Security and Cryptography 2015

Mirosław Kutyłowski

grading criteria: 50% exam, 50% assignments

skills to be learned: developing end-to-end security systems, they must be flawless!

rules: do not memorize the standards, they come and go. Only the skills are important

exam date: TBA (quickly to enable internships in February)

I. EXAMPLE TO LEARN FROM: PKI FAILURE

reasons for PKI failure (According to Schneier):

1. whom we trust and for what? why CA should be trusted??
2. who is using my key? (private key - there are really no clones??)
3. how secure is the verifying computer? (no cryptography can help is the verifier software is cheating)
4. who is the signer? (ambiguity unless there is a trustworthy ID registry)
5. is CA an authority? (really not an authority for data contained in the certificate. Certificate bsed on fake documents...)
6. is the user part of the security design? (no, the user is free to behave in a stupid way)
7. separation CA and RA brings new threats
8. How did CA verify the certificate holder? (certificate issued for ..., but how to know that this was really this person)
9. How secure are the certification practices? (revocation, etc)
10. the customers wish to run single-sign-on

Answers: yes, but

- tradition in Nordic countries
- honest system participants
- the best one can do
- ...

  no solutions from crypto community

MAJOR PROBLEM: how to design/buy sound systems?

II. COMMON CRITERIA FRAMEWORK

http://www.commoncriteriaportal.org/

Idea:

- standardize the process of
  - designing products (Security Target ST),
  - designing requirements (Protection Profile, PP)
  - evaluation of products (licensed labs checking conformance of implementation with the documentation)
- international agreement of bodies from some countries (USA, France, UK, Germany, India, Turkey, Sweden, Spain, Australia, Canada, Malaysia, Netherlands, Korea, New Zeland, Italy, Turkey) but Israel only "consuming", no Poland, China, Singapore,
- idea: ease the process,
- support for certification industry

Value:

- CC certification does not mean a product is secure
- it only says that is has been developed according to PP
- assurance level concerns only the stated requirements , e.g. trivial requirements ⇒ high EAL level (common mistake in public procurement: EAL level ... without specifying PP
- clean up the zoo of different assumptions, descriptions, ...

Example for PP: BAC (Basic Access Control)

- encryption primitive $\mathrm{EM}(K, S) = \mathrm{Enc}(\mathrm{KB}_{\mathrm{Enc}}, S) \| \mathrm{MAC}(\mathrm{KB}_{\mathrm{Mac}}, \mathrm{Enc}(\mathrm{KB}_{\mathrm{Enc}}, S), S)$ where $K = \{\mathrm{KB}_{\mathrm{Enc}}, \mathrm{KB}_{\mathrm{Mac}}\}$
- steps:
  1. The MRTD chip sends the nonce $r_{\mathrm{PI}\mathbb{C}C}$ to the terminal
  2. The terminal sends the encrypted challenge $e_{\mathrm{PCD}} = \mathrm{EM}(K, r_{\mathrm{PCD}}, r_{\mathrm{PI}\mathbb{C}C}, K_{\mathrm{PCD}})$ to the MRTD chip, where $r_{\mathrm{PI}\mathbb{C}C}$is the MRTD chip's nonce, r_{PCD} is the terminal's randomly chosen nonce, and K_{PCD} is keying material for the generation of the session keys.
  3. The MRTD chip decrypts and verifies $r_{\mathrm{PI}\mathbb{C}C}$, responds with $e_{\mathrm{PICC}} = \mathrm{EM}(K, r_{\mathrm{PICC}}, r_{\mathrm{PCD}}, K_{\mathrm{PICC}})$
  4. The terminal decrypts and verifies r_{PCD}

5. both sides derive K_{Enc}, K_{Mac} from master key K_{PICC} XOR K_{PCD} and sequence number derived from randoms (key derivation function)

- K derived from information available on the machine readable zone (optical)
- implementation: biometric passports.
- simple system. Really?

Common Criteria Protection Profile Machine Readable Travel Document with ICAO Application, Basic Access Control BSI-CC-PP-0055

1. Introduction

1.1 PP reference

1 Title: Protection Profile - Machine Readable Travel Document with ICAO Application and Basic Access Control (MRTD-PP)

Sponsor: Bundesamt für Sicherheit in der Informationstechnik CC Version: 3.1 (Revision 2)

Assurance Level: The minimum assurance level for this PP is EAL4 augmented.

General Status: Final

Version Number: 1.10

Registration: BSI-CC-PP-0055

Keywords: ICAO, machine readable travel document, basic access control

1.2 TOE Overview

- Target of Evaluation
- "is aimed at potential consumers who are looking through lists of evaluated TOEs/Products to find TOEs that may meet their security needs, and are supported by their hardware, software and firmware"
- important sections:
  - Usage and major security features of the TOE
  - TOE type
  - Required non-TOE hardware/software/firmware
- Definition, Type

  which parts, which general purpose, which functionalities are present and which are missing, eg. ATM card with no contactless payments

- Usage and security features

  crucial properties of the system (high level) and security features from the point of view of the security effect and not how it is achieved

- life cycle

  the product in the whole life cycle including manufacturer and destroying

- Required non-TOE hardware/software/firmware: other components that can be crucial for evaluation

2. Conformance Claim

- CC Conformance Claim: version of CC
- PP claim: other PP taken into account in a plug-and-play way
- Package claim: which EAL package level

EAL packages:

- The CC formalizes assurance into 6 categories (the so-called "assurance classes" which are further subdivided into 27 sub-categories (the so-called "assurance families"). In each assurance family, the CC allows grading of an evaluation with respect to that assurance family.
- assurance classes:
  - → development:
    - – ADV_ARC - 1 1 1 1 1 1 architecture requirements
    - – ADV_FSP 1 2 3 4 5 5 6 functional specifications
    - – ADV_IMP - - - 1 1 2 2 implementation representation
    - – ADV_INT - - - - 2 3 3 "is designed and structured such that the likelihood of flaws is reduced and that maintenance can be more readily performed without the introduction of flaws"?
    - – ADV_SPM - - - - - 1 1 security policy modeling
    - – ADV_TDS - 1 2 3 4 5 6 TOE design
  - → guidance documents
    - – AGD_OPE 1 1 1 1 1 1 1 Operational user guid ance
    - – AGD_PRE 1 1 1 1 1 1 1 Preparative procedures
  - → life-cycle support
    - – ALC_CMC 1 2 3 4 4 5 5 CM capabilities
    - – ALC_CMS 1 2 3 4 5 5 5 CM scope
    - – ALC_DEL - 1 1 1 1 1 1 Delivery

    - ALC_DVS - - 1 1 1 2 2 Development securit
    - ALC_FLR - - - - - - - Flaw remediation
    - ALC_LCD - - 1 1 1 1 2 Life-cycle definition
    - ALC_TAT - - - 1 2 3 3 Tools and techniques
  - security target evaluation
    - ASE_CCL 1 1 1 1 1 1 1 Conformance claims
    - ASE_ECD 1 1 1 1 1 1 1 Extended components definition
    - ASE_INT 1 1 1 1 1 1 1 ST introduction
    - ASE_OBJ 1 2 2 2 2 2 2 Security objectives
    - ASE_REQ 1 2 2 2 2 2 2 Security requirements
    - ASE_SPD - 1 1 1 1 1 1 Security problem definition
    - ASE_TSS - 1 1 1 1 1 1 TOE summary specification
  - tests
    - ATE_COV 1 2 2 2 3 3 Coverage
    - ATE_DPT 1 1 3 3 4 Depth
    - ATE_FUN 1 1 1 1 2 2 Functional tests
    - ATE_IND 1 2 2 2 2 2 3 Independent testing
  - vulnerability assesment
    - AVA_VAN 1 2 2 3 4 5 5 Vulnerability analysis

- for example, a product could score in the assurance family developer test coverage (ATE_COV):
  - 0: It is not known whether the developer has performed tests on the product;
  - 1: The developer has performed some tests on some interfaces of the product;
  - 2: The developer has performed some tests on all interfaces of the product;
  - 3: The developer has performed a very large amount of tests on all interfaces of the product
- example more formal: ALC_FLR
  - ALC_FLR.1:
    - The flaw remediation procedures documentation shall describe the procedures used to track all reported s ecurity flaws in each release of the TOE.

    - The flaw remediation procedures sha ll require that a description of the nature and effect of each security flaw be provided, as well as the status of finding a correction to that flaw.

    - The flaw remediation procedures shall require that corrective actions be identified for each of the security flaws.

    - The flaw remediation procedures documentation shall describe the methods used to provide flaw information, corrections and guidance on corrective actions to TOE users.

  - ALC_FLR.2:

    - first four like before

    - The flaw remediation procedures sh all describe a means by which the developer receives from TOE users reports and enquiries of suspected security flaws in the TOE.

    - The procedures for processing reported security flaws shall ensure that any reported flaws are remediated and the remediation procedures issued to TOE users.

    - The procedures for processing repor ted security flaws shall provide safeguards that any corr ections to these security flaws do not introduce any new flaws.

    - The flaw remediation guidance sha ll describe a means by which TOE users report to the developer any susp ected security flaws in the TOE.

  - ALC_FLR.3:

    - first 5 as before

    - The flaw remediation procedures shall include a procedure requiring timely response and the automatic distri bution of security flaw reports and the associated corrections to registered users who might be affected by the security flaw.

    - next 3 as before

    - The flaw remediation guidance shall describe a means by which TOE users may register with the developer, to be eligible to receive security flaw reports and corrections.

    - The flaw remediation guidance shall iden tify the specific points of contact for all reports and enquiries about security issues involving the TOE.

- 7 predefined ratings, called evaluation assurance levels or EALs. called EAL1 to EAL7, with EAL1 the lowest and EAL7 the highest

- Each EAL can be seen as a set of 27 numbers, one for each assurance family. EAL1 assigns a rating of 1 to 13 of the assurance families, and 0 to the other 14 assurance families, while EAL2 assigns the rating 2 to 7 assurance families, the rating 1 to 11 assurance families, and 0 to the other 9 assurance families

- monotonic: EALn+1 gives at least the same assurance level as EALn in each assurance families

- levels:

  - EAL1: Functionally Tested:

    - correct operation, no serious threats

    - minimal effort from the manufacturer

  - EAL2: Structurally Tested

    - delivery of design information and test results,

    - effort on the part of the developer than is consistent with good commercial practice.

  - EAL3: Methodically Tested and Checked

    - maximum assurance from positive security engineering at the design stage without substantial alteration of existing sound development practices.

    - developers or users require a moderate level of independently assured security, and require a thorough investigation of the TOE and its development without substantial re-engineering.

  - EAL4: Methodically Designed, Tested and Reviewed

    - maximum assurance from positive security engineering based on good commercial development practices which, though rigorous, do not require substantial specialist knowledge, skills, and other resources.

    - the highest level at which it is likely to be economically feasible to retrofit to an existing product line.

  - EAL5: Semiformally Designed and Tested

  - EAL6: Semiformally Verified Design and Tested

  - EAL7: Formally Verified Design and Tested

CEM -Common Evaluation Methodology

- given CC documentation, EAL classification etc, perform a check

- idea: evaluation by non-experts, semi-automated, mainly paper work

- mapping:

  - assurance class $\Rightarrow$ activity

  - assurance component $\Rightarrow$ sub-activity

- evaluator action element ⇒ action
- developer action element ⇒ work-unit
- content and presentation of evidence element ⇒ work unit

- responsibilities:
  - sponsor: requesting and supporting an evaluation. different agreements for the evaluation (e.g. commissioning the evaluation), providing evaluation evidence.
  - developer: produces TOE, providing the evidence required for the evaluation on behalf of the sponsor.
  - evaluator: performs the evaluation tasks required in the context of an evaluation, performs the evaluation sub-activities and provides the results of the evaluation assessment to the evaluation authority.
  - evaluation authority: establishes and maintains the scheme, monitors the evaluation conducted by the evaluator, issues certification/validation reports as well as certificates based on the evaluation results
- verdicts: pass, fail, inconclusive
- parts:
  - evaluation input task (are all documents available to perform evaluation?)
  - evaluation sub-activities
  - evaluation output task (de scribe the Observation Report (OR) and the Evaluation Technical Report (ETR)).
  - demonstration of the technical competence task

3 Security Problem Definition

- **Object Security Problem (OSP)**: "The security problem definition defines the security problem that is to be addressed.

  – axiomatic. deriving the security problem definition outside the CC scope

  – the usefulness of the results of an evaluation strongly depends on the security problem definition.

  – spend significant resources and use well-defined processes and analyses to derive a good security problem definition.

- good example:

  Secure signature-creation devices must, by appropriate technical and operational means, ensure at the least that:

1) The signature-creation-data used for signature-creation can practically occur only once, and that their secrecy is reasonably assured;

2) The signature-creation-data used for signature-creation cannot, with reasonable assurance, be derived and the signature is protected against forgery using currently available technology;

3) The signature-creation-data used for signature-creation can be reliably protected by the legitimate signatory against the use of others

- **assets:** entities that someone places value upon. Examples of assets include: - contents of a file or a server; - the authenticity of votes cast in an election; - the availability of an electronic commerce process; - the ability to use an expensive printer; - access to a classified facility.

  no threat no asset

- **Threats:** threats to assets

- **Assumptions:** assumptions are acceptable, where certain properties of the TOE environment are already known,

  – but not when they are derived from specific properties of the TOE

4. Security objectives

- "The security objectives are a concise and abstract statement of the intended solution to the problem defined by the security problem definition. Their role:

  - a high-level, natural language solution of the problem;

  - divide this solution into partwise solutions, each addressing a part of the problem;

  - demonstrate that these partwise solutions form a complete solution to the problem.

- bridge between the security problem and Security Functional Requirements (SFR)

- **mapping objectives to threats**: table, each threat shoud be covered, each objective has to respond to some threat

  answers to questions:

  – what is really needed?

  – have we forgot about something?

- **rationale:** verifiable explanation why the mapping is sound

5. Extended Component Definition

- In many cases the security requirements (see the next section) in an ST are based on components in CC Part 2 or CC Part 3.

- in some cases, there may be requirements in an ST that are not based on components in CC Part 2 or CC Part 3.

- in this case new components (extended components) need to be defined

6.1 **SFR (Security Functional requirements)**

- *The SFRs are a translation of the security objectives for the TOE. They are usually at a more detailed level of abstraction, but they have to be a complete translation (the security objectives must be completely addressed) and be independent of any specific technical solution (implementation). The CC requires this translation into a standardised language for several reasons: - to provide an exact description of what is to be evaluated. As security objectives for the TOE are usually formulated in natural language, translation into a standardised language enforces a more exact description of the functionality of the TOE. - to allow comparison between two STs. As different ST authors may use different terminology in describing their security objectives, the standardised language enforces using the same terminology and concepts. This allows easy comparison.*

- predefined classes:

  - Logging and audit class FAU

  - Identification and authentication class FIA

  - Cryptographic operation class FCS

  - Access control families FDP_ACC, FDP_ACF

  - Information flow control families FDP_IFC, FDP_IFF

  - Management functions class FMT

  - (Technical) protection of user data families FDP_RIP, FDP_ITT, FDP_ROL

  - (Technical) protection of TSF data class FPT

  - Protection of (user) data during communication with external entities families FDP_ETC, FDP_ITC, FDP_UCT, FDP_UIT, FDP_DAU, classes FCO and FTP

- There is no translation required in the CC for the security objectives for the operational environment, because the operational environment is not evaluated

- customizing SFRs: refinement (more requirements), selection (options), assignment (values), iterations (the same component may appear at different places with different roles)

- rules:

  check dependencies between SFR - In the CC Part 2 language, an SFR can have a dependency on other SFRs. This signifies that if an ST uses that SFR, it generally needs to use those other SFRs as well. This makes it much harder for the ST writer to overlook including necessary SFRs and thereby improves the completeness of the ST.

  security objectives must follow from SFR's - Security Requirements Rationale section (Sect.6.3) in PP

  if possible, use only standard SFR's

6.2 Security Assurance Requirements

- The SARs are a description of how the TOE is to be evaluated. This description uses a standardised language (to provide exact description, to allow comparison between two PP).

III. EIDAS REGULATION

goals:

- interoperability, comparable levels of trust
- merging national systems into pan-European one
- trust services, in particular: identification, authentication, signature, electornic seal, timestamping, delivery, Web authentication
- supervision
- information about
- focused on public administration systems. However, the rules for all trust services except for closed systems (not available to anyone).

tools:

- common legal framework
- supervision system
- obligatory exchange of information about security problems
- common understanding of assurance levels

technical concept:

- Member State provides an online system enabling identification and authentication with means from ths member state used abroad
- notification scheme for national systems
- if notified (some formal and technical conditions must be fulfilled), then every member state must admit it in own country within 12 month

Identification and authentication:

- eID cards – Member States are free to introduce any solution, the Regulation attempts to change it and build a common framework from a zoo of solutions
- breakthrough claimed, but likely to fail

Signature:

- electronic seal with the same conditions as electornic signature,
- the seal is aimed for legal persons
- weakening conditions for qualified electronic signatures: admitting server signatures and delegating usage of private keys

new:

- electronic registered delivery service

- Webpage authentication

Example of requirements (electronic seal):

Definition:

“electronic seal creation device” means configured software or hardware used to create an electronic seal;

“qualified electronic seal creation device” means an electronic seal creation device that meets mutatis mutandis the requirements laid down in Annex II;

Art. 36

An advanced electronic seal shall meet the following requirements:

(a) it is uniquely linked to the creator of the seal;

(b)it is capable of identifying the creator of the seal;

(c)it is created using electronic seal creation data that the creator of the seal can, with a high level of confidence under its control, use for electronic seal creation; and

(d) it is linked to the data to which it relates in such a way that any subsequent change in the data is detectable.

Annex II:

(a) the confidentiality of the electronic signature creation data used for electronic signature creation is reasonably assured;

(b) the electronic signature creation data used for electronic signature creation can practically occur only once;

(c) the electronic signature creation data used for electronic signature creation cannot, with reasonable assurance, be derived and the electronic signature is reliably protected against forgery using currently available technology;

(d) the electronic signature creation data used for electronic signature creation can be reliably protected by the legitimate signatory against use by others.

2. Qualified electronic signature creation devices shall not alter the data to be signed or prevent such data from being presented to the signatory prior to signing.

3. Generating or managing electronic signature creation data on behalf of the signatory may only be done by a qualified trust service provider.

4. Without prejudice to point (d) of point 1, qualified trust service providers managing electronic signature creation data on behalf of the signatory may duplicate the electronic signature creation data only for back-up purposes provided the following requirements are met:

(a) the security of the duplicated datasets must be at the same level as for the original datasets;

(b) the number of duplicated datasets shall not exceed the minimum needed to ensure continuity of the service.

Art. 30

1. Conformity of qualified electronic signature creation devices with the requirements laid down in Annex II shall be certified by appropriate public or private bodies designated by Member States.

notification system:

An electronic identification scheme eligible for notification if:

(a) issued by the notifying state

(b) at least one service available in this state;

(c) at least assurance level low;

(d) ensured that the person identification data is given to the right person

(e) ...

(f) availability of authentication online, for interaction with foreign systems (free of charge for public services), no specific disproportionate technical requirements

(g) description of that scheme published 6 months in advance

(h) meets the requirements from the implementing act

Assurance levels:

- regulation, Sept. 2015, implementation of eIDAS
- reliability and quality of
    - enrolment
    - electronic identification means management
    - authentication
    - management and organization
- authentication factors
    - posession based
    - knowledge based
    - inherent (physical properties)
- enrolment: (for all levels):

    1. Ensure the applicant is aware of the terms and conditions related to the use of the electronic identification means.

    2. Ensure the applicant is aware of recommended security precautions related to the electronic identification means.

    3. Collect the relevant identity data required for identity proofing and verification.

- identity proofing and verification (for mnatural persons):

    low:

    1. The person can be assumed to be in possession of evidence recognised by the Member State in which the application for the electronic identity means is being made and representing the claimed identity.

    2. The evidence can be assumed to be genuine, or to exist according to an authoritative source and the evidence appears to be valid.

    3. It is known by an authoritative source that the claimed identity exists and it may be assumed that the person claiming the identity is one and the same.

substantial: low plus:

1. The person has been verified to be in possession of evidence recognised by the Member State in which the application for the electronic identity means is being made and reprensenting the claimed identity

and

the evidence is checked to determine that it is genuine; or, according to an authoritative source, it is known to exist and relates to a real person

and

steps have been taken to minimise the risk that the person's identity is not the claimed identity, taking into account for instance the risk of lost, stolen, suspended, revoked or expired evidence; or

2. options related to other trustful sources

high: substantial plus

(a) Where the person has been verified to be in possession of photo or biometric identification evidence recognised by the Member State in which the application for the electronic identity means is being made and that evidence represents the claimed identity, the evidence is checked to determine that it is valid according to an authoritative source; and the applicant is identified as the claimed identity through comparison of one or more physical characteristic of the person with an authoritative source; or

- electornic identification means management:

  low:

  1. The electronic identification means utilises at least one authentication factor.

  2. The electronic identification means is designed so that the issuer takes reasonable steps to check that it is used only under the control or possession of the person to whom it belongs.

  substantial:

  1. The electronic identification means utilises at least two authentication factors from different categories.

  2. The electronic identification means is designed so that it can be assumed to be used only if under the control or possession of the person to whom it belongs.

  high:

  1. The electronic identification means protects against duplication and tampering as well as against attackers with high attack potential

  2. The electronic identification means is designed so that it can be reliably protected by the person to whom it belongs against use by others.

- Issuance , delivery and activation:

  low:

  After issuance, the electronic identification means is delivered via a mechanism by which it can be assumed to reach only the intended person.

  substantial:

  After issuance, the electronic identification means is delivered via a mechanism by which it can be assumed that it is delivered only into the possession of the person to whom it belongs.

high:

The activation process verifies that the electronic identification means was delivered only into the possession of the person to whom it belongs.

- suspencion, revocation and reactivation:

  all levels:

  1. It is possible to suspend and/or revoke an electronic identification means in a timely and effective manner.

  2. The existence of measures taken to prevent unauthorised suspension, revocation and/or reactivation.

  3. Reactivation shall take place only if the same assurance requirements as established before the suspension or revocation continue to be met.

- authentication mechanism:

  substantial:

  1. The release of person identification data is preceded by reliable verification of the electronic identification means and its validity.

  2. Where person identification data is stored as part of the authentication mechanism, that information is secured in order to protect against loss and against compromise, including analysis offline.

  3. The authentication mechanism implements security controls for the verification of the electronic identification means, so that it is highly unlikely that activities such as guessing, eavesdropping, replay or manipulation of communication by an attacker with enhanced-**basic attack potential** can subvert the authentication mechanisms.

  high:

  .... by an attacker with **high attack potentia**l can subvert the authentication mechanisms.

- audit:

  low:

  The existence of periodical internal audits scoped to include all parts relevant to the supply of the provided services to ensure compliance with relevant policy.

  substantial:

  The existence of periodical **independent** internal or external audits ....

  high:

  1. The existence of periodical i**ndependent external audits** scoped to include all parts relevant to the supply of the provided services to ensure compliance with relevant policy.

  2. Where a scheme is directly managed by a government body, it is audited in accordance with the national law.

IV. eIDAS TOKEN SPECIFICATION, BSI

- Technical guideline, security mechanisms for electronic travel documents, not focused on readers

- cryptographic mechanisms:
  - Password Authenticated Connection Establishment (PACE)
  - Terminal Authentication Version 2 (TA2).
  - Chip Authentication Version 3 (CA3)
  - Restricted Identification (RI)
  - Pseudonymous Signatures (PS)
- procedures
  - General Authentication Procedure (GAP)
  - Enhanced Role Authentication (ERA)
  - PIN Management
- terminal types:
  - inspection system
  - authentication terminal - government or private, terminal rights to be checked, GAP must be used
  - attribute terminal- extension of Authentication Terminal, ERA must be used
  - signature management terminal - key creation, signature creation
  - signature terminal - GAP must be used
  - priviledged terminals: category: inspection terminals and some authentication terminals explicitly authorized. Signature terminals are never priviledged
- user credentials:
  - MRZ-Password
  - CAN
  - PIN - always blocking (RC reaches 0 then blocked)
  - PUK - blocking or non-blocking
- password blocking: RC=0 password blocked, RC=1 - password suspended and the correct CAN must be entered during the same session to resume the password. Resume is volatile.
- switching session context: a stack of protocols, when terminating a protocol we return to the context on the top of the stack
- password authentication:
  - PACE- global passwords, VERIFY-application local
  - Inspection terminal SHALL use CAN or MRZ

  - authentication terminal SHALL use PIN, but the CAN can be allowed by the terminal

  - signature terminal: PIN, CAN or PUK

- Extended Access Control:

  - 1. Terminal Authentication v2: terminal SHALL generate ephemeral keys used later for Chip Authentication, only standard parameters, ephemeral keys authenticated, result: read/write access granted

  - 2. Passive Authentication: terminal reads and verifies Security Objects, compares the data obtained before PACE

  - 3. Chip Authentication v2 or v3: afterwards secure channel restarted

- General Authentication Procedure:

  i. password verification - PACE

  ii. EAC

  iii. read/write data

- Enhanced Role Authentication – authentication terminal with proper rules can proceed as follows:

  i. authentication terminal sends an ATTRIBUTE REQUEST to eIDAS token. token makes a link between the request and the terminal's sector

  ii. restore session context of PACE, store context of Chip authentication

  iii. EAC with attribute provider

  iv. proceed attribute request, write the resulting attributes to the eIDAS token, the access rights restricted to terminals with proper rights

  v. restore session context: PACE, then Chip Authentication

  vi. terminal may read the stored attributes

- online authentication:

  - eID server: remote part of authentication terminal

  - user device: interacts with user, eIDAS token and eID server, but not authorized to read eIDAS token data, access rights only after authentication with the eID server

Protocol chart:

token user device eID server Attribute Provider

GENERAL AUTHENTICATION

————PACE————

——————EAC———————

———read data, perform special functions———

ERA

<——————————store attribute request

————— switch to PACE context —————

<——————————EAC——————————>

——————————retreive attribute request—————>

——————————read data ——————————>

<——————————store attribute ——————————

——————————— switch to PACE context ———————

— switch to e-ID session context —

————read attribute ——————————>

- unauthenticated terminals:

  i. password verification based on PACE:

     – terminal does not show its type

     – can choose password type

     – after authentication secure messaging

  ii. authentication with CAN resumes PIN

  iii. updating retry counter

- authenticated terminals: after terminal authentication the terminal becomes authenticated

Cryptographic building blocks:

– hash $\boldsymbol{H}(m)$

– compression function for public key: $\boldsymbol{Comp}(\mathrm{PK})$

– projected representation of a public key $\mathbf{\Pi}(\mathrm{PK})$

– symmetric key algorithms:

  – deriving key for encryption $K_{\mathrm{Enc}} = \boldsymbol{KDF}_{\mathrm{Enc}}(K, [r])$

  – $K_{\mathrm{Mac}} = \boldsymbol{KDF}_{\mathrm{Mac}}(K, [r])$

  – $K_{\pi} = \boldsymbol{KDF}_{\pi}(\pi)$

  – encryption and decryption

    - MAC
- asymmetric algorithms:
    - domain parameters
    - keys (page 19):
        - eIDAS: ephemeral on both sides
        - Chip authentication: static on side of the chip
        - Chip authentication version 3: ephemeral on both sides based on static Chip's key
        - Restricted Identification: token uses a static key, sector public key, sector specific identifier
    - KA - key agreement (like DH)
    - signatures, mapping to RSA and ECDSA described

Pseudonymous signature:

- used for anonymous signature and for Chip Authentication v3
- keys:
    - domain parameters D_M and a pair of global keys $(\mathrm{PK}_M, \mathrm{SK}_M)$
    - public key $\mathrm{PK}_{\mathrm{ICC}}$ for a group of eIDAS tokens, the private key $\mathrm{SK}_{\mathrm{ICC}}$ known to the issuer of eIDAS tokens (called manager)
    - for a token the manager chooses $\mathrm{SK}_{\mathrm{ICC},2}$ at random, then computes $\mathrm{SK}_{\mathrm{ICC},1}$ such that $\mathrm{SK}_{\mathrm{ICC}} = \mathrm{SK}_{\mathrm{ICC},1} + \mathrm{SK}_M \cdot \mathrm{SK}_{\mathrm{ICC},2}$
    - a sector (domain) holds private key $\mathrm{SK}_{\mathrm{sector}}$ and public key $\mathrm{PK}_{\mathrm{sector}}$.
    - a sector has revocation private key $\mathrm{SK}_{\mathrm{revocation}}$ and public key $\mathrm{PK}_{\mathrm{revocation}}$
    - sector specific identifiers $I^{\mathrm{sector}}_{\mathrm{ICC},1}$ and $I^{\mathrm{sector}}_{\mathrm{ICC},2}$ of the eIDAS token in the sector
- signing: with keys $\mathrm{SK}_{\mathrm{ICC},1}$, $\mathrm{SK}_{\mathrm{ICC},2}$ and $I^{\mathrm{sector}}_{\mathrm{ICC},1}$ and $I^{\mathrm{sector}}_{\mathrm{ICC},2}$ for $\mathrm{PK}_{\mathrm{sector}}$ and message m

    i. choose K_1, K_2 at random

    ii. compute

    - $Q_1 = g^{K_1} \cdot (\mathrm{PK}_M)^{K_2}$
    - $A_1 = (\mathrm{PK}_{\mathrm{sector}})^{K_1}$
    - $A_2 = (\mathrm{PK}_{\mathrm{sector}})^{K_2}$

    iii. $c = \mathrm{Hash}(Q_1, I^{\mathrm{sector}}_{\mathrm{ICC},1}, A_1, I^{\mathrm{sector}}_{\mathrm{ICC},2}, A_2, \mathrm{PK}_{\mathrm{sector}}, m)$ (variant parameters and $\mathbf{\Pi}$ omitted here)

iv. compute

   - $s_1 = K_1 - c \cdot \mathrm{SK}_{\mathrm{ICC},1}$
   - $s_1 = K_2 - c \cdot \mathrm{SK}_{\mathrm{ICC},2}$

v. output (c, s_1, s_2)

- verification:

  compute

  - $Q_1 = (\mathrm{PK}_{\mathrm{ICC}})^c \cdot g^{s_1} \cdot (\mathrm{PK}_M)^{s_2}$
  - $A_1 = (I^{\mathrm{sector}}_{\mathrm{ICC},1})^c \cdot (\mathrm{PK}_{\mathrm{sector}})^{s_1}$
  - $A_2 = (I^{\mathrm{sector}}_{\mathrm{ICC},2})^c \cdot (\mathrm{PK}_{\mathrm{sector}})^{s_2}$
  - recompute c and check against the c from the signature

- why it works?

$$\begin{aligned}(\mathrm{PK}_{\mathrm{ICC}})^c \cdot g^{s_1} \cdot (\mathrm{PK}_M)^{s_2} &= (\mathrm{PK}_{\mathrm{ICC}})^c \cdot g^{K_1} \cdot (\mathrm{PK}_M)^{K_2} \cdot g^{-\mathrm{cSK}_{\mathrm{ICC},1}} \cdot (\mathrm{PK}_M)^{\mathrm{cSK}_{\mathrm{ICC},2}} \\ &= (\mathrm{PK}_{\mathrm{ICC}})^c \cdot g^{K_1} \cdot (\mathrm{PK}_M)^{K_2} \cdot g^{-\mathrm{cSK}_{\mathrm{ICC},1}} \cdot (g)^{-\mathrm{cSK}_M \cdot \mathrm{SK}_{\mathrm{ICC},2}} \\ &= (\mathrm{PK}_{\mathrm{ICC}})^c \cdot g^{K_1} \cdot (\mathrm{PK}_M)^{K_2} \cdot g^{-c \cdot \mathrm{SK}_{\mathrm{ICC}}} = g^{K_1} \cdot (\mathrm{PK}_M)^{K_2} = Q_1\end{aligned}$$

- there is a version without A_1, A_2 and the pseudonyms $I^{\mathrm{sector}}_{\mathrm{ICC},1}, I^{\mathrm{sector}}_{\mathrm{ICC},2}$

PACE (Password Authenticated Connection Establishment)

- ICAO Doc 9303: Basic Access Control/PACE and EAC v1 (=Chip Authentication v1+ Terminal Authentication v1) MUST be used
- password based authentication protocol
- password on the side of the token: stored, on the terminal: input by the user
- steps:

  i. token chooses s at random

  ii. token computes $z = \mathrm{Enc}(K_\pi,\ s)$, where $K_\pi = \mathrm{KDF}(\pi)$ and sends z to the reader together with the parameters D_{PICC}

  iii. the reader recovers s

  iv. the reader and the token compute $D_{\mathrm{Mapped}} = \mathrm{Map}(D_{\mathrm{PICC}}, s)$ (mapping function)

  v. the reader and the token perform anonymous Diffie-Hellman key agreement based on the ephemeral domain parameters (ephemeral values based on D_{Mapped} as an generator), shared secret K obtained

  vi. they create session keys $K_{\mathrm{Mac}} = \mathrm{KDF}_{\mathrm{Mac}}(K)$ and $K_{\mathrm{Enc}} = \mathrm{KDF}_{\mathrm{Enc}}(K)$

  vii. exchange and verification of tokens: $T_{\mathrm{PCD}} = \mathrm{MAC}(K_{\mathrm{MAC}}, \text{ephemeral key of PICC})$

$T_{\mathrm{PICC}} = \mathrm{MAC}(K_{\mathrm{MAC}}, \text{ephemeral key of PCD})$

viii. Secure Messaging restarted

Terminal authentication v2

- Chip Authentication MUST be performed after Terminal Authentication (condition repeated in the description of CHA v2 only)
- simple challenge-response algorithm, undeniable, resistant to replay
- ephemeral public key for ChA as a side effect
- steps:

  i. the terminal send the certificate chain to eIDAS token, it has to confirm the key $\mathrm{PK}_{\mathrm{PCD}}$

  ii. the token checks $\mathrm{PK}_{\mathrm{PCD}}$

  iii. the terminal creates ephemeral pair of keys, sends the compressed version of $\widetilde{\mathrm{PK}^{\mathrm{CA}}_{\mathrm{PCD}}}$ to the token

  iv. token replies with a random nonce r_{PICC}

  v. the terminal signs with $\mathrm{SK}_{\mathrm{PCD}}$ the following data: r_{PICC}, compressed version of $\widetilde{\mathrm{PK}^{\mathrm{CA}}_{\mathrm{PCD}}}$

  vi. the token checks the signature

Chip authentication v2

- static DH authentication with the ephemeral key of the terminal
- steps:

  i. the token sends its public key $\mathrm{PK}_{\mathrm{PICC}}$

  ii. the terminal sends ephemeral public key from TA (uncompressed)

  iii. static DH key agreement with $\mathrm{SK}_{\mathrm{PICC}}$ and ephemeral public key on side of the token, and $\mathrm{PK}_{\mathrm{PICC}}$ and ephemeral secret key on side of the terminal, master key K generated

  iv. token chooses r_{PICC}, computes $K_{\mathrm{Enc}} = \mathrm{KDF}_{\mathrm{Enc}}(K, r_{\mathrm{PICC}})$, $K_{\mathrm{Mac}} = \mathrm{KDF}_{\mathrm{Mac}}(K, r_{\mathrm{PICC}})$

  v. token computes the tag $T_{\mathrm{PICC}} = \mathrm{MAC}(K_{\mathrm{Mac}}, \text{ephemeral public key of the terminal})$

  vi. the terminal checks the tag

vii. secure messaging restarted using K_{Enc} and K_{Mac}

Chip authentication v3

- alternative to Chip authentication v2 and RI
- claimed: "message-deniable strong authentication", "pseudonymity without using the same key on several chips", "possibility of whitelisting eIDAS tokens"
- scheme:

  i. phase 0: terminal authentication, ephemeral key for terminal in phase 1 chosen and signed

  ii. phase 1: key agreement like DH with ephemeral keys on both sides, restarting secure messaging with new keys

  iii. phase 2:

     – static keys on the side of the chip: $\mathrm{SK}_{\mathrm{ICC},1}, \mathrm{SK}_{\mathrm{ICC},2}, \mathrm{PK}_{\mathrm{ICC}}$ and the parameters

     – terminal sends $\mathrm{PK}_{\mathrm{sector}}$ to the chip, the chip compares it with the "compressed" version received during Terminal Authentication

     – chip reconstructs $I^{\mathrm{sector}}_{\mathrm{ICC},1} = (\mathrm{PK}_{\mathrm{sector}})^{\mathrm{SK}_{\mathrm{ICC},1}}$ and $I^{\mathrm{sector}}_{\mathrm{ICC},2} = (\mathrm{PK}_{\mathrm{sector}})^{\mathrm{SK}_{\mathrm{ICC},2}}$

     – chip creates pseudonymous signature using $I_{\mathrm{ICC},1}$, $I_{\mathrm{ICC},2}$ as pseudonym and the secret keys $\mathrm{SK}_{\mathrm{ICC},1}$, $\mathrm{SK}_{\mathrm{ICC},2}$ over the ephemeral key given by the terminal

- If PACE GM used before ChA v3 then one can reuse the ephemeral key from the terminal
- checking the key PK_M is obligatory (otherwise it would be easy to forge the token)

Restricted Identification

- optional
- depending on the version, deanonymization might be possible or not (depending on $\mathrm{PK}_{\mathrm{sector}}$)
- executed after Terminal Authentication and Chip Authentication (not specified which version, but with v3 it does not makes sense)
- sector specific identifier computed as Hash(key computed via DH from $\mathrm{PK}_{\mathrm{sector}}$ and $\mathrm{SK}_{\mathrm{ID}}$)
- blacklisting impossible in case of group key compromise (from ChA v2)

Pseudonymous Signature as replacement of RI

- whitelisting possible in case of group key compromise (claimed as new but possible for RI)
- the second part from ChA v3, the key $\mathrm{PK}_{\mathrm{sector}}$ used as sector public key

PSA - Pseudonymous Signature Authentication

- the sector public key = the ephemeral public key from ephemeral DH key agreement (now DH explicitly mentioned)

PSM - Pseudonymous Signature of a Message

- TA and ChA must be executed before
- message to be signed comes from the terminal
- public key unspecified

PSC - Pseudonymous Signature of Credentials

- used in combination with ERA
- Attribute Terminal involved, but eIDAS token creates the signature himself (after breaking group key one can also create the PSC)
- public key unspecified
- terminal rights to get the attributes are to be checked

PROBLEMS:

- security properties not stated, they can be derived via tedious analysis
- lack of security proofs
- underspecified (details may turn the token to be insecure)
- powerful adversary able to break into the token may crate fake ID's, unless whitelist approach used

---

V. STANDARS VERSUS SECURITY

Bleichenbacherr's RSA signature forgery based on implementation error

The attack works for PKCS-1 padding.

The PKCS-1 padding consists of a byte of 0, then 1, then a string of 0xFF bytes,
then a byte of zero, then the "payload" which is the hash+ASN.1 data.
Graphically:

```
00 01 FF FF FF ... FF 00  ASN.1  HASH
```

The signature verifier first applies the RSA public exponent to reveal this PKCS-1 padded data, checks and removes the PKCS-1 padding, then compares the hash with its own hash value computed over the signed data.

The error that Bleichenbacher exploits is if the implementation does not check that the hash+ASN.1 data is right-justified within the PKCS-1 padding. Some implementations remove the PKCS-1 padding by looking for the high bytes of 0 and 1, then the 0xFF bytes, then the zero byte; and then they start parsing the ASN.1 data and hash. The ASN.1 data encodes the length of the hash within it, so this tells them how big the hash value is. These broken implementations go ahead and use the hash, without verifying that there is no more data after it. Failing to add this extra check makes implementations vulnerable to a signature forgery, as follows.

An attacker forges the RSA signature for an exponent of 3 by constructing a value which is a perfect cube. Then he can use its cube root as the RSA signature. He starts by putting the ASN.1+hash in the middle of
the data field instead of at the right side as it should be. Graphically:

```
00 01 FF FF ... FF 00  ASN.1  HASH  GARBAGE
```

This gives him complete freedom to put anything he wants to the right of the hash. This gives him enough flexibility that he can arrange for the value to be a perfect cube.

There are some other variations of this attack, for example some implementations of the signature verification algorithm neglect to check if the field “parameters” inside “digestAlgorithm” field is NULL. In such a case an attacker may put some GARBAGE here, making the attack still possible even if the algorithm verifies that the HASH is right-justified.

Chosen Ciphertext Attacks Against Protocols Based on RSA Encryption Standard PKCS-1 – the Million Message Attack.

An attacker has access to an oracle that, for any chosen ciphertext, indicates whether the corresponding plaintext $C^d \bmod n$ has the correct format according to the encryption standard.

Then after querying the oracle with about 2^{20} adaptively chosen ciphertexts the attacker is able to calculate the plaintext correpsonding to the original ciphertext.

The oracle might be for example a HSM that receives ciphertexts resulting from the key-wrap algorithm.

The attack exploits such vulnerabilities like

- different error messages returned by the attacked device when decryption fails on different stages of the decryption algorithm

- different timings of execution of the decryption algorithm when the PKCS-1 encryption padding is correct and when it is incorrect.

If a device supports the PKCS-1 encryption padding and the implementation of the PKCS-1 decryption on the device is vulnerable, then the million message attack works also when

- the ciphertext is calculated according to a padding different than PKCS-1

- the “ciphertext” is the plaintext for which we want to obtain a signature (dangerous for a situation when the same key is used for decryption and for signatures, and decryption is not PIN protected).

VI. FORMAL SECURITY PROOFS

Security model e.g. for PACE

Background (Hanzlik, MK)

data confidentiality: nobody can understand any data from the communication between an eID and a terminal, except for this eID and this terminal. By "data" we mean:

- workload data to be transmitted via the channel established according to the protocol,
- partner specific data (such as partner identity) - if sending them (explicitly or implicitly) results from the protocol execution.

data integrity: a third person cannot manipulate without detection the data exchanged between the eID and the terminal. This concerns in particular manipulating identity data.

session integrity: if a party A accepts at some moment a session executed presumably with a single partner, then indeed this interaction of A emerged in interaction with a single partner.

partner authentication: if a partner A accepts a session as a session withparty C, then A indeed has been talking with C until this moment (maybe with somebody playing man-in-the-middle, but only passively). Partner authentication might be mutual or one-sided. In case of PACE, there is one-sided authentication of an eID.

owner's consent: eID is used only when the user agrees and with the terminal chosen by the user.

proof non-transferability: a party A interacting with a party B cannot prove against a third party C that it is interacting with B, and cannot authenticate in this way the data received from B. This should be understood that executing the protocol does not provide additional cryptographic evidence over the data mentioned in the data confidentiality condition.

Case study: KEA

- Diffie-Hellman based key-exchange protocol, mutual authentication for the parties
- developed by NSA, declassified in 1998, no security analysis
- attacked in 2005, Lauter, Mityagin, extension KEA+ proposed, security proven by reduction proofs
- naive protocol:
  - party A chooses x at random and sends to B:
    - g^x and $\mathrm{sign}_A(g^x, B)$
  - party B chooses y at random and sends to BA:
    - g^y and $\mathrm{sign}_B(g^y, A)$
  - both: verify the signature, compute $g^{x \cdot y}$ as for DH protocol
  - attack:
    - if ephemeral x of A from communication between A and B revealed, then ...
    - the adversary resends g^x and $\mathrm{sign}_A(g^x, B)$ to C and can impersonate A as he can compute the session key

- KEA:
    - A and B hold, respectively, the keys: private a and b, and public keys g^a and g^b
    - A and B select ephemeral secret keys x and y at random and exchange g^x and g^y
    - each party computes $g^{a \cdot y}$ and $g^{b \cdot x}$ (static DH protocol)
    - session key computed as $F(g^{a \cdot y} \operatorname{xor} g^{b \cdot x})$ (just like Blake-Wilson, D. Johnson, and A. Menezes: $\operatorname{Hash}(g^{a \cdot y}, g^{b \cdot x})$)
- Unknown Key Share (UKS) – a formal attack on KEA:
    - Mallet registers the same key g^a as Alice
    - Alice starts a session with Bob but session intercepted by Mallet
    - Mallet starts a session with Bob as Mallet
    - Mallet forwards the values g^x and g^y
    - therefore Alice and Bob compute the same session key
    - Mallet corrupts one sesson and get a session key for the second one - contradicting AKE security
- KEA+
    - session key computed as $F(g^{a \cdot y}, g^{b \cdot x}, A, B)$
- KEA+C
    - keys as for KEA
    - A chooses x at random and sends g^x
    - B chooses y at random, computes $L = \operatorname{Hash}(g^{a \cdot y}, g^{b \cdot x}, A, B)$
    - B responds with g^y and $\mathrm{MAC}_L(0)$
    - A computes L, checks $\mathrm{MAC}_L(0)$and responds with $\mathrm{MAC}_L(1)$
    - B checks $\mathrm{MAC}_L(1)$
- security properties:
    - AKE (Authenticated Key Exchange)-
        - the adversary controls all communication
        - the adversary can corrupt some of the parties.
        - the adversary must select an uncorrupted session called a test session and then he is given a challenge, which is either the session key of the test session or a randomly selected key.
        - the adversary wins if can distinguish between these 2 cases.

- PFS (Perfect Forward Security):
  - AKE experiment
  - the adversary can corrupt a party A (reveal the long-term secret key),
  - test session: a session of A occurred before corrupting A
- KCI (Key Compromise Impersonation)
  - the adversary gets a long-term secret key of A
  - attempt to impersonate as other party to A
  - of course, the adversary can impersonate A to anyone
- advantage of the adversary A running algorithm $\mathcal{A}$:

  $|\Pr(\mathcal{A}(\text{data}, \text{real key}) = 1) - \Pr(\mathcal{A}(\text{data}, \text{random key}))|$

  the advantage should be "negligibly small"

- reduction proofs:
  - → assume that that there is an advarsary A breaking scheme U
  - → choose a cryptographic assumption P
  - → from a case p for P construct a case u for U
  - → show how to run A on u
    - → the environment need not to behave exactly as the scheme U
    - → the difference between real U and the simulated one should be impossible to detect by A
  - → breaking u should lead to breaking p with a fair probability
  - → finally: compute the advantage of the resulting adversary breaking p
- modelling via oracles:
  - atomic actions that can be initiated by the adversary
  - all interactions with the system defined by the oracles
  - specification of adversary's power
- typical oracles:
  - Reveal: reveal ephemeral key
  - Reveal: reveal session key
  - Corrupt: reveal long-time key
  - Execute(A, B): make A and B execute the protocol

  - Send: send a message to A and get its reaction (if any) – the messages may come form the protocol, but might be faulty

  - Test: a session ends after key establishment, no workload communication (this can be added with the tested key), must concern a *fresh session*

  - *fresh session:* exclude situation where for instance via corruptions it is possible to break the session

- AKE for KEA+:

  - reduction via Gap Diffie-Hellman (CDH under assumption that DDH easy)

  - ROM for hash function

  - ways to distinguish between the random from real key: hash value must be asked

  - possibilities for the real key K to appear in the experiment:

    1. Forging: enforce Hash on the tuple $(\mathrm{CDH}(A,Y),\mathrm{CDH}(B,X),A,B)$

    2. Key-replication attack. succeed to create another session with the same "signature" $(\mathrm{CDH}(A,Y),\mathrm{CDH}(B,X),A,B\ )$ and so the same secret key

  - key replication: impossible, since $A' = A$ and $\mathrm{CDH}(A',\,Y') = \mathrm{CDH}(A,\,Y)$ implies $Y = Y'$. Similarly $X = X'$ and the sessions are identical

  - forging: case of a single session:

    - adversary observes a single session between honest A and B

    - problem GDH for (X_0, Y_0)

    - the long term key of A chosen as X_0, the response of B chosen as Y_0, the rest executed as in the scheme description

    - learning the key requires asking hash oracle about $(\mathrm{CDH}(X_0, Y_0), g^{b\cdot x}, A, B)$

  - forging the in general case: problem since A involved in many interactions but we do not know the secret key. Idea: replace with a random key

    - all users initialized according to the scheme, except for A

    - Hash simulated by HSim

    - sessions not involving A executed according to the protocol (and HSim)

    - a session $(\boldsymbol{A,C},\mathrm{role})$:

      - C public key of $\boldsymbol{C}$

      - if $\boldsymbol{A}$ initiator, then it chooses x at random, sends g^x, gets reply Y, session key $\mathrm{HSpec}(1, Y, C^x, A, C)$

      - if $\boldsymbol{A}$ responder, then it waits for X, chooses y at random, sends g^y, gets reply Y, session key $\mathrm{HSpec}(2, X, C^y, C, A)$

    - a session $(\boldsymbol{C}, \boldsymbol{A}, \text{role})$:
        - as in the scheme description
        - except for test session where Y_0 sent and the session key not computed
- reveal and corrupt key: as described by the scheme
- $\text{HSim}(Z_1, Z_2, B, C)$ – random oracle on valid signatures
    - if asked before, then repeat the answer
    - check all previous $\text{HSpec}(i, Y, Z, B, C) = v$ and check if $Z = Z_{3-i}$ and $\text{DDH}(X_0, Y, Z_i) = \text{true}$. If yes, then return v.
    - if not found then return random w and remember it
- $\text{HSpec}(i, Y, Z, B, C)$ - random oracle for cases when adversary does not know the secret key of A. For input (Z_1, Z_2, B, C), where $Z_i = \text{CDH}(X_0, Y)$ and $Z_{3-i} = Z$

VII. CATACRYPT

catastrophy cryptography

- what happens if assumptions broken (e.g. DL solvable for some group)?
- ”post-quantum crypto”

reality:

- post-quantum is at early stage, no industrial products, logistically impossible to replace
- no plans, scenarios, ...
- catastrophy is already there

TLS and DH real security

mistakes:

- risk of common (standard) groups
- cryptanalysis: most efficient number field sieve (NFS):
    - complexity subexponential (for $\mathbb{Z}_\mathbb{p}$ it is

$$\exp\,(1.93 + o(1))\big(\log p^{\,1/3}(\text{loglog}\,p)^{2/3}\big)$$

    - most time precomputation independent from the target number y (where $\log y$ to be computed in a given group)

    - the time dependant from y can be optimized to subexponential but much lower

    - 512-bit groups can be broken, MitM attack can be mounted

- standard safe primes – seem to be ok, but attacker can amortize the cost over many attacks

- TLS with DH: frequently "export-grade" DH with 512 bit primes, about 5% of servers support DHE_EXPORT, most servers (90% and more) use a few primes of a given length, after a precomputation breaking for a given prime: reported as 90 sec

- TLS: client wants DHE, server offers DHE_EXPORT, but one can manipulate the messages exchanged, so that the client treats the (p_{512}, g, g^b) as a response to DHE – it is not an implementation bug!

    - handshake time is a problem, but some protocols allow. sending TLS warning alert that reset the countdown

    - ephemeral key hashing

    - sometimes non safe prime used ($\frac{\text{p-1}}{2}$ composite), Pohling-Hellman method can be used

    - DH-768 breakable on academic level, DH-1024 on the state level

- recommendations:

    - avoid fixed prime groups

    - transition to EC

    - deliberately do not downgrade security even if seems to be ok

    - follow the progress in computer algebra

VIII. HARDWARE TROJANS

methods of testing:

- functional tests

- internal tests circuitry

- optical inspection (distructive) - can detect modifications on layout level

Idea: change properties that are not visible under microscope: increase aging effects, manipulate transistors so that the output is fixed

Dopant Trojans

CMOS inverter: (image Wikipedia)

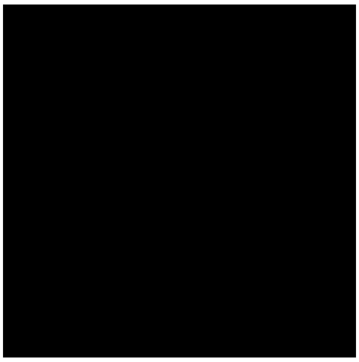


Figure 1.

where: A is the source, Vdd positive supply , Vss is ground

upper transistor: PMOS (allows current flow at low voltage)

lower transistor: NMOS (allows current flow at high voltage)

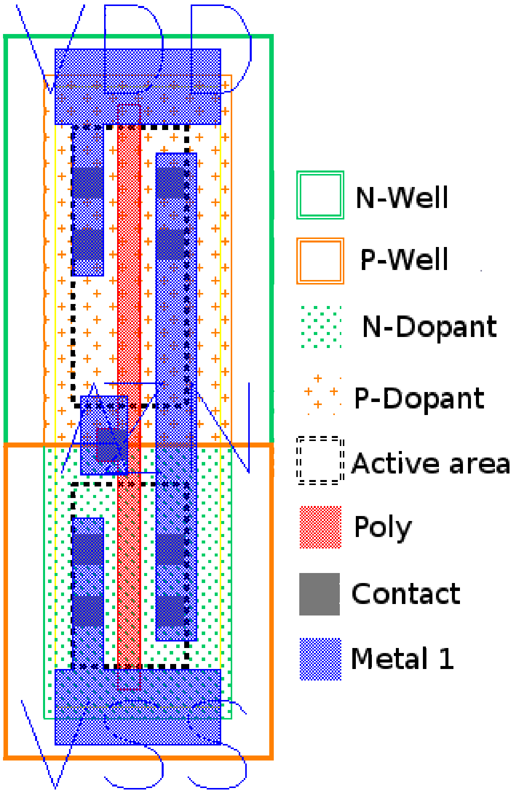
how it works:

- if voltage is low then the lower transistor is in high resistance state and the current from Q flows to Vdd (high voltge)
- if voltage is high then the upper transistor is in high resistance state and the current from Q flows to Vss while Vdd has low voltage

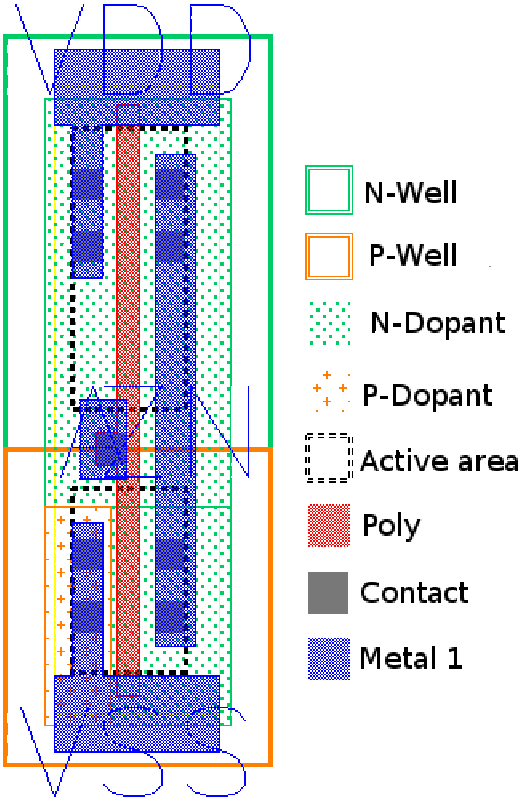
PMOS: in dopant area "holes" (positive) playing the role of conductor, low voltage creates depletion area, high voltage attracts them

NMOS: in dopant area electrons (negative) playing the role of conductor, high voltage pushes the electrons out

CMOS inverter in the "bird eye perspective":



Trojan design:



- whatever happens the VDD is connected to the output

Trojan TRNG

TRNG cosnsists of

- entropy source (physical)
- self test circuit (OHT - inline health test)
- deterministic RNG, Intel version:
    - conditioner (computes seeds to rate matcher) and rate matcher (computes 128 bit numbers)
    - derivation, internal state (K, c):
        1. $c := c + 1$, $r := \mathrm{AES}_K(c)$
        2. $c := c + 1$, $x := \mathrm{AES}_K(c)$
        3. $c := c + 1$, $y := \mathrm{AES}_K(c)$
        4. $K := K \oplus x$
        5. $c := c \oplus y$

- attack: fix K by applying Trojan transistors, if K is known, then it is easy to find internal state c from r and then the consecutive random numbers r

- problem with OHT: tests with some values have to create known outputs (32 CRC from the last 4 outputs), knowing the test one can find K by exaustive search

Side channel Trojan:

- side channel resistant logic: Masked Dual Rail Logic

  i. for each a both a and negation of a computed

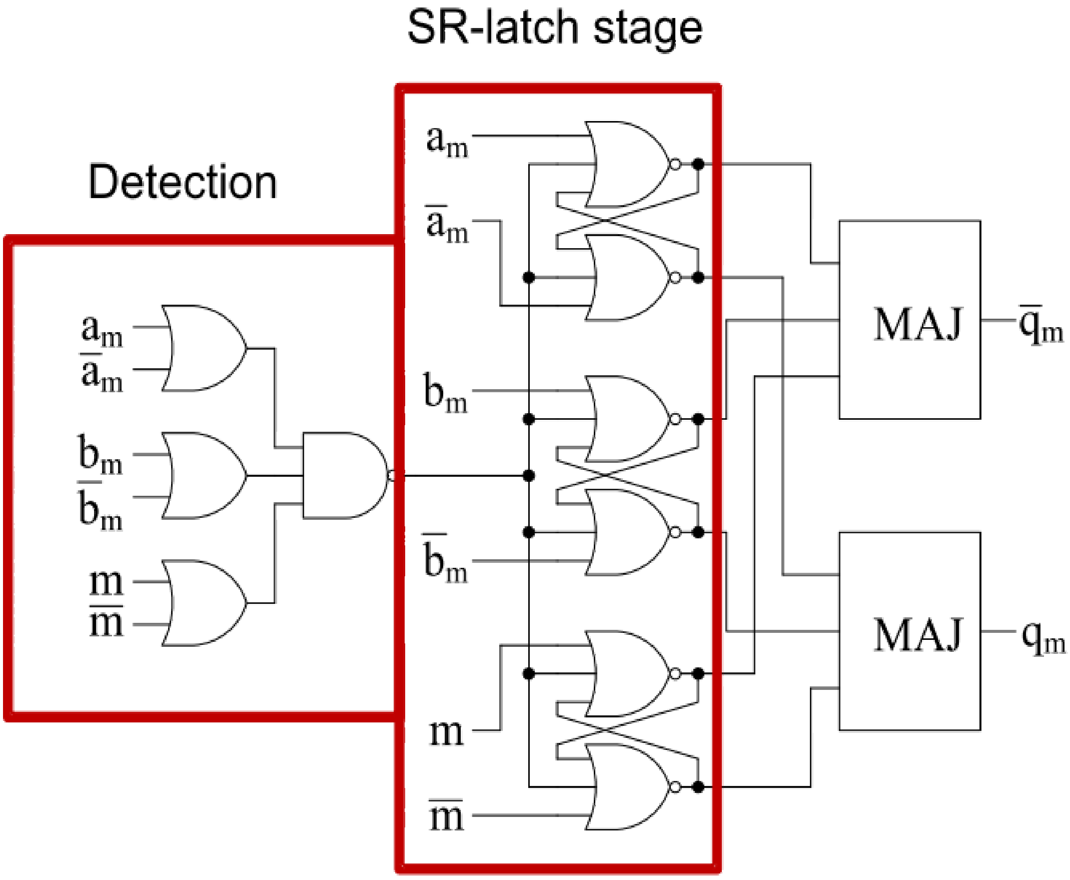
  ii. precharge: each phase preceded by charging all gates

  iii. masking operations by random numbers:

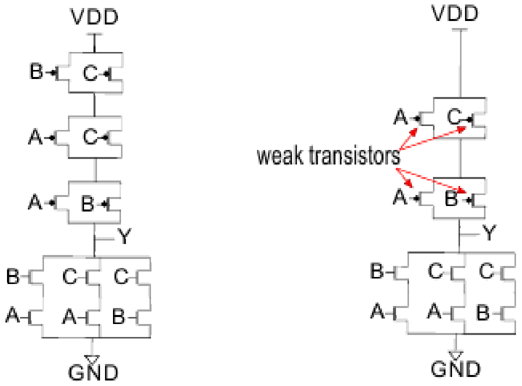
     computing $a \wedge b$:

     - input $a \oplus m$, $a \oplus \neg m$, $b \oplus m$, $b \oplus \neg m$, m, $\neg m$

     - detection, SR-latch stage and majority gat



attacking not-majority gate:



a) Trojan free AOI222 Gate b) Trojan AOI222 Gate

Idea: instead of cutting output a low voltage

- the same behavior except for $A = 0$ and B, $C = 1$, where good output but high power consumption due to connection between VDD and VSS

Defense methods:

- problem: Trojan may be triggered by some particular event, detection becomes harder
- problem: Trojan may work in very particular physical conditions, e.g. temperature, voltage
- on-chip checks: detection of unexpected behavior, e.g. delay characteristics: workload path and a shadow path that provides result after fixed time, + comparison
- methods to enable activation in certain areas only
- inserting PUFs, (either randomize as much a s possible - noise over trojan information) or keep deterministic

---

VIII. HOW TO CREATE A SYSTEM IN THE WORST POSSIBLE WAY?

Example: CHIP AUTHENTICATION PROGRAMME

“optimisation is the process of taking something that works and replacing it with something that almost works but is cheaper”

CAP - idea:

- cheap, Chip&PiN device
- keyboard, display, chip reader
- protecting PIN (it does not go to the PC)
- CAP device not personalized, one can use own card with CAP in a bank, or borrow from somebody

- recommended to use own CAP device
- optimized to be as much as possible based on EMV (standard for electronic purse)

used in UK

operation modes:

- identify: returns one-time code (like RSA-token) (based on symmetric key)
- respond: responds to a challenge using symmetric key
- sign: just as respond, however takes account number and value to generate the respone

Protocol overview:

1. select application of the card (CAP has some fixed identifiers)
2. read records: account number, certificates , ... but important: CDOL1, CDOL2 (card object lists) and CAP (bit filter defining the protocol execution)
3. PIN verification
4. ciphertext generation: GENERATE AC command, response: Authorisation Request Cryptogram (ARQC), then the reader asks for Application Authentication Cryptogram (AAC) indicating cancelling the transaction (according to EMV)

challenge: AA (Authorized Amount), UN (Unpredictable number)

- for identify both are 0
- for respond: AA=0, UN=challenge
- for sign: AA=transaction value, UN= destination account

Response:

- based on the following data: ATC (application transaction counter), CID (Cryptogram Identification Data), IAD (Issuer Application Data - contains result of PIN verification), AC (Application Cryptogram - MAC (3DES CBC MAC) of the rest)
- CAP filter used to determine which bits to take
- NatWest: 5 least significant bits of ATC, 20 least significant bits of MAC, 1 bit from IAD
- Barclay: top bit of CID, 8 least significant bits of ATC, 17 least significant bits of MAC
- HBOS: top bit of CID, 7 least significant bits of ATC, 17 bits of MAC (not in one block), 1 bit from IAD

Verification: recomputed with the secret key shared with the card

Application:

- bank decides how to use (mode + semantic field)
- NatWest: respond mode, 8 bits of challenge, 4 random, 4 =last 4 digits of destination account, not used for login, transaction value not authenticated

- Barclay: identify necessary for login, for transaction: sign with destination account and transaction value (no freshness from bank, only ACT against replay – but might be played later)

Serious mistakes:

- → checking PIN, result available on the device (mugging threat) – this concerns also cards of other banks
- → the same PIN for ATM and online authentication – some keys on the CAP clean and some used - after stealing it one has 3 trials, 24 permutations on 4 keys, pbb to guess PIN to ATM becomes $\frac{1}{8}$
- → CAP has no secret, infected PC may emulate CAP
- → GSM in CAP to transmit secrets
- → complicated instruction manual, the user may insert something else than intended account number
- → overloading: sign with transaction with 0 value is valid for response (for a random account-nounce)
- → NatWest: nonce as 4 digits in respond challenge, Chip&PIN terminal requests a number of responses from the card, later number of challenges from the online bank, there would be a match due to birthday paradox

  (there are info indicating the attack: the number of requests, the change of transaction counter)

critical mistake: MITM regarding PIN verification

- PIN verification result never explicitly stated. Info to the bank contained in TVR (terminal verification results) and IAD (Issuer Application Data)
- TVR states possible failure conditions for authentication, in success not indicated which method used
  - → bit8=1: carholder verification was not successful
  - → bit7=1: unrecognized CVM
  - → bit6=1: PIN Try limit exceeded
  - → bit5=1: PIN required and PIN pad not present
  - → bit4=1:PIN required, PIN pad present and PIN not entered
  - → bit3=1: online PIN entered
- IAD may contain info on whether the PIN has been verified, but cannot be read by the terminal (proprietary format), So terminal can have a different picture of the situation
  - → bi4=1: Issuer Authentication performed and failed

  - → bit3=1: offline PIN performed
  - → bit2=1: offline PIN verification performed and failed
  - → bit1=1: unable to go online

- attack:

  1. tricking the terminal by sending 0x9000 to `Verify` without sending PIn to the card
  2. card thinks that the terminal is not supporting PIN and skip PIN or uses signature
  3. card does not increase PIN retry counter
  4. issuer thinks that the terminal was not supporting PIN and accepts

- practical case (as described in 2015 paper after 2011 case in Belgium)

  - credit cards stolen, used in Belgium, police used intersection analysis (card usage, SIM cards in the proximity) to identify the criminals
  - ”minimal effort design”, just to work. Implementation of the attack with MiTM
  - hardware: FUN chip attached to the original chip, wires connected (contacts of the FUN with contacts of the original chip), the card has traces of manipulation. thickness: .82 mm (instead of .76mm)
  - functional: data embossed on the card does not match the data from the chip, accepts any PIN, some wrong responses

What went wrong:

- no evaluation, no public certification report
- no reaction to S&P paper from 2011
- specification EMV: thousands of pages
- certification costs
- designing a solution: chaos, no sufficiently detailed documentation and regime
- CC very likely to fail:

  - → asset: PIN, password, protected against use on a PC
  - → no methodology to answer the question: **what are side-effects of protecting one asset**
  - → important: security is **not monotonic**: improving situation with respect to one threat may worsen situation to another one. **Not reflected by CC framework**.
  - → **optimization is necessary, but may lead to situation that is worse than the original one**

(other solution: a shadow PIN for the case of mugging)

IX. MODELLING UNSECURITY

attacks:

- hit-and-run
- hit-and-stay
- insider

life-cycle of a solution based on key secrecy:

1. T_0: key created
2. T_1 : forensics-based key non-compromised
3. T_2: key compromise (known to the adversary)
4. T_3 : forensics-based key already compromised
5. T_4: key ceased from operation

[T_1,T_4] is a gray period. Should be as short as possible

Example contermeasure: DSAS framework

archive for signatures,

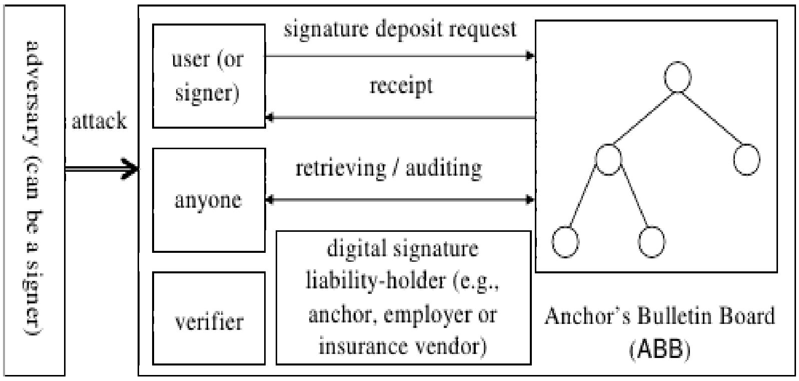

adversary (can be a signer)
attack
user (or signer)
signature deposit request
receipt
anyone
retrieving / auditing
verifier
digital signature liability-holder (e.g., anchor, employer or insurance vendor)
Anchor's Bulletin Board (ABB)

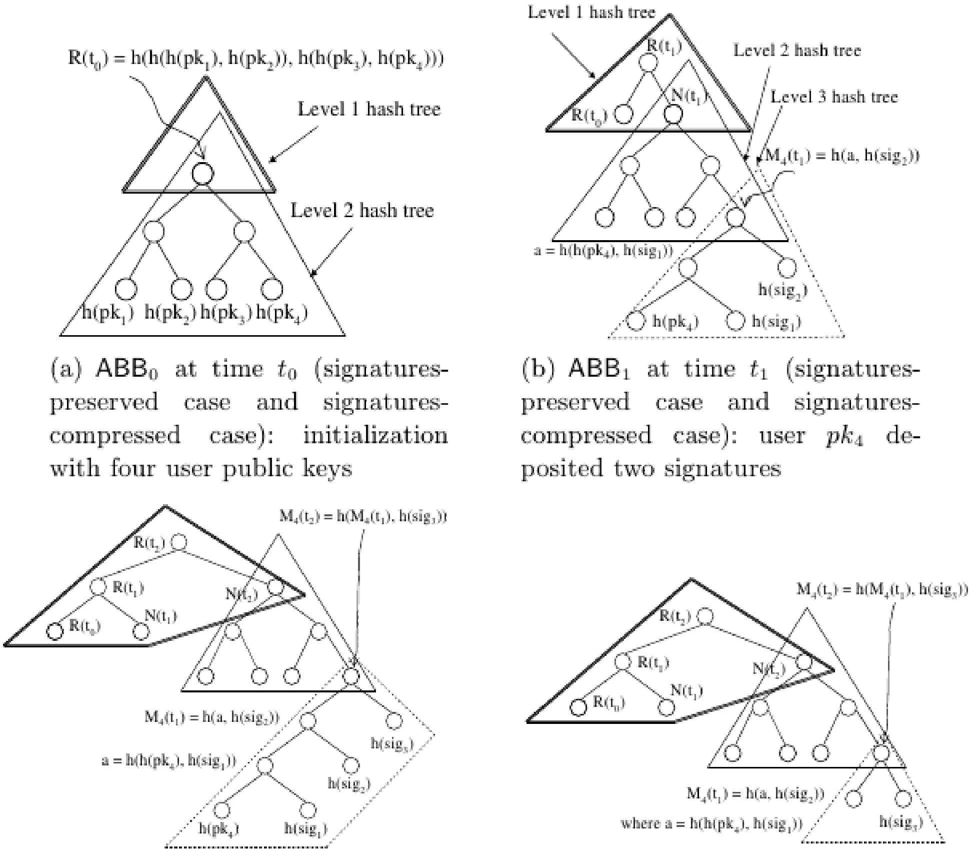
ABB:

— 3 levels of trees

— bottom level: signatures corresponding to one user in a separate tree, leftmost leaf holds public key, the root is a leaf in the level 2 tree

— middle level trees: binary tree for all user, the root is a leaf in top level tree

— top tree has nonleaf nodes corresponding to old roots and old leaves of trees of level 2



(a) ABB_0 at time t_0 (signatures-preserved case and signatures-compressed case): initialization with four user public keys

(b) ABB_1 at time t_1 (signatures-preserved case and signatures-compressed case): user pk_4 deposited two signatures

(c) ABB_2 at time t_2 (signatures-preserved case): user pk_4 deposited one new signature

(d) ABB_2 at time t_2 (signatures-compressed case): user pk_4 deposited one new signature

X. CRYPTOGRAPHIC FORENSICS

how to detect that a card has been cloned:

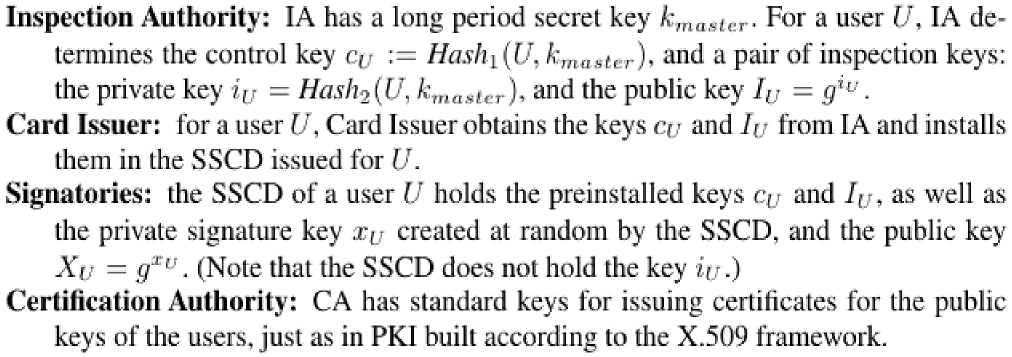
fail stop signatures: work if the clone created by cryptanalysis and deriving secret key and not by card inspection

- key generation by a trusted party: p, q chosen as for RSA, a - odd integer such that $\frac{p-1}{2a}$ is a prime and $q-1$ and a are coprime
- user chooses secret keys $\mathrm{sk}_1, \mathrm{sk}_2 \in Z_n^2$, public keys: $\mathrm{pk}_1 = \alpha^a$, $\mathrm{pk}_2 = \mathrm{sk}_1^a \bmod n^2$
- signing m: $s := \mathrm{sk}_1 \cdot \mathrm{sk}_2^m$
- verification: $s^a := \mathrm{pk}_1 \cdot \mathrm{pk}_2^m$
- fail-stop idea: there are many solutions for sk_1 and sk_2 (namely a for each)

  a different solution yields $s'^a = s^a \bmod n$, then $s'^a = s^a \bmod q$, $s' = s \bmod q$ since a is invertible modulo q

ctrl-signatures:

actors:



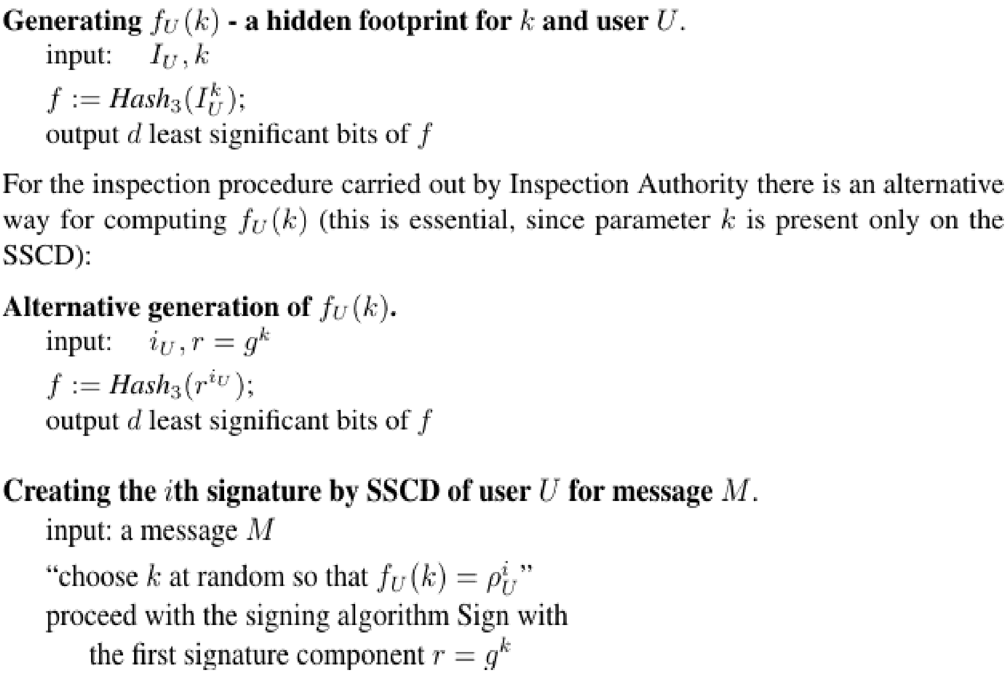
Inspection Authority: IA has a long period secret key k_{master}. For a user U, IA determines the control key $c_U := Hash_1(U, k_{master})$, and a pair of inspection keys: the private key $i_U = Hash_2(U, k_{master})$, and the public key $I_U = g^{i_U}$.

Card Issuer: for a user U, Card Issuer obtains the keys c_U and I_U from IA and installs them in the SSCD issued for U.

Signatories: the SSCD of a user U holds the preinstalled keys c_U and I_U, as well as the private signature key x_U created at random by the SSCD, and the public key $X_U = g^{x_U}$. (Note that the SSCD does not hold the key i_U.)

Certification Authority: CA has standard keys for issuing certificates for the public keys of the users, just as in PKI built according to the X.509 framework.

footprints:



Generating $f_U(k)$ - a hidden footprint for k and user U.

```
input:    $I_U, k$
$f := Hash_3(I_U^k)$;
output $d$ least significant bits of $f$
```

For the inspection procedure carried out by Inspection Authority there is an alternative way for computing $f_U(k)$ (this is essential, since parameter k is present only on the SSCD):

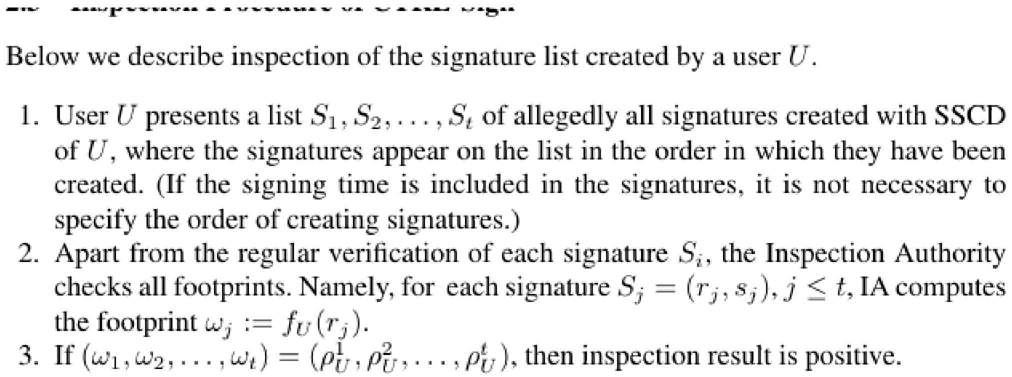
Alternative generation of $f_U(k)$.

```
input:    $i_U, r = g^k$
$f := Hash_3(r^{i_U})$;
output $d$ least significant bits of $f$
```

Creating the ith signature by SSCD of user U for message M.

```
input: a message $M$
"choose $k$ at random so that $f_U(k) = \rho_U^i$"
proceed with the signing algorithm Sign with
    the first signature component $r = g^k$
```

Inspection



Below we describe inspection of the signature list created by a user U.

1. User U presents a list $S_1, S_2, \ldots, S_t$ of allegedly all signatures created with SSCD of U, where the signatures appear on the list in the order in which they have been created. (If the signing time is included in the signatures, it is not necessary to specify the order of creating signatures.)
2. Apart from the regular verification of each signature S_i, the Inspection Authority checks all footprints. Namely, for each signature $S_j = (r_j, s_j)$, $j \leq t$, IA computes the footprint $\omega_j := f_U(r_j)$.
3. If $(\omega_1, \omega_2, \ldots, \omega_t) = (\rho_U^1, \rho_U^2, \ldots, \rho_U^t)$, then inspection result is positive.

XI. COMMUNICATION SECURITY – SSL/TLS

Padding attack (Serge Vaudenay)

Scenario:

- for encryption the plaintext should have the length as a multiply of b
- pad the plaintext with n occurences of n, always pad something
- the resulting padded plaintext $x_1,...,x_N$ encrypt in CBC mode with IV (fixed or random) and a block cipher:

$$y_1 = \mathrm{Enc}(\mathrm{IV} \oplus x_1), \quad y_i = \mathrm{Enc}(y_{i-1} \oplus x_i)$$

- CBC:
  - efficiency
  - confidentiality limits: if IV fixed one can check that two plaintexts have the same prefix of a given size
  - CBC-MAC has security flaws: m_1 and m_2 augment by extra blocks: due to birthday paradox we might create the same MAC

attack:

- manipulate the ciphertext
- destination node decrypts, can see incorrect padding
- decision: what to do if padding incorrect?
  - → reject: creates padding oracle
  - → proceed: enables manipulation of the data

last word oracle:

- goal: compute $\mathrm{Dec}(y)$
- create an input for padding oracle:
  - $r = r_1...r_b$ chosen at random, $c := r|y$
  - oracle call: if $O(c) = \mathrm{valid}$, then $y_b = r_b \oplus 1$ whp
  - recognizing other cases:
    1. pick $r_1, r_2..., r_b$ at random, take $i = 0$

2. put $r = r_1 r_2 ... r_{b-1}(r_b \oplus i)$

3. run padding oracle on $r||y$, if result “invalid” then increment i and goto (2)

4. $r_b := r_b \oplus i$

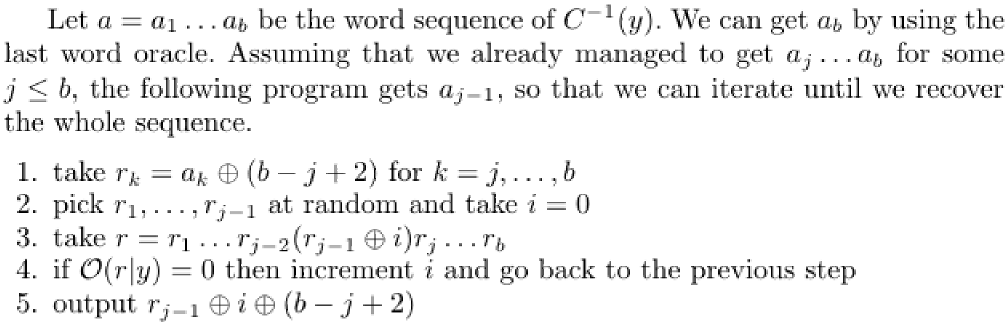
5. for $j = b$ to 2:

   $r := r_1 ... r_{b-j}(r_{b-j+1} \oplus 1) r_{b-j} ... r_b$

   ask padding oracle for $r||y$, if “invalid” then output $(r_{b-j+1} \oplus j) ... (r_b \oplus j)$ and halt

6. output $r_b \oplus 1$

block decryption oracle



Let $a = a_1 \ldots a_b$ be the word sequence of $C^{-1}(y)$. We can get a_b by using the last word oracle. Assuming that we already managed to get $a_j \ldots a_b$ for some $j \leq b$, the following program gets a_{j-1}, so that we can iterate until we recover the whole sequence.

1. take $r_k = a_k \oplus (b - j + 2)$ for $k = j, \ldots, b$
2. pick $r_1, \ldots, r_{j-1}$ at random and take $i = 0$
3. take $r = r_1 \ldots r_{j-2}(r_{j-1} \oplus i) r_j \ldots r_b$
4. if $\mathcal{O}(r|y) = 0$ then increment i and go back to the previous step
5. output $r_{j-1} \oplus i \oplus (b - j + 2)$

decryption oracle

- block by block

- the only problem with the first block if IV is secret

bomb oracles:

- padding oracle in SSL/TLS breaks the connection if padding error, so can be used only once

- bomb oracle: try a longer part at once

other paddings:

- 00….0n instead of nn….n – also vulnerable

- 12….n instead of nn….n – also vulnerable

- <random>n instead of nn….n – last word only, possible detection of padding length 1 (if encrypted twice with fixed IV)

Applications for (old) versions of SSL/TLS, ...

- MAC applied before padding, so padding oracle techniques can be applied

- wrong MAC and wrong padding create the same error message - from SSL v3.0, debatable whether it is impossible to recognize situation via side channel (response time)

- TLS attempts to hide the plaintext length by variable padding

- checking the length of padding: take the last block y, send $r|y$ where the last word of r is $n \oplus 1$. acceptance means that the padding is of length n

- checking longer paddings: send ry_1y_2 where y_1y_2 are the last blocks

- IPSEC: discards message with a wrong padding, no error message

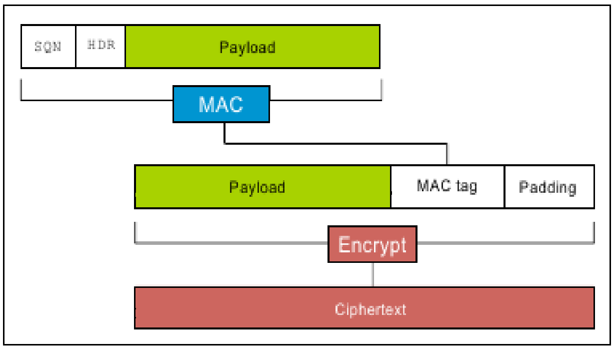
- WTLS: decryption-failed message in clear (!) session not interrupted

- SSH: MAC after padding (+)

Lucky Thirteen

- concerns DTLS (similar to TLS for UDP connections)

- MAC-Encode-Encrypt paradigm (MEE), MAC is HMAC based

- 

- 8-byte SQN, 5-byte HDR (2 byte version field, 1 byte type field, 2 byte length field)

- size of the MAC: 16 bytes (HMAC-MD5), 20 bytes (HMAC-SHA1), 32 bytes (HMAC-SHA-256)

- padding: $p+1$ copies of p, at least one byte must be added

- after receiving: checking the details: padding, MAC, (underflow possible if padding manipulated and removing blindly)

- HMAC of M:

  $T := H((K_a \oplus \text{opad})||H((K_a \oplus \text{ipad})||M))$

  to M append the length field encoded

- **Distinguishing attack:**

→ M_0: 32 arbitrary bytes followed by 256 copies of 0xFF

→ M_1: 287 bytes followed by $0x00$

→ both 288 bytes, 18 plaintext blocks

→ encoded $M_d||T||\text{pad}$, we aim to guess d

→ C – the ciphertext

→ create a ciphertext C' by truncating all parts corresponding to $T||\text{pad}$

→ give $\text{HDR}||C'$ for decryption

→ if M_0: the 256 copies of 0xFF interpreted as padding and removed, remaining 32 bytes as short message and MAC, calculating MAC: 4 hash computed, then typically error returned to the attacker

→ if M_1: 8 hash evaluations

Plaintext recovery attacks

- C^* – the block of ciphertext to be broken, C' – the ciphertext block preceding it
- we look for P^*, where $P^* = \text{Dec}(C^*) \oplus C'$
- assume CBC with known IV, $b = 16$ (as for AES). $t = 20$ (as for HMAC-SHA-1)
- let Δ be a block of 16 bytes, consider

  $$C^{\text{att}}(\Delta) = \text{HDR}||C_0||C_1||C_2||C' \oplus \Delta||C^*$$

  4 non-IV blocks in plaintext, the last:

  $$P_4 = \text{Dec}(C^*) \oplus (C' \oplus \Delta) = P^* \oplus \Delta$$

- case 1: P_4 ends with 0x00 byte:
  - 1 byte of padding is removed, the next 20 bytes interpreted as MAC, 43 bytes left - say R. MAC computed on SQN|HDR|R of 56 bytes
- case 2: P_4 ends with padding pattern of ≥ 2 bytes:
  - at least 2 bytes of padding removed, 20 bytes interpreted as MAC, at most 42 bytes left, MAC over at least 42+13=55 bytes
- case 3: P_4 ends with no valid padding:
  - according to RFC of TLS 1.1, 1.2 treated as with no padding , 20 bytes treated as MAC, verification of MAC over 44+13=57 bytes

    – MAC computed to avoid other timing attack!
- time: case 1 and 3: 5 evaluations of SHA-1, case 2: 4 evaluations of SHA-1, detection of case 2 possible in LAN

- in case 2: most probable is the padding 0x01 0x01, all other paddings have probability about $\approx\frac{1}{256}$ of probability of 0x01 0x01, so we may assume that $P_4 = P^* \oplus \Delta$ ends with 0x01 0x01. Then we derive the last two bytes of P^*.

  repeat the attack with Δ' that has the same last two bytes to check if the padding has the length bigger than 2.

- after recovery of the last two bytes the rest recovered byte by byte from right to left:

  - the original padding attack

  - e.g. to find 3rd rightmost byte set the last two bytes Δ so that P_4 ends with 0x02 0x02, then try different values for the Δ_{13} so that Case 2 occurs (meaning that P_4 ends with 3 bytes 0x02

  - average time: $14 \cdot 2^7$ trials

- practical issues:

  → for TLS after each trial connection broken, so multi-session scenario

  → timing difference small, so necessary to gather statistical data

  → complexity in fact lower, since the plaintexts not from full domain : e.g. http username and password are encoded Base64

  → partial knowledge may speed up the recovery of the last 2 bytes

  → less efficient configuration of the lengths for HMAC-MD5 and HMAC-SHA-256

BEAST

attack, phase 0:

1. P to be recovered (e.g. a password, cookie, etc), requires ability to force Alice to put secret bits on certain positions

2. force Alice to send $0...0P_0$ (requires malware on Alice computer)

3. eavesdrop and get $C_p = \mathrm{Enc}(C_{p-1} \oplus 0...0P_0)$

4. guess a byte g

5. force Alice to send the plaintext $C_{i-1} \oplus C_{p-1} \oplus 0...0g$

6. Alice sends $C_i = \mathrm{Enc}(C_{i-1} \oplus C_{i-1} \oplus C_{p-1} \oplus 0...0g) = \mathrm{Enc}(C_{p-1} \oplus 0...0g)$

7. if $C_i = C_p$ then $P_0 = g$

attack phase 1:

1. P_0 already known

2. force Alice to send $0...0P_0P_1$ and proceed as in phase 0

last phase: we get the test for the whole $P_0...P_{15}$

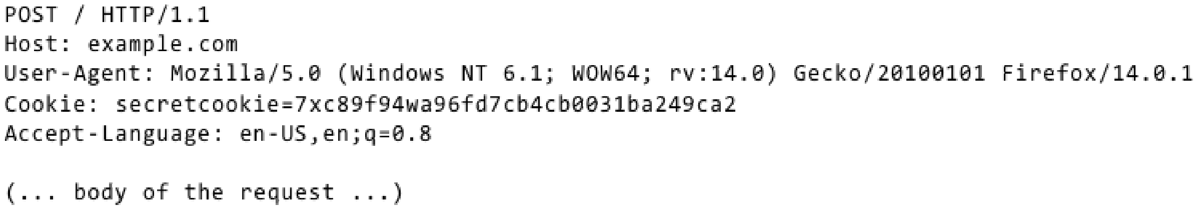
protection: browser must be carefully designed and do not admit injecting plaintexts (SOP- Same Origin Protection). Some products do not implement it.

CRIME (2012)

- based on compression algorithm used by some (more advanced) versions of TLS

- compression: LZ77 and then Huffman encoding, LZ77- sliding window approach: instead of a string put a reference to a previous occurence of the same substring

- idea of recovering cookie:

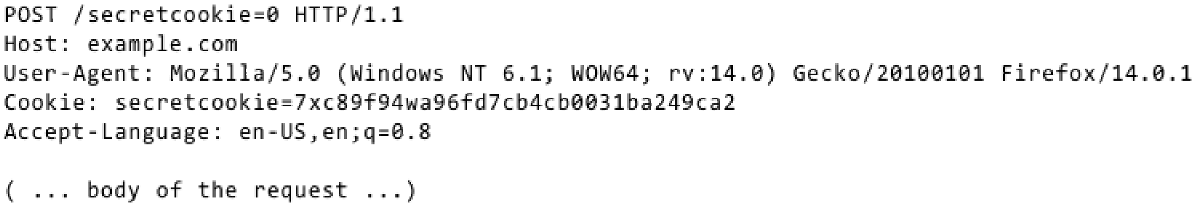


```
POST / HTTP/1.1
Host: example.com
User-Agent: Mozilla/5.0 (Windows NT 6.1; WOW64; rv:14.0) Gecko/20100101 Firefox/14.0.1
Cookie: secretcookie=7xc89f94wa96fd7cb4cb0031ba249ca2
Accept-Language: en-US,en;q=0.8

(... body of the request ...)
```

Listing 1: *HTTP request of the client*

modified POST:



```
POST /secretcookie=0 HTTP/1.1
Host: example.com
User-Agent: Mozilla/5.0 (Windows NT 6.1; WOW64; rv:14.0) Gecko/20100101 Firefox/14.0.1
Cookie: secretcookie=7xc89f94wa96fd7cb4cb0031ba249ca2
Accept-Language: en-US,en;q=0.8

( ... body of the request ...)
```

Listing 2: *HTTP request modified by the attacker*

LZ77 compresses the 2nd occurence of secretcookie= or secretcookie=0. We try all

secretcookie=i to find out the case when compression is easier (secretcookie=7)

when the first character recovered the attacker repeats the attack for the second character (trying all “secretcookie=7i” in the preamble)

TIME

- again based on compression but now on the server side (from the client to the server compression might be disabled and CRIME fails)

- works if the server includes the client’s request in the response (most do!)

- works even if SOP is enabled. SOP does not control data with the tag `img`, so the attacker can manipulate length

- attacker requires malicious Javascript on the client’s browser

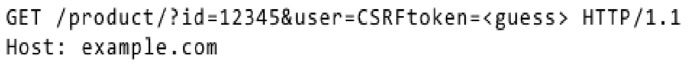
- attacker tries to get the secret value sent from the server to the client

- mechanism:
  - → as in CRIME, the request sends “secretvalue=x” where x varies
  - → the response is compressed, so it takes either “secretvalue=” or “secretvalue=x”
  - → the length manipulated so that either two or one packets – connection specific data must be used: Maximum Transmission Unit
  - → RTT (round trip time) measured
- independent on the browser, it is not an implementation attack!
- countermeasure: restrict displaying images

BREACH

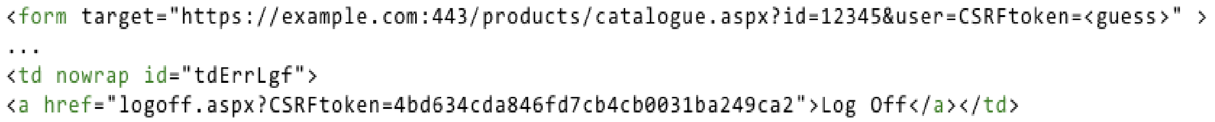
Browser Reconnaissance and Exfiltration via Adaptive Compression of Hypertext

- attack against HTTP compression and not TLS compression as in case of CRIME
- a victim visits attacker-controlled website (phishing etc).
- force victim’s computer to send multiple requests to the target website.
- check sizes of responses



```
GET /product/?id=12345&user=CSRFtoken=<guess> HTTP/1.1
Host: example.com
```

Listing 4: *Compromised HTTP request*



```
<form target="https://example.com:443/products/catalogue.aspx?id=12345&user=CSRFtoken=<guess>" >
...
<td nowrap id="tdErrLgf">
<a href="logoff.aspx?CSRFtoken=4bd634cda846fd7cb4cb0031ba249ca2">Log Off</a></td>
```

Listing 5: *HTTP response*

- requirements: application supports http compression, user’s input in the response, sensitive data in the response
- countermeasures:
  - → disabling compression
  - → hiding length
  - → no secrets in the same response as the user’s data
  - → masking secret: instead of S send $R||S \oplus R$ for random R (fresh in each response)
  - → trace behaviour of requests and warn the user

POODLE (2014)

in SSL v.3.0 using technique from BEAST:

- encrypted POST request:

  POST /path Cookie: name=value... ⟨r\n\r\n⟩ body ||20-byte MAC||padding

- manipulations such that:

  - the padding fills the entire block (encrypted to C_n)

  - the last unknown byte of the cookie appears as the last byte in an earlier block encrypted into C_i

- attack: replace C_n by C_i and forward to the server

  usually reject

  accept if $\mathrm{Dec}_K(C_i)[15] \oplus C_{n-1}[15] = 15$, thereby $P_i[15] = 15 \oplus C_{n-1}[15] \oplus C_{i-1}[15]$

  proceed in this way byte by byte

- downgrade dance: provoke lower level of protection by creating errors say in TLS 1.0, and create connection with SSL v3.0

- the attack does not work with weak (!) RC4 becouse of no padding

Weaknesses of RC4

- known weaknesses:

  → the first 257 bytes of encryption strongly biased, ≈200 bytes can be recovered if ≈232 encryptions of the same plaintext available

  simply gather statistics as in case of Ceasar cipher

  → at some positions (multiplies of 256) if a zero occurs then the next position more likely to contain a zero

- broadcast attack: force the user to encrypt the same secret repeatedly and close to the beginning

- countermeasure: no secrets in the initial part!

TLS 1.2

differences with TLS 1.1 and TLS 1.0 (Edukacja runs with TLS 1.0):

- explicit IV instead of implicit IV

- IDEA and DES 64bit removed

- MD5/SHA-1 PRF 65 is replaced with a suite specified hash function – SHA-256 for all TLS 1.2 suites, but in the future also SHA-3, ...

- digitally-signed element includes the hash algorithm used
- Verify_data length is no longer fixed length ⇒ TLS 1.2 can define SHA-256 based cipher suites
- new encryption modes allowed:
  - **CCM**

    Prerequisites: block cipher algorithm; key K; counter generation function; formatting function; MAC length $Tlen$

    Input: nonce N; payload P of $Plen$ bits; valid associated data A

    Computation: Steps:

    1. formatting appleid to (N, A, P), result: blocks $B_0, ..., B_r$

    2. $Y_0 := \mathrm{Enc}_K(B_0)$

    3. for $i = 1$ to r

    a) $Y_i := \mathrm{Enc}_K(B_i \oplus Y_{i-1})$

    b) $T := \mathrm{MSB}_{Tlen}(Y_r)$

    c) generate the counter blocks $\mathrm{Ctr}_0, \mathrm{Ctr}_1, ..., \mathrm{Ctr}_m$ for $m = Plen/128$

    d) for $j = 0$ to m: $S_j := \mathrm{Enc}_K(\mathrm{Ctr}_j)$

    e) $S := S_1 || ... || S_m$

    f) $C := (P \oplus \mathrm{MSB}_{Plen}(S)) || (T \oplus \mathrm{MSB}_{Plen}(S))$

    Decryption:

    1. return INVALID, if $Clen < Tlen$

    2. generate the counter blocks $\mathrm{Ctr}_0, \mathrm{Ctr}_1, ..., \mathrm{Ctr}_m$ for $m = Plen/128$

    3. for $j = 0$ to m: $S_j := \mathrm{Enc}_K(\mathrm{Ctr}_j)$

    4. $S := S_1 || ... || S_m$

    5. $P: = \mathrm{MSB}_{Clen}(C) \oplus \mathrm{MSB}_{Plen}(S)$

    6. $T := \mathrm{LSB}_{Tlen}(C) \oplus \mathrm{MSB}_{Tlen}(S_0)$

    7. If N, A or P invalid, then return INVALID, else reconstruct $B_0, ..., B_r$

    8. recompute $Y_0, ..., Y_r$

    9. if $T \neq \mathrm{MSB}_{Tlen}(Y_r)$, then return INVALID, else return P.

  - **GCM (The Galois/Counter Mode)**

    (a) $H = \mathrm{Enc}(K, 0^{128})$

    (b) $Y_0 = \mathrm{IV} || 0^{31}1$ if length of IV should be 96

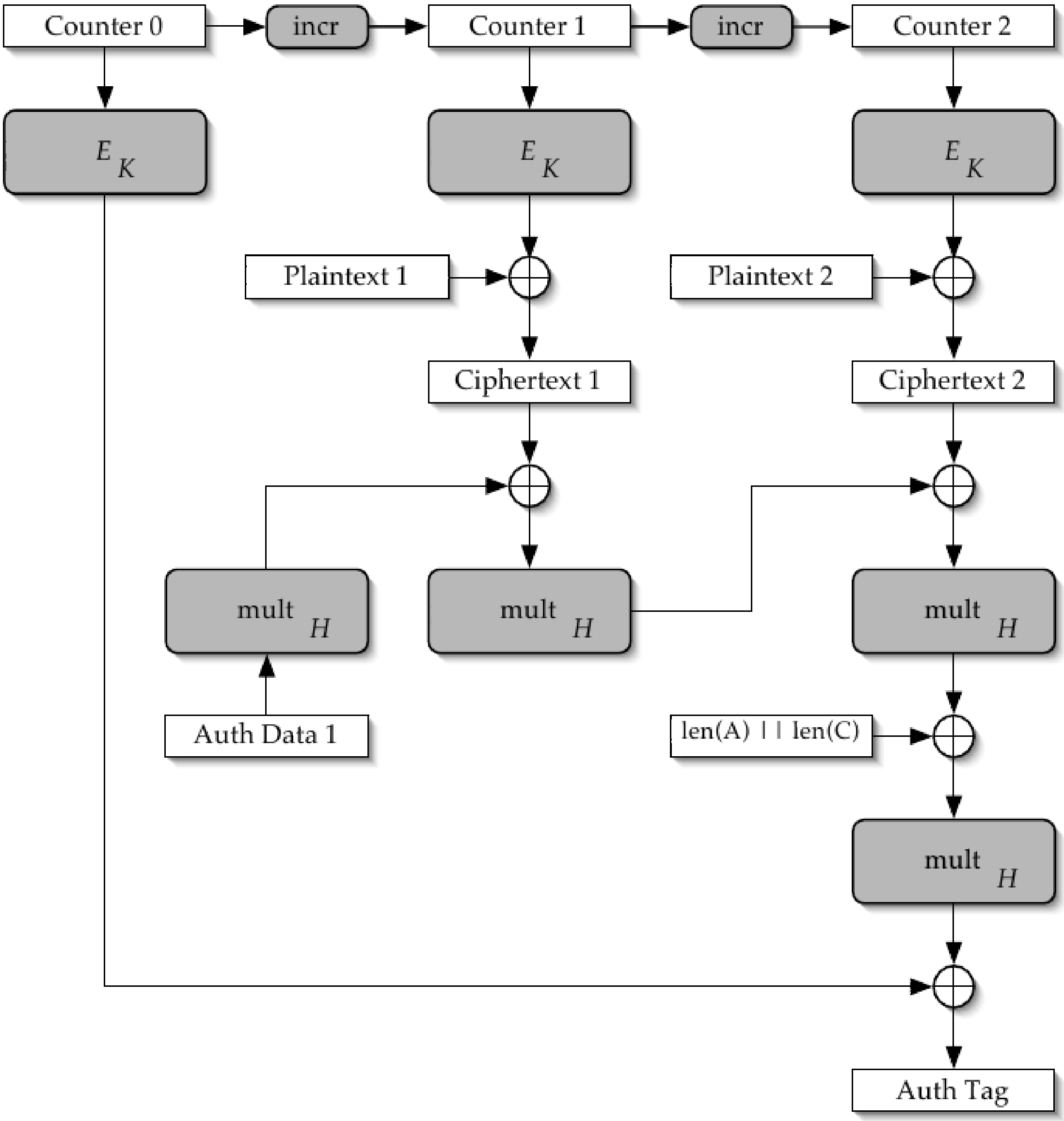
    or $Y_0 = \mathrm{GHASH}(H, \{\}, \mathrm{IV})$

    (c) $Y_i: = \mathrm{incr}(Y_{i-1})$ for $i = 1, ..., n$

    (d) $C_i := P_i \oplus \mathrm{Enc}(K, Y_i)$ for $i = 1, ..., n - 1$

(e) $C^*_n := P_n \oplus \mathrm{MSB}_u(\mathrm{Enc}(K, Y_n))$

(f) $T := \mathrm{MSB}_t(\mathrm{GHASH}(H, A, C) \oplus \mathrm{Enc}(K, Y_0))$



$\mathrm{GHASH}(H, A, C) = X_{m+n+1}$ where

$$X_i = \begin{cases} 0 & \text{for } i = 0 \\ (X_{i-1} \oplus A_i) \cdot H & \text{for } i = 1, \ldots, m-1 \\ (X_{m-1} \oplus (A^*_m \| 0^{128-v})) \cdot H & \text{for } i = m \\ (X_{i-1} \oplus C_i) \cdot H & \text{for } i = m+1, \ldots, m+n-1 \\ (X_{m+n-1} \oplus (C^*_m \| 0^{128-u})) \cdot H & \text{for } i = m+n \\ (X_{m+n} \oplus (\mathrm{len}(A) \| \mathrm{len}(C))) \cdot H & \text{for } i = m+n+1. \end{cases}$$

Decryption:

$$H = E(K, 0^{128})$$

$$Y_0 = \begin{cases} IV \| 0^{31}1 & \text{if } \mathrm{len}(IV) = 96 \\ \mathrm{GHASH}(H, \{\}, IV) & \text{otherwise.} \end{cases}$$

$$T' = \mathrm{MSB}_t(\mathrm{GHASH}(H, A, C) \oplus E(K, Y_0))$$

$$Y_i = \mathrm{incr}(Y_{i-1}) \text{ for } i = 1, \ldots, n$$

$$P_i = C_i \oplus E(K, Y_i) \text{ for } i = 1, \ldots, n$$

$$P_n^* = C_n^* \oplus \mathrm{MSB}_u(E(K, Y_n))$$

Certified Lies

– rogue certificates + MiTM

– no control over root CA's

– compelled assistance from CA's

ROGUE Certificates and MD5

- target: create a certificate (webserver, client) that has not been issued by CA
- not forging a signature but:

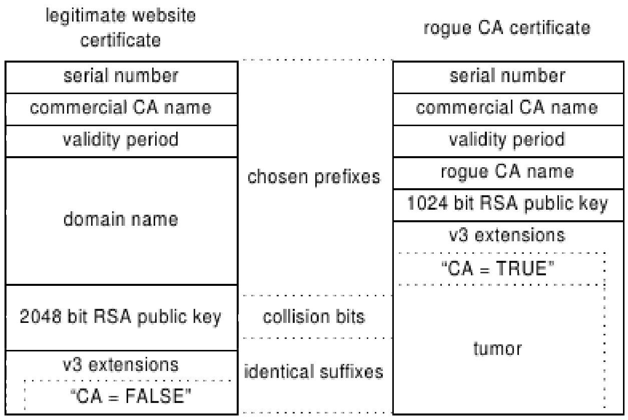
  i. find two messages that Hash(M_0) = Hash(M_1) and M_0 as well as M_1 have some common prefix that you expect in a certificate

  ii. submit a request corresponding to M_0, get a certificate with the signature over Hash(M_0)

  iii. copy the signature to a certificate based on M_1

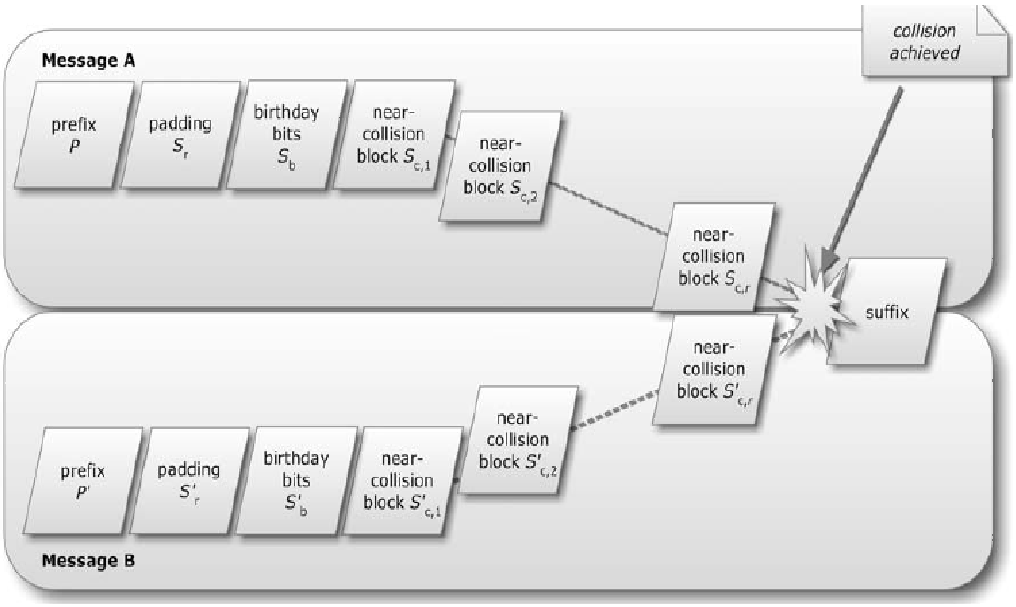
- problems: some data in M_0 are to be guessed : sequential number, validity period,

  other are known in advance: distinguished name, ...



- finding M_0 and M_1 has to be fast (otherwise the guess about the serial number and validity will fail) - e.g. a day over the weekend

- attack on MD5, general picture:


collision achieved
Message A
prefix P
padding S_r
birthday bits S_b
near-collision block $S_{c,1}$
near-collision block $S_{c,2}$
near-collision block $S_{c,r}$
suffix
near-collision block $S'_{c,r}$
near-collision block $S'_{c,2}$
prefix P'
padding S'_r
birthday bits S'_b
near-collision block $S'_{c,1}$
Message B

- identical prefix, birthday bits, near collision blocks:
  - birthday bits: 96, end at the block boundary, RSA bit in certificate, tumor (ignored part by almost all software) in rogue

    birthday bits make the difference of intermediate hash value fall into a good class
  - then 3 near-collision 512-bit blocks. website 208 + 96 + 3·512 = 1840 bits of RSA modulus. rogue certificate: tumor
  - after collision bits, 2048-1840 = 208 bits needed to complete the RSA modulus of the webpage.

    – continued so that two prime factors:

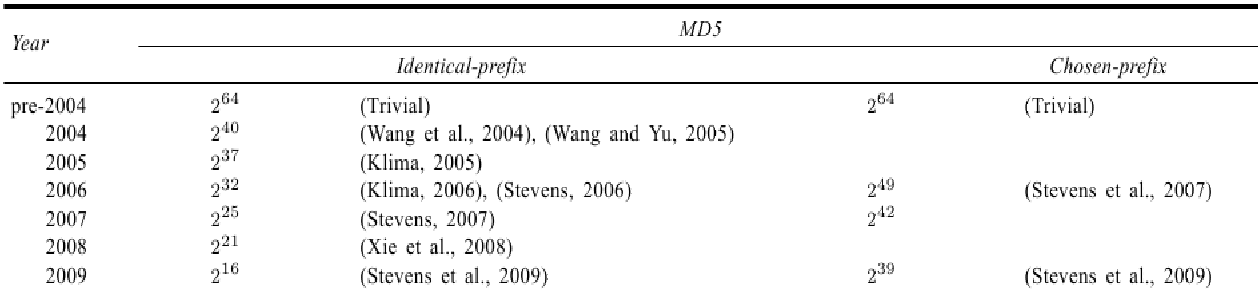
    → B denotes the fixed 1840-bit part of the RSA modulus followed by 208 bits

    → select a random 224-bit integer q until $B \bmod q < 2^{208}$, continue until both q and $\lfloor B/q \rfloor$ are prime

    → (purely esthetic reasons: smallest fact is more than 67-digit prime)

    → ... one can create RSA signature for the webpage for the certificate request

- attack complexity (number of hash block evaluations)



Year	*MD5*			
	Identical-prefix		*Chosen-prefix*	
pre-2004	2^{64}	(Trivial)	2^{64}	(Trivial)
2004	2^{40}	(Wang et al., 2004), (Wang and Yu, 2005)		
2005	2^{37}	(Klima, 2005)		
2006	2^{32}	(Klima, 2006), (Stevens, 2006)	2^{49}	(Stevens et al., 2007)
2007	2^{25}	(Stevens, 2007)	2^{42}	
2008	2^{21}	(Xie et al., 2008)		
2009	2^{16}	(Stevens et al., 2009)	2^{39}	(Stevens et al., 2009)

Year	*SHA-1*			
	Identical-prefix		*Chosen-prefix*	
pre-2004	2^{80}	(Trivial)	2^{80}	(Trivial)
2005	2^{69}	(Wang et al., 2005b)		
	(u: 2^{63})	(Wang et al., 2005a)		
2006			(u: $2^{80-\epsilon}$)	(Rechberger, 2006)
2007	(u: 2^{61})	(Mendel et al., 2007)		
2008				
2009	(w: 2^{52})	(McDonald et al., 2009)		
2012	2^{65}	(Stevens, 2012)	2^{77}	(Stevens, 2012)