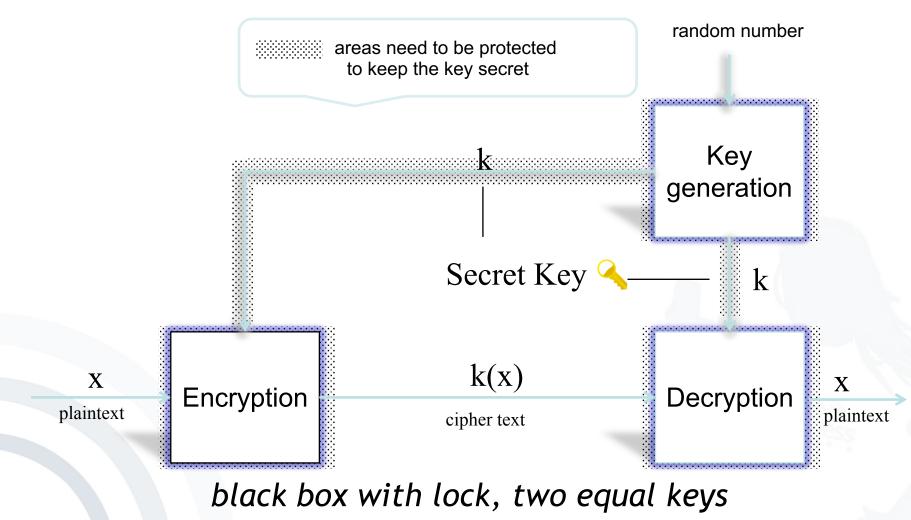


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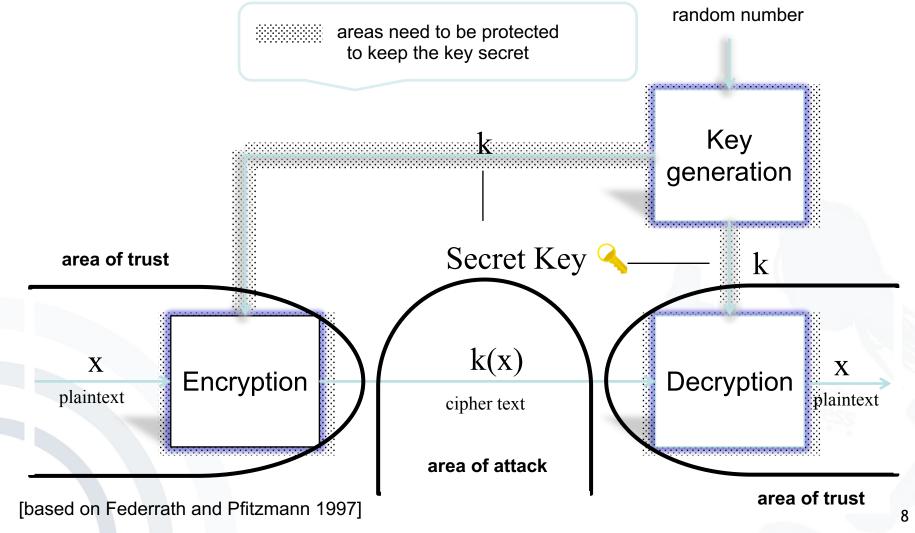


Symmetric Encryption Systems (1)



[based on Federrath and Pfitzmann 1997]

mobile Symmetric Encryption Systems (2)





- Keys have to be kept secret (secret key crypto system).
- It must not be possible to derive the plaintext or the used keys from the encrypted text (ideally encrypted text is not distinguishable from a numerical random sequence).
- Each key shall be equally probable.
- In principle each system with limited key length is breakable by testing all possible keys.
- Publication of encoding and decoding functions (algorithms) is considered as good style and is trust-building.
- Security of cryptosystems should base on the strength of chosen key lengths.

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Agenda

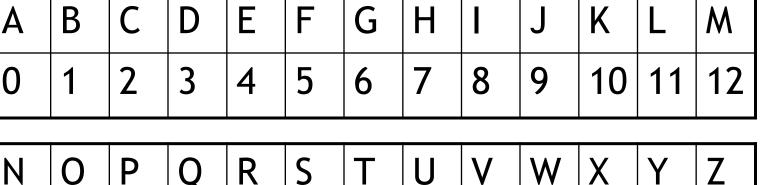
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Caesar Cipher



18 19 20 21 22 23 24 25

We assign a number for every character.

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This enables us to calculate with letters as if they were numbers.

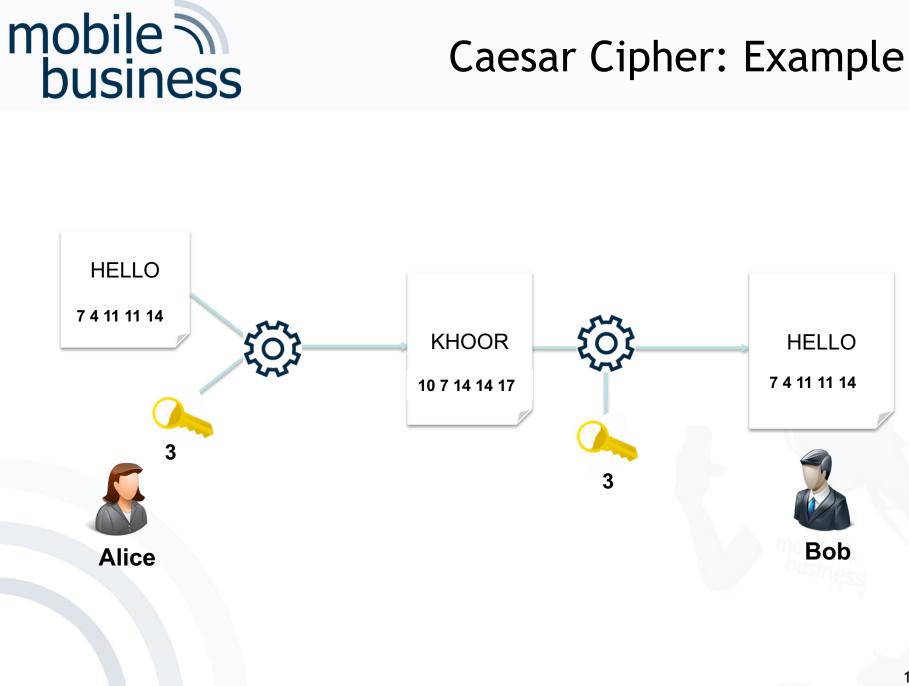
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- Very simple form of encryption.
- The encryption and decryption algorithms are very easy and fast to compute.
- It uses a very limited key space (n=26)
- Therefore, the encryption is very easy and fast to compromise.

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Advanced Encryption Standard

- The Data Encryption Standard (DES) was designed to encipher sensitive but not classified data.
- The standard has been issued in 1977.
- In 1998, a design for a computer system and software that could break any DES-enciphered message within a few days was published.
- By 1999, it was clear that the DES no longer provided the same level of security it had 10 years earlier, and the search was on for a new, stronger cipher.
- AES Rijndael was a winner of U.S. National Institute of Standards and Technology bid for advanced encryptions.
- AES has been approved for Secret or even Top Secret information by the NSA.

[Bishop 2005]

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Symmetric Encryption

Advantage: Algorithms are very fast

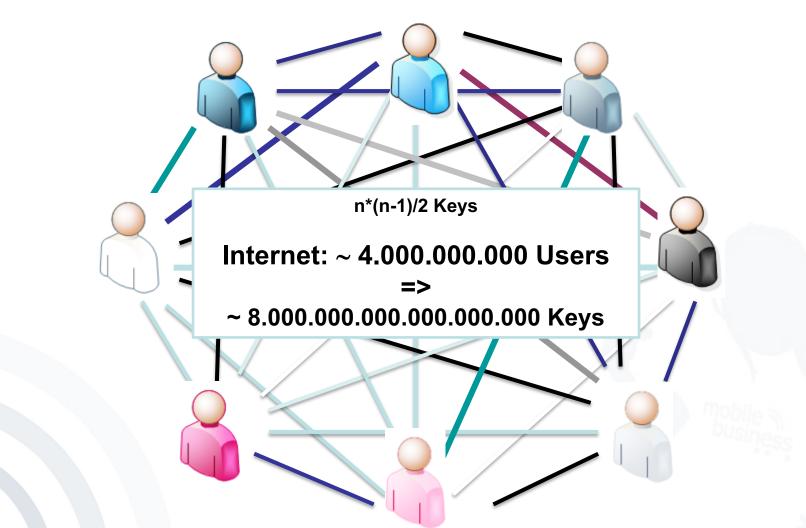
| Algorithm | Performance* | | |
|----------------|--------------|--|--|
| RC6 | 78 ms | | |
| SERPENT | 95 ms | | |
| IDEA | 170 ms | | |
| MARS | 80 ms | | |
| TWOFISH | 100 ms | | |
| DES-ede | 250 ms | | |
| RIJNDEAL (AES) | 65 ms | | |

* Encryption of 1 MB on a Pentium 2.8 GHz, using the FlexiProvider Java)

[J. Buchmann: Lecture Public Key Infrastrukturen, FG Theoretische Informatik, TU-Darmstadt]

Problems of Symmetric Cryptosystems: Key Exchange

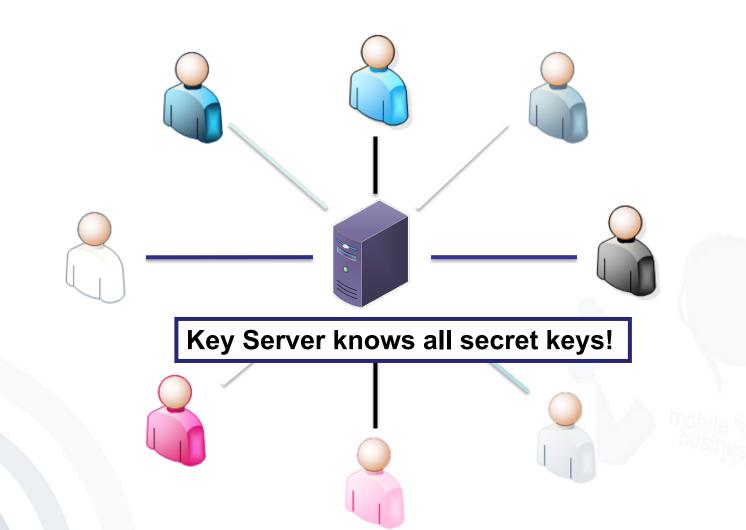




[adopted from J. Buchmann: Lecture Public Key Infrastrukturen, FG Theoretische Informatik, TU-Darmstadt]

Symmetric Encryption: A Possible Solution



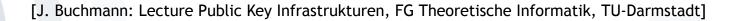


[J. Buchmann: Lecture Public Key Infrastrukturen, FG Theoretische Informatik, TU-Darmstadt]

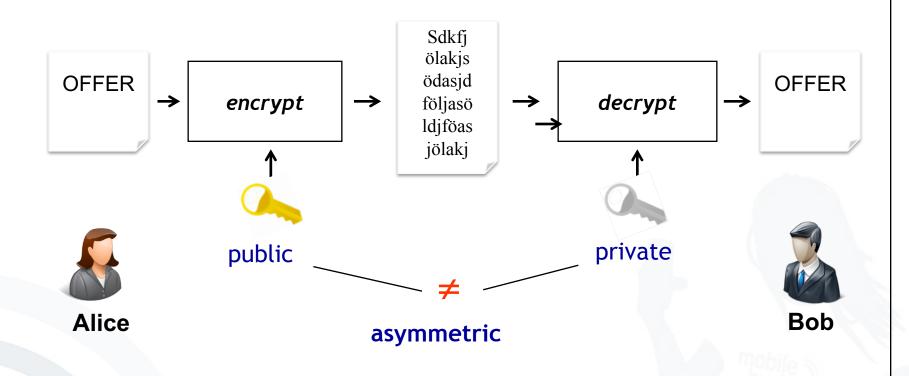


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 - Algorithms
 - Hybrid Systems
 - Digital Signature
 - Key Management
 - Example: PGP

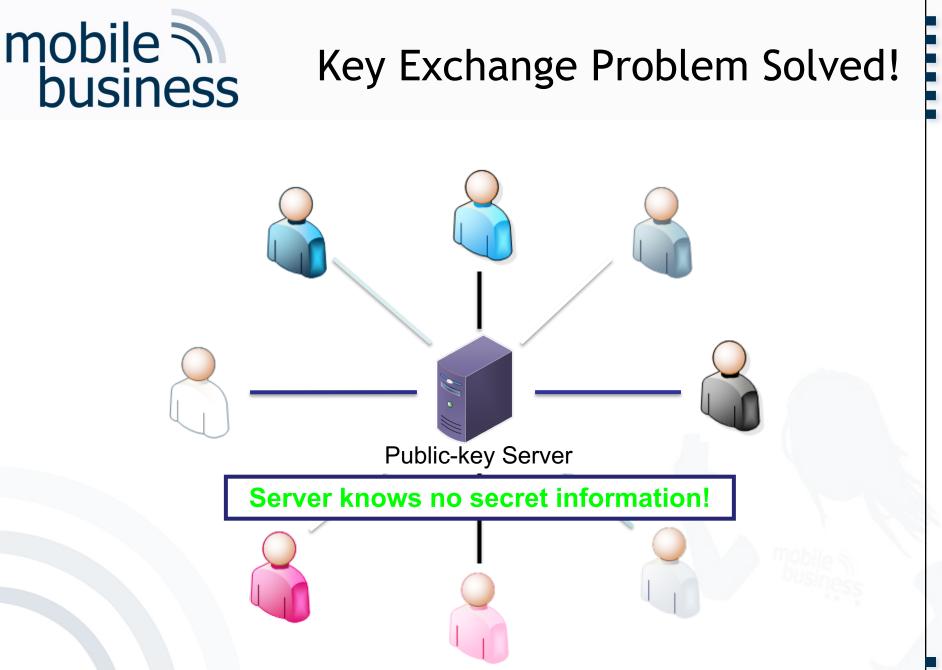




Public Key Encryption



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[J. Buchmann: Lecture Public Key Infrastrukturen, FG Theoretische Informatik, TU-Darmstadt]



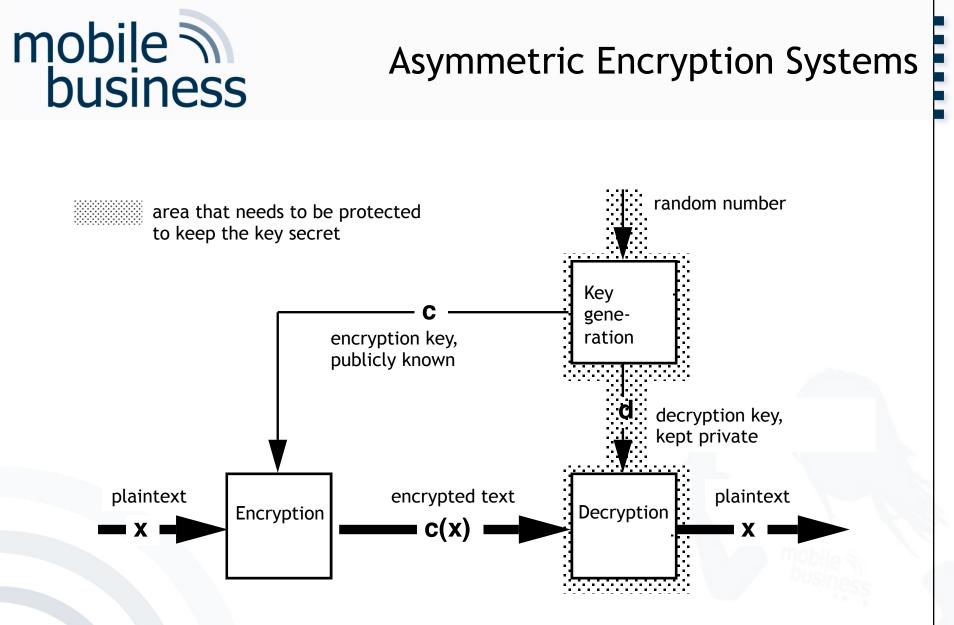
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Concept of Asymmetric Encryption Systems

- Public key systems are based on asymmetric encryption.
- Use of 'corresponding' key pairs instead of one key:
 - **Public key** is **solely** for encryption.
 - Encrypted text can only be decrypted with the corresponding private (undisclosed) key.
- Deriving the private key from the public key is hard (practically impossible).
- The public key can be distributed freely, even via insecure ways (e.g. directory (public key crypto system)).
- Messages are encrypted via the public key of the addressee.
- Only the addressee possesses the private key for decoding (and has to manage the relation between the private and the public key).



box with slot, access to messages only with a key





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Asymmetric Encryption Systems: Examples



RSA

- Rivest, Shamir, Adleman, 1978
- is based on the assumption that the factorization of the product of two (big) prime numbers (p*q) is "difficult" (product is basis for the keys)
- key lengths typically 1024 bit, today rather 2048

[Rivest et al., 1978]

Diffie-Hellman

- Diffie, Hellman, 1976, first patented algorithm with public keys
- allows the exchange of a secret key
- is based on the "difficulty" of calculating discrete logarithms in a finite field

[Diffie, Hellman, 1976]



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Performance of Public Key Algorithms

| Algorithm | Performance* | Performance compared to Symmetric encryption (AES) |
|-----------------|--------------|---|
| RSA (1024 bits) | 6.6 s | Factor 100 slower |
| RSA (2048 bits) | 11.8 s | Factor 180 slower |

Disadvantage: Complex operations with very big numbers

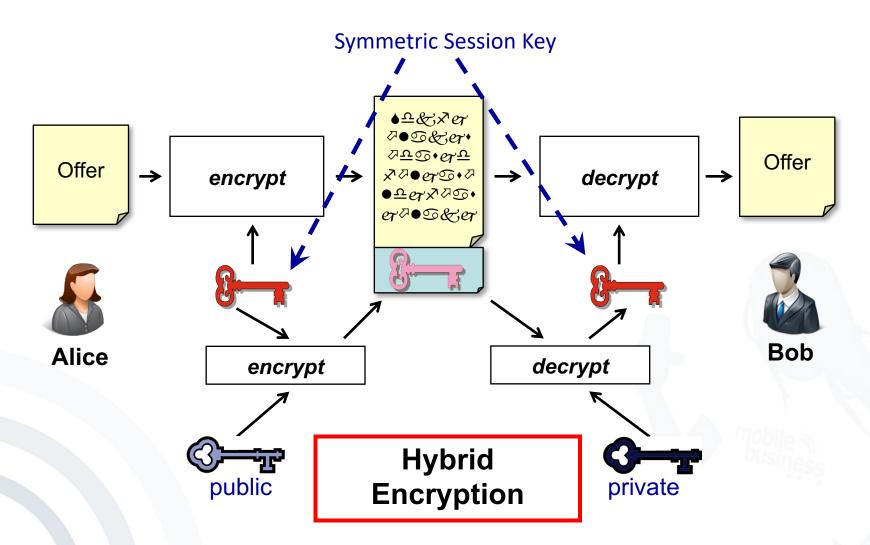
 \Rightarrow Algorithms are very slow.

* Encryption of 1 MB on a Pentium 2.8 GHz, using the FlexiProvider (Java)

[J. Buchmann: Lecture Public Key Infrastrukturen, FG Theoretische Informatik, TU-Darmstadt]



Solution: Hybrid Systems



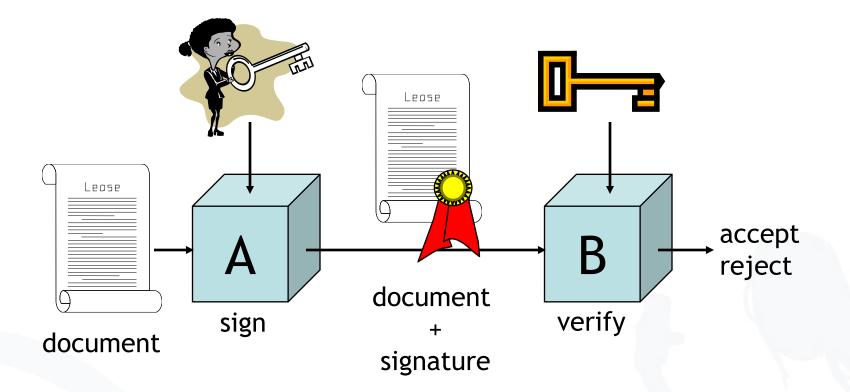
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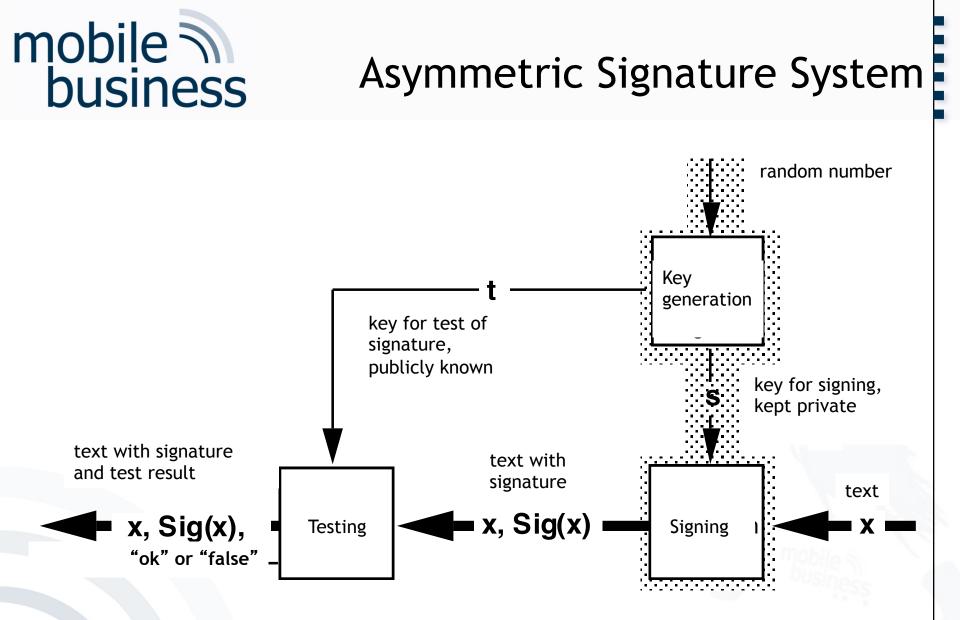
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Digital Signatures



- Protect the authenticity and integrity of documents signed by A
- \bigcirc B has to get an authentic copy of A' s public key.



Iocked glass show-case; just one key to put something in

Example PGP: Encrypt and Sign a Message

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Example PGP: Decrypt and Check a Message

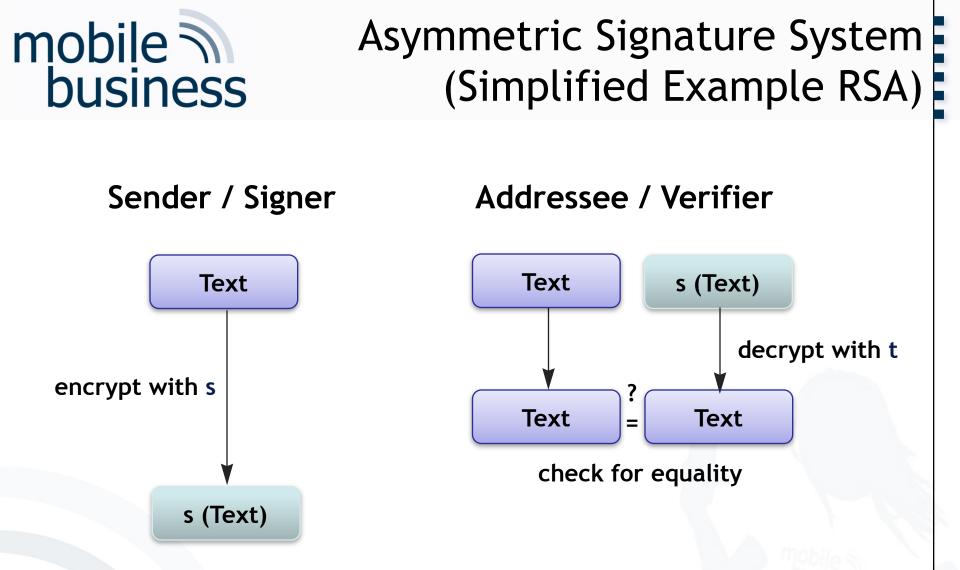
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| Version: PGP 8.0 - not licensed for comm | ercial use: www. | pgp | | | |
| | | 20222 | ssnagel <heiko.rossnagel@m-le< td=""><td></td><td></td></heiko.rossnagel@m-le<> | | |
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| B5TXKtUB8YJdpPnck61as78RBP1sq8VDrA1YopEA | eqMMw2pkBuoxyo3K | CIR | | | |
| Ag4DIYlowhVX6ZwQCAD2L9WAA97xEUBWMET6kR9n | 5+oafTBF+R01v6UO | 22T | | | |
| Alkh23iQOlI9Drye/uygpcQpT2HhTtZY1AjjudLv | i+GsegOlWmBjY8q8 | G1Y Enter pass | phrase for your private key : | | Hide Typing |
| kDP3GEanyDiDU6R9F1XFOvxPNMk6Ek8hH6qZ37hh | DNDCXkxkSjM3nJ2V | 'uuL | | | |
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| dfvQ3NiGrUEQsOHVxwjQdMtr8C09kREYLuAdD7j/ | O5WtsAdbAVMn72PY | FOI | | | |
| i77MitBfAbxXF0gFS7/b2LccbaK8fx6e1VNFnV07 | B/9qpd0Gg5WZVP2e | QA5: | | | |
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| END PGP MESSAGE **** Signed: | 26.02.2004 | 11:40:49 | | | |
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Asymmetric Signature Systems: Examples

- RSA: Rivest, Shamir, Adleman
 - Asymmetric encryption system which also can be used as a signature system via "inverted use",
 - Message encrypted with the private key (= signing key) gives the signature,
 - Decoding with the public key (=testing key) has to produce the message.

[Rivest et al. 1978]

- DSA: Digital Signature Algorithm
 - Determined in the Digital Signature Standard of the NIST (USA),
 - Based on discrete logarithms (Schnorr, ElGamal),
 - Key length is set to 1024 bit.



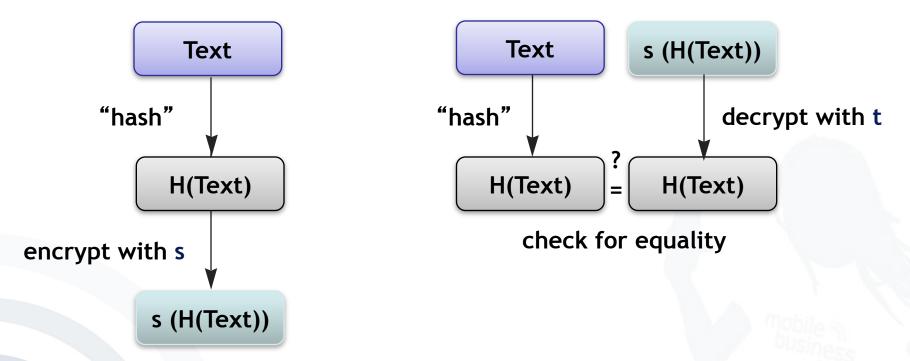
Signing key s only with the sender, test key t public
 Example is often mistakenly generalized.



Asymmetric Signature System (Example RSA)

Sender / Signer





Signing key s only with the sender, test key t public
 Example is often mistakenly generalized.



Hash Functions

- General hash functions (H(s))
 - Transformation of an input string s into an output string h of fixed length which is called hash value.
 - Example: mod 10 in the decimal system
- Cryptographic hash functions
 - Generally require further characteristics
 - H(s) is easily to compute for each s.
 - *H*(*s*) must be difficult to invert: In terms of figures it is difficult to compute *s* from *h*.
 - Virtual collision freedom: In terms of figures it is difficult to create collisions H(s1) = H(s2).
 - Examples: SHA-1, MD5, MD4



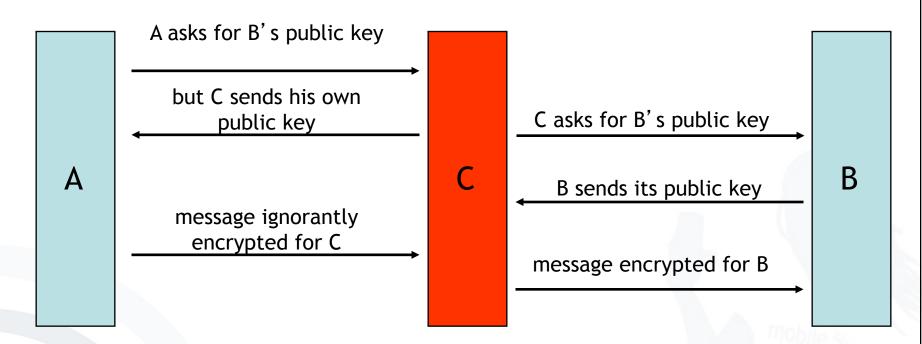
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"Man in the middle attack"



Keys are certified: a 3rd person/institution confirms (with its digital signature) the affiliation of the public key to a person.

Certification of Public Keys (1)

- **B** can freely distribute his own public key.
- But: Everybody (e.g. C) could distribute a public key and claim that this one belongs to B.
- If A uses this key to send a message to B, C will be able to read this message!

Thus:

How can **A** decide if a public key was really created and distributed by **B** without asking **B** directly?

- Keys get certified, i.e. a third person/institution confirms with its (digital) signature the affiliation of a public key to entity B.
- Public Key Infrastructures (PKIs)

Certification of Public Keys (2)

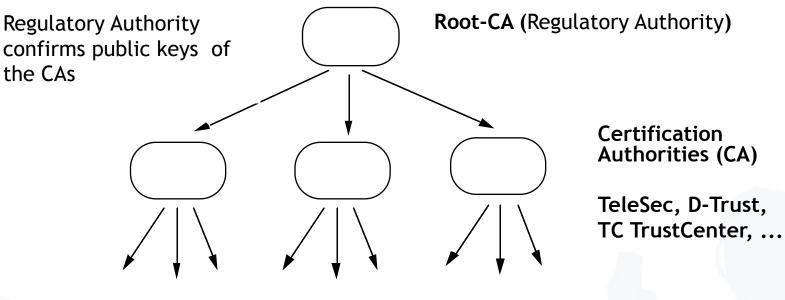
Three types of organization for certification systems (PKIs?):

- Central certification authority (CA)
 - A single CA, keys often integrated in checking software
 - Example: older versions of Netscape (CA = Verisign)
- Hierarchical certification system
 - CAs which in turn are certified by "higher" CA
 - Examples: PEM, Teletrust, infrastructure according to Signature Law
- Web of Trust
 - Each owner of a key may serve as a CA
 - Users have to assess certificates on their own
 - Example: PGP (but with hierarchical overlay system)



Hierarchical Certification of Public Keys

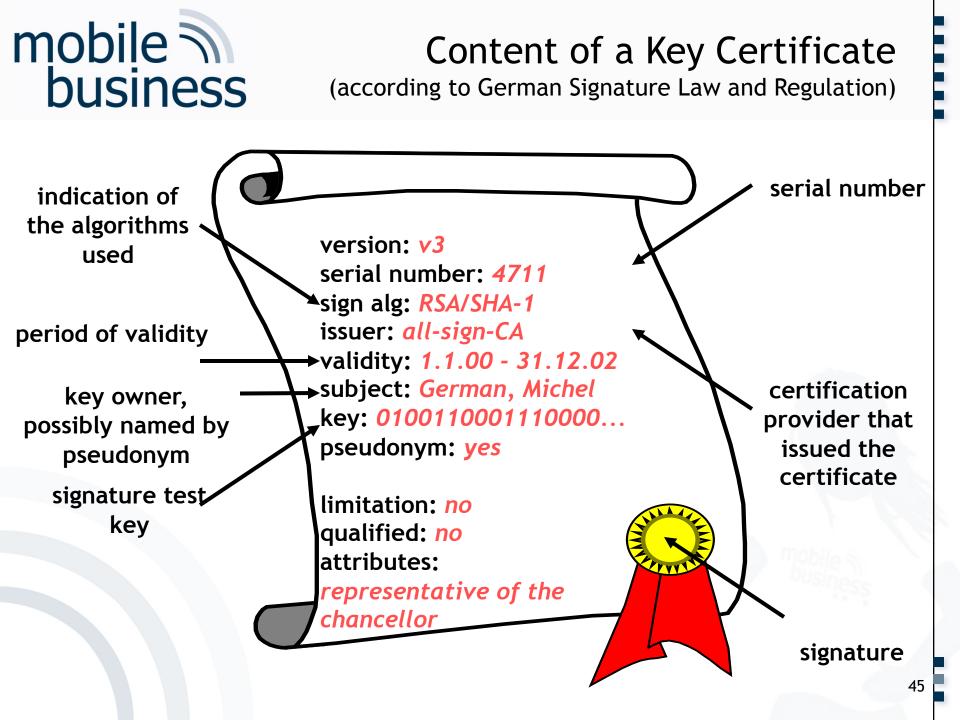
(Example: German Signature Law)



persons

organizations

- The actual checking of the identity of the key owner takes place at so called Registration Authorities (e.g. notaries, bank branches, T-Points, ...)
- Security of the infrastructure depends on the reliability of the CAs.







- Reliable identification of persons who apply for a certificate
- Information on necessary methods for fraud resistant creation of a signature
- Provision for secure storage of the private key
 - at least Smartcard (protected by PIN)
- Publication of the certificate (if wanted)
- Barring of certificates
- If necessary issuing of time stamps
 - for a fraud resistant proof that an electronic document has been at hand at a specific time





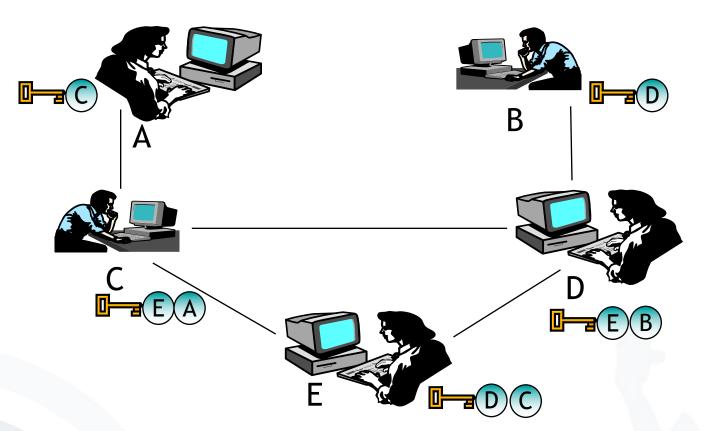
- Checking of the following items by certain confirmation centers (BSI, TÜVIT, ...)
 - Concept of operational security
 - Reliability of the executives and of the employees as well as of their know-how
 - Financial power for continuous operation
 - Exclusive usage of licensed technical components according to SigG and SigV
 - Security requirements as to operating premises and their access controls
- Possibly license of the regulation authority

mobile business Web of Trust "Introducer" David Bob knows David and has received David's public key by David himself Alice lets David sign her public key Bob can verify Alice' key Alice sends the signed on the basis of David's key to Bob signature Bob encrypts his message to Alice Bob Alice with the received key 5

- Each user can act as a "CA".
- Mapping of the social process of creation of trust.
- Keys are "certified" through several signatures.
- Expansion is possible by public key servers and (hierarchical) CAs.



Web of Trust Example



Web of Trust:

- Certification of the public keys mutually by users
- Level of the mutual trust is adjustable.



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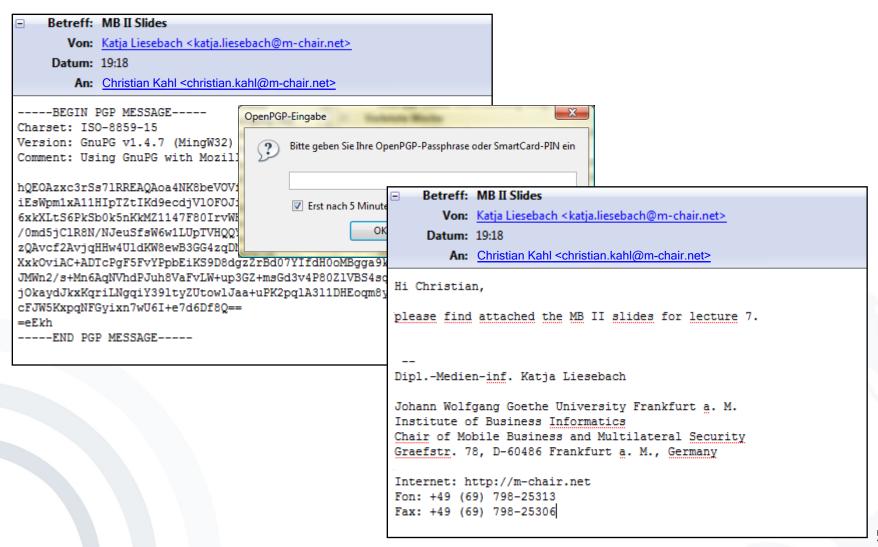
Protection of Email Example PGP

- PGP = Pretty Good Privacy
 - De facto-Standard for freely accessible e-mail encryption systems on the Internet
 - First implementation by Phil Zimmermann
 - Long trial against Phil Zimmermann because of suspicion of violation of export clauses
 - In U.S., free version in cooperation with MIT (agreement with RSA because of the patent)
 - Meanwhile commercialized: www.pgp.com
 - Gnu Privacy Guard (GPG): non-commercial Open Source variant (OpenPGP, RFC2440)

OpenPGP: Encrypt Message

| enden Kontakte | | | S/MIME Speichern | | | | |
|---|--|------------|---|---------------|------------|--------------|----|
| on: Katja Liesebach | h <katja.liesebach@m-chair.net> - ka</katja.liesebach@m-chair.net> | OpenP(| iP-Schlüssel auswählen | 100 | | | |
| - An: E | Christian Kahl < christian.kahl@m-le | | ht gefundene Empfänger | | | | |
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| No. 16. | | | | - | | A0D40924 | |
| hann Wolfgang Stitute of Bus | VERSCHLÜSSELTE Nachricht ar | in folgend | e Empfänger senden: | - | | 79B42C58 | |
| hair of Mobile | christian.kahl@m-lehrstuhl.de | | | - | | B06F3816 | |
| raefstr. 78, D- | | | | - | | 0789B57F | |
| | | | e> | - | 11.04.2011 | 165A5F90 | |
| ternet: http:/ | Hinweis: Die Nachricht wurde n 0x42B8B29914E21EDA, 0x23EE4E | | nden Benutzer-IDs / Schlüsseln verschlüsselt: | - | | 9347DB3C | |
| on: +49 (69) 79 | 0x42b6b29914E21EDA, 0x25EE4L | 0900449. | Aro | - | 20.02.2009 | 48CC64C2 | |
| ax: +49 (69) 79 | | Ja | Nein | - | | 8EF041F1 | |
| | | <u>.</u> | | - | | 289E7DB2 | |
| | 1 | | Katja Liesebach < katja.iiesebach@m-chair.net> | absolutes Ver | | C4495AF0 | |
| | | | 🗉 Katrin Borcea <kati@inf.tu-dresden.de></kati@inf.tu-dresden.de> | - | | F7C207CE | - |

OpenPGP: Decrypt Message



PGP-Certification of Keys

- Certification of public keys by users: "Web of Trust"
- Differentiation between 'validity' and 'trust'
 - 'Trust': trust that a person / an institution signs keys only if their authenticity has really been checked
 - 'Validity': A key is valid for me if it has been signed by a person / an institution I trust (ideally by myself).
- Support through key-servers:
 - Collection of keys
 - Allocation of 'validity' and 'trust' remains task of the users
- Path server:

Finding certification paths between keys

OpenPGP: Key Management

| ige Schlüssel, deren Benutzer-ID oder Schlüssel-ID folgendes enthalten: | | [| Alle <u>z</u> eig | en | | | |
|---|-------------------------|----------|-------------------------|----|--|--|--|
| Benutzer-ID Alexander Boettcher ("Nur wenige wissen, wie viel man wissen muss, um z | Vertrauen abgelaufen | Ablauf-D | Typ öffentlig | t, | | | |
| Alexander Boettcher (Nor Wenge Wissen, We vier nor Wissen mass, um 2 Alexander Boettcher | | | | | | | |

Schlü

OpenPGP-Schlüssel herunterladen

| | Schlüssel gefunden - Auswählen zum Importieren | | | |
|--|--|------------|--------------|--------|
| | Benutzer-ID | Erstellt | Schlüssel-ID | Ę |
| | □ | 1997-03-09 | 8EF041F1 | |
| | | 1997-09-18 | AF1FDF70 | |
| | | 1997-03-09 | 6623E0DD | |
| lüssel-Server auswählen uche nach Schlüssel Kai Rannenber | | | | |
| chlüssel-Server subkeys.pgp.n | et Abbrechen | | | |
| | | 0 | K Abbr | rechei |
| | | | | |

Key-Server



X

PGP: Public Key Catalogs

| le Edt ywe Ravortes Iool Heb Back + + · · · · · · · · · · · · · · · · · | Public Key Server Ver | bose Index ``Kai Rannenberg " - Microsoft Internet Explorer |
|---|------------------------------|---|
| if http://blackhole.pca.din.de:11371/pls/hookup?op=windex&search=Kai+Rannenberg Image: Content of the state of the | | |
| Public Key Server Verbose Index ``Kai Rannenberg '' Type bits/keyID Date User ID Dub 1024/AFIFDF70 1997/09/18 kara <kara@iig.uni-freiburg.de> Dig 0E6375FD Mathias Schunter <schunter@acm.org> Dig 0502003 Herbert Damker <damker@iig.uni-freiburg.de> Dig 05020041 Birgit Pfitzmann 1 <pre>/// fitzb@informatik.uni-hildesheim.de> No LEGAL RELEVANCE Dig 079AC041 Birgit Pfitzmann 1 <pre>// fitzb@informatik.uni-freiburg.de> Dig 0279D5039 Kai R. Rannenberg 2040 Kara@iig.uni-freiburg.de> Dig 279D5039 Kai Martius <kai@imib.med.tu-dresden.de> Dig 49F104 Hannes Federrath <federrath@inf.tu-dresden.de> Dig 0E6375FD Mathias Schunter <schunter@acm.org> Mathias Schunter <schunter@acm.org> Dig 0E6663F Martin Reichenback <marel@iig.uni-freiburg.de> Mig 0E6675FD Mathias Schunter <schunter@acm.org> Mati Reichenback <marel@iig.uni-freiburg.de> Mig 0E6663F Martin Reichenback <marel@iig.uni-freiburg.de> <</marel@iig.uni-freiburg.de></marel@iig.uni-freiburg.de></schunter@acm.org></marel@iig.uni-freiburg.de></schunter@acm.org></schunter@acm.org></federrath@inf.tu-dresden.de></kai@imib.med.tu-dresden.de></kai@imib.med.tu-dresden.de></kai@imib.med.tu-dresden.de></kai@imib.med.tu-dresden.de></pre></pre></damker@iig.uni-freiburg.de></schunter@acm.org></kara@iig.uni-freiburg.de> | 🖙 Back 🔹 🔿 🗸 🙆 💋 | 🔐 🔞 Search 📾 Favorites 🛞 Media 🧭 🛃 + 🎒 🔕 + 📃 🖓 |
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| Type bits/keyID Date User ID Dub 1024/ <u>AFIFDF70</u> 1997/09/18 kara < <u>kara@iig.uni-freiburg.de></u> Big DB6375FD Matthias Schunter < <u>schunter@acm.org></u> Dig D5CDE033 Herbert Damker < <u>diamker@iig.uni-freiburg.de></u> Dig 879AC041 Birgit Pfitzb@informatik.uni-hildesheim.de> NO LEGAL RELEVANCE Big 879AC041 Birgit Pfitzb@informatik.uni-hildesheim.de> NO LEGAL RELEVANCE Big 8128DC75 Gerhard Weck < <u>73064.2271@compuserve.com></u> Big 8128DC75 Gerhard Weck < <u>43064.2271@compuserve.com></u> Big 8128DC75 Gerhard Weck < <u>43064.2271@compuserve.com></u> Big SC3C4FE4 Holger Reif < <u>teif@prakinf.tu-ilmenau.de></u> Matthias Schunter <schunter@acm.org> Kai R. Rannenberg <<u>kai@microsoft.com></u> Big 0B6375FD Matthias Schunter <<u>schunter@acm.org></u> Big 0F4584B5 Douglas Swiggum <<u>Swiggum@Waisman.Wisc.Edu></u> Big 0F4584B5 Douglas Swiggum <<u>Swiggum@Waisman.Wisc.Edu></u> Big 0F45863FFD Kara <<u>kara@iig.uni-freiburg.de></u> Mattina Schunter <<u>schunter@acm.org></u> Kara <<u>kara@iig.uni-freiburg.de></u> Mig AF1FDF70 Kara <<u>kara@iig.uni-freiburg.d</u></schunter@acm.org> | | |
| <pre>1024/AFIFDF70 1997/09/18 kara <kara@iig.uni-freiburg.de> 10g D86375FD Matthias Schunter <schunter@acm.org> 10g D5CDEC083 Herbert Dawker <damker@iig.uni-freiburg.de> 10g 879AC041 Birgit Pfitzmann 1 <pfitzb@informatik.uni-hildesheim.de> NO LEGAL RELEVANCE 10g 8128DC75 Gerhard Weck <73064.2271@compuserve.com> 10g 8EF041F1 Kai R. Rannenberg 2048 <kara@iig.uni-freiburg.de> 10g 2F6D5039 Kai Martius <kai@imib.med.tu-dresden.de> 10g 45EF1064 Hannes Federrath <federrath@inf.tu-ilmenau.de> 10g 45EF1064 Hannes Federrath <federrath@inf.tu-dresden.de> 10g 065375FD Matthias Schunter <schunter@acm.org> 10g 0458485 Douglas Swiggum@Waisman.Wisc.Edu> 10g 04458485 Douglas Swiggum@Waisman.Wisc.Edu> 10g 0286537FD Martin Reichenbach <mare@iig.uni-freiburg.de> 10g 0286537FD Martin Reichenbach <mare@iig.uni-freiburg.de> 10g 0286537FD Martin Reichenbach <mare@iig.uni-freiburg.de> 10g 0445845 Douglas Swiggum@Waisman.Wisc.Edu> 10g 045657FD Martin Reichenbach <mare@iig.uni-freiburg.de> 10g 0456575FD Martin Reichenbach <mare@iig.uni-freiburg.de> 10g 045675FD Martinas Schunter <schunter@acm.org> 10g 045675FFD Martinas Schunter <schunter@acm.org> 10g 045675FFD Mathias Schunter <schunter@acm.org> 10g 0456375FD Mathias Schunter <schunter@acm.org> 10g 0456375FFD Mathias Schunte</schunter@acm.org></schunter@acm.org></schunter@acm.org></schunter@acm.org></schunter@acm.org></schunter@acm.org></schunter@acm.org></schunter@acm.org></schunter@acm.org></mare@iig.uni-freiburg.de></mare@iig.uni-freiburg.de></mare@iig.uni-freiburg.de></mare@iig.uni-freiburg.de></mare@iig.uni-freiburg.de></mare@iig.uni-freiburg.de></mare@iig.uni-freiburg.de></mare@iig.uni-freiburg.de></mare@iig.uni-freiburg.de></mare@iig.uni-freiburg.de></mare@iig.uni-freiburg.de></schunter@acm.org></federrath@inf.tu-dresden.de></federrath@inf.tu-ilmenau.de></kai@imib.med.tu-dresden.de></kai@imib.med.tu-dresden.de></kai@imib.med.tu-dresden.de></kai@imib.med.tu-dresden.de></kara@iig.uni-freiburg.de></pfitzb@informatik.uni-hildesheim.de></damker@iig.uni-freiburg.de></schunter@acm.org></kara@iig.uni-freiburg.de></pre> | Public Ke | y Server Verbose Index ``Kai Rannenberg '' |
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| | - | |
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| | • | |
| | 8) | 🚺 👔 Internet |

- Network of public-key servers:
 - www.cam.ac.uk.pgp.net/pgpnet/email-key-server-info.html
 - http://pgp.mit.edu/





PGP: Practical Attacks and Weaknesses

- Brute-Force-Attacks on the pass phrase
 - PGPCrack for conventionally encrypted files
- Trojan horses, changed PGP-Code
 - e.g. predictable random numbers, encryption with an additional key
- Attacks on the computer of the user
 - Not physically deleted files
 - Paged memory
 - Keyboard monitoring
- Analysis of electromagnetic radiation
- Non-technical attacks
- Confusion of users [Whitten, Tygar 1999]

Remark

"Anybody who asserts that a problem is readily solved by encryption, understands neither encryption nor the problem."

(Roger Needham / Butler Lampson)

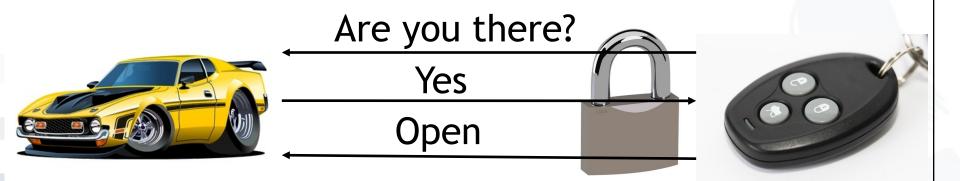
[Marshall Symposium 1998] [Randell 2004]





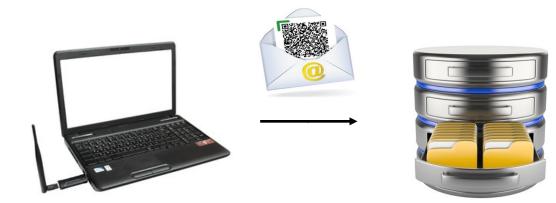


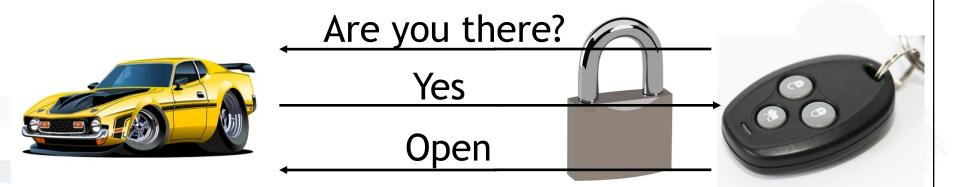
- Solution: Protect communication with crypto?
- e.g. symmetric cryptography + hash/signature

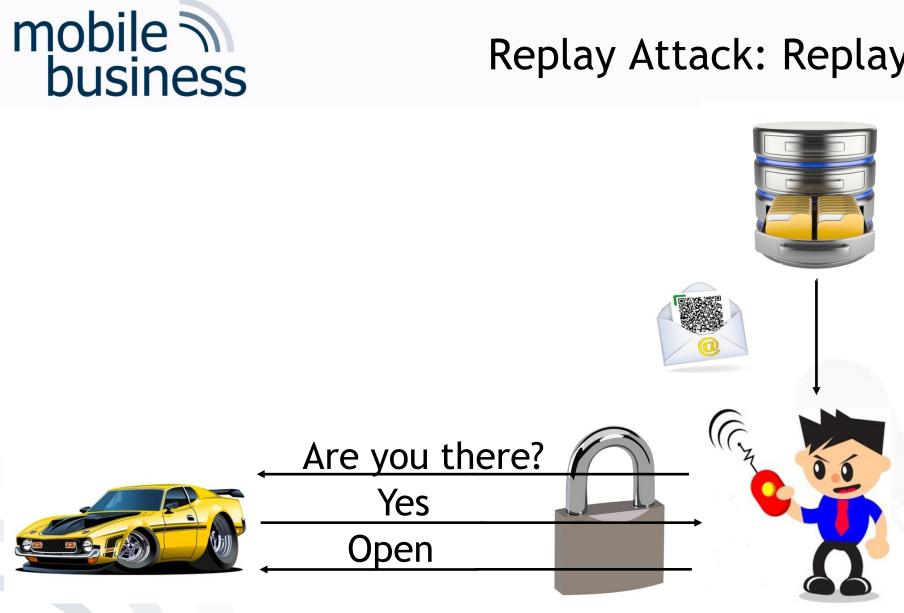


Replay Attack: Eavesdrop

mobile business





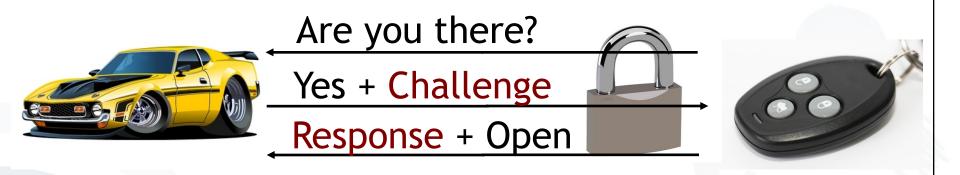


Replay Attack: Replay



Replay Attack: Solution

e.g. Challenge-Response helps





Side-Channel Attacks I

 A secure cryptoalgorithm does not imply that the implementation is also secure

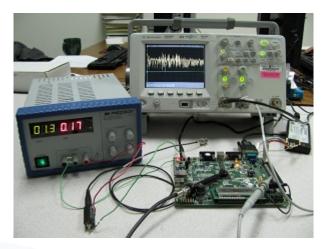


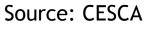
Source: Eran Tromer

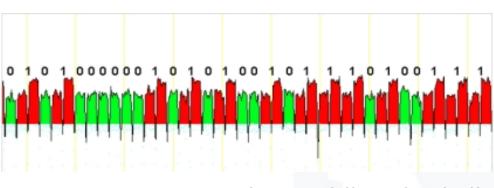


Side-Channel Attacks II

Side-Channels: Time, Power, Noise, Radiation, ...





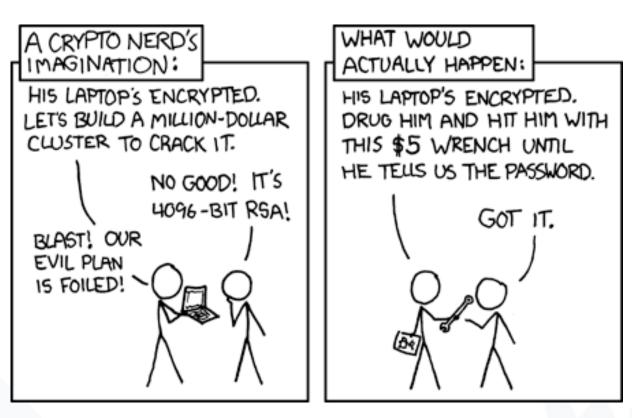


Source: Gilbert Goodwill

- Other data (side-channel) leaks information
- Conclusion on processed bits possible



The Human Element



Source: https://xkcd.com/538/

Human Element: Behavior and Passwords

- Florencio, D. & Herley, C., 2007. A large-scale study of web password habits. *Proceedings of the 16th international conference on World Wide Web - WWW '07*, p.657. Available at: http://portal.acm.org/citation.cfm?doid=1242572.12426 61.
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