

Chapter 6

Methods of cryptanalysis

Applications of cryptoalgorithms in other contexts than secure communication

Future prospects of cryptography

Methods of cryptanalysis

Cryptanalysis = the art and process of analyzing and decrypting ciphers, codes, and encrypted text without using the real key

Cryptanalyst = expert in the field of cryptanalysis

1. Ciphertext only -attack
2. Known plaintext - attack
3. Chosen plaintext -attack
4. Brute Force attack
5. Man in the Middle attack
6. Dictionary attack
7. Backdoors
8. Replay -attack
9. Side channel attack
10. Terminal attack
11. Quantum attack

1. Ciphertext - only attack (COA)

Cryptanalyst has large amounts of encrypted data

Classical ciphers including Enigma cipher machine can be broken with frequency analysis, if the cryptanalyst gets hold of adequately long encrypted messages.

2. Known plaintext attack (KPA)

Cryptanalyst has in possession both plaintexts and their encrypted versions

In WW2 the Allies knew how Germans used to finish their messages.

3. Chosen plaintext attack (CPA)

Cryptanalyst has in possession the encryption software of encryption machine and is able to make unlimited number of experiments with different plaintext

In WW2 the Allies managed to get in their hands one German Enigma- encryption machine.

Wikipedia has articles of these methods

4. Brute force attack

If the cryptanalyst has lots of computing power, he can browse the whole key space for the key.

Method can be used if key space is much lower than 80 bits. (DES and GSM encryption A5)

Generally 128 bit key is considered to have adequate safety margin against Brute Force

5. Man in the middle attack (MMA):

A third party E acts between communicating parties A and B pretending to be the other party to both directions. E can read and change data. **CA network, which provides authentic public keys, is planned to prevent the MMA -attack.**

6. Dictionary attack against password hashes

The hacker has a precalculated list of hash values of thousands of most common passwords. He looks matches from servers password files.

Countermeasures against dictionary attack are

- 1) Using only "strong passwords"
- 2) "salting" the passwords with random characters before hashing or
- 3) hiding password hashes to a so called "shadow file".

7. Backdoors

There are algorithms which have a intentional backdoor, a security hole, which can be used to break the decryption.

It is reported that in 2006 NIST accepted Dual EC-DRBG as a standard random number generator for international use.

It was withdrawn shortly after Edward Snowden revealed in 2013 that Dual EC-DRBG had a backdoor.

8. Replay attack:

The hacker captures from the channel users login – data reuses the data trying to log into the system.

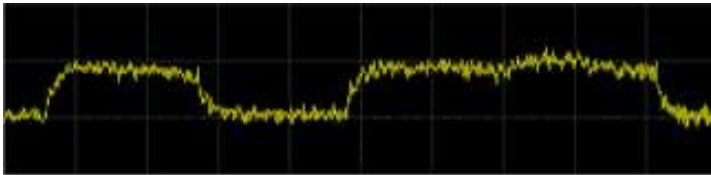
Using time stamps and serial numbers prevents this attack

Car thieves have used replay attack succesfully by recording the signals of car keys and reusing the signals

9. Side channel attack :

Example: An equipment measures radiation of processor, when RSA private key is used to calculate power $R^d \bmod n$.

Analysis of the spectrum of radiation or power consumption can give information about the private key d .



An attempt to decode RSA key bits using power analysis. The left peak represents the CPU power variations during the step of the algorithm without multiplication, the right (broader) peak – step with multiplication, allowing to read bits 0, 1.

Another example used against AES, is so called cache-timing attack, which tries to reduce effective key space by measuring time, which the computer uses for encryption. The time varies between different key choices.

10. Terminal takeover attack

Cryptoalgorithms are powerless, if the hacker has taken over the terminal of the user. Takeover is a significant cyber thread for businesses and individuals.

11. Quantum attack

AES256 is considered quantum resistant. It has the 128-bit resistance against quantum computing. By the 128-bit resistance, we mean the same kind of resistance that AES128 has against traditional computing. Current public key cryptography such as RSA is not quantum resistant.

NSA's attack forms

NSA = National Security Agency of USA

Public documents contain some information about NSA:s attack types.
Basic forms are following

- 1) Terminal takeover attacks
- 2) Tampering messages sent by email servers
- 3) Cooperation with service providers (Google, Facebook, RSA-lab,CA:s)
- 4) Mathematical methods¹⁾

¹⁾ It is generally assumed that mathematical methods are used for attempts to break 1024 –bit RSA public keys. Some experts think that this may already have succeeded.

Applications of cryptoalgorithms in other contexts than data encryption

- Password Tokens
- Remote Keyless Entry (RKE)
- Secret Sharing Systems
- Internet Voting

"Password Tokens"



The device produces fixed length one-time passwords for login.

TOTP (Time based One Time Password): The device creates a new password, for example, every half minute. Device and service should have synchronized clocks.

COTP (Counter based One Time Password): The device creates a new password every time when the button is pressed. Counter value acts as an input for the next password.

One-time passwords with HMAC

Generation of OTP is usually based on HMAC function which creates a fixed length hash from the SIM key K and the counter value C. Time T can also be used instead of a counter. The formula of HMAC is as follows.

$$\text{HMAC}(K, C) = \text{sha}(K \oplus \text{opad} || \text{sha}(K \oplus \text{ipad} || C))$$

HMAC has 60- bits. Truncate function reduces HMAC value to a 6 digit password.

The server has a precalculated list of passwords corresponding f.e. 128 counter values. The user is accepted to service, if the password send by the user is found in the list.

How secure are Security Tokens?

HMAC is secure. It is impossible to calculate SIM- key or counter value from the password.

From one password it is impossible to calculate the next one.

HMAC values fulfill all three properties of pseudorandomness.



REMOTE KEY ENTRY (RKE) OF CARS

1. IN FIRST GENERATION OF RKE the signal from the key is always the same.

Skilled criminals could record the signal, and, as soon as the owner was not present the thieves replayed the signal to open the doors.

2. IN SECOND GENERATION OF RKE the key had Counter based One Time Password (=COTP) generator. The lock of the car precalculated a list of 256 one-time passwords. If a signal received from the key was found on the list, the doors opened or were locked.

If the button of the key was pressed more than 256 times outside the range of the signal, the list ran out of keys and the owner had to call the service of car manufacturer to open the doors.

3. In third generation RKE the car key creates a **Time-Based one-time passwords (TOTP)**. The key and the lock generate a new password for example every half minute. Use of TOTP prevents a vulnerability of COTP explained below

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***Samy Kamkar** showed in Defcon 2015 conference an equipment which can be used for replay attack against 2nd generation RKE.*

Equipment used 3 radio devices. Two of them sends strong disturbance signals which prevent the signal from the key reach the lock. Third radio records and saves the signal.

When the owner pressed the button to shut the doors, lock does not react. Then the owner presses button again, the lock does not react to the second signal. The device of the thieves has recorded both signals. It sends quickly the first signal to the lock, which reacts and doors are closed.

As a result the thieves have one unused recorder signal in the device. They can replay it to steel the car.

Secret sharing

Secret sharing is an secure method of storing classified and important information. Examples: 1) safe deposits of important encryption keys 2) storage of missile launch codes 3) using anonymous bank accounts (Swiss banks)

Principle: Key for access to classified information is shared to parts called subkeys in such a way that n individuals have parts of the key. The key can be reconstructed if a minimum number k , which is a number less than n , of these individuals use their subkeys

Examples.

In a superpowers defence organization seven persons have subkeys to the launch codes of missiles. Launch codes can be accessed if any three of them use their subkeys.

Withdrawals can be made from an anonymous number account in a Swiss bank, when at least 3 persons use their subkeys (some of them may be bank clerks). The person making the withdrawal does not have to reveal his identity.

"Shamir's secret sharing scheme"

- A parabola $y = f(x) = a x^2 + b x + c$ is uniquely determined if three points on the parabola are known.
- Assume seven individuals are given one point (x,y) of a parabola.
- If any three of them give their points, the system can solve a , b and c .
- The shared key can be a value of $f(x)$ at a given point, for example $f(10)$.
- Shamir's scheme uses discrete parabola $y = a x^2 + b x + c \pmod{q}$, where a , b , c and modulus q are integers. It consists of integer pairs (x,y) , which satisfy the above equation.

Example of Shamir's scheme

1. Shared key K is the value of $f(x) = ax^2 + bx + c \pmod{q}$ at point $x = 10$, where modulus $q = 113$.
2. Seven individuals are given following keys (one for each):
 $\{7,91\}$ $\{49,41\}$ $\{110,85\}$ $\{51,49\}$ $\{18,74\}$ $\{58,87\}$ $\{72,59\}$

Users 1,3 and 7 give their subkeys $\{7,91\}, \{110,85\}, \{72,59\}$ to the system.

Now we can calculate parameters a, b and c . Manually it takes time, but with Mathematica software it is quite easy.

Mathematica software
solves a, b and c :

```
Reduce[a * 7^2 + b * 7 + c == 91 ∧  
a * 110^2 + b * 110 + c == 85 ∧  
a * 72^2 + b * 72 + c == 59, {a, b, c},  
Modulus -> 113]
```

```
a == 45 && b == 24 && c == 91
```

Shared key $K = (45 \cdot 10^2 + 24 \cdot 10 + 91) \pmod{113} = 85$

Internet -voting

In Net Voting the voter proves his identity with electronic ID card or mobile certificate.

Estonia is pioneer of net voting. Net voting has been widely used only in Estonia, where the system has been used for many years. In the last parliamentary election 51% of the voters voted in the Internet.

A group of data security experts (among others Finnish **Harri Hursti**) has criticized the safety of net voting in their article:

<https://jhalderm.com/pub/papers/ivoting-ccs14.pdf>

“As we have observed, the procedures Estonia has in place to guard against attack and ensure transparency offer insufficient protection. Based on our tests, we conclude that a state-level attacker, sophisticated criminal, or dishonest insider could defeat both the technological and procedural controls in order to manipulate election outcomes”

Netherlands moved back from net voting to paper ballots because of security concerns.

Future prospects

Algorithms are not changed unless there is a compelling need.

("Old, tested algorithms are better than a dozen of new")

When quantum computing reaches a certain level, major changes must be done:

Survivals in post-quantum era:

AES256 and AES512 survive as standard block ciphers

Useless methods in post-quantum era:

Key Exchange protocols RSA, DH, ECDHE become useless.

Some digital signatures, for example, sha256RSA cannot be used.

In July 2022, as a result of a competition, NIST approved two PQC algorithms as candidates to be standardized for most use cases in key exchange and digital signatures:

- 1) Crystals-Kyber key encapsulation mechanism
- 2) Crystals-Dilithium digital signature algorithm