

# Appunti Information System Security

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## Contents

<b>1</b>	<b>Introduzione</b>	<b>3</b>
<b>2</b>	<b>Some classes of attacks</b>	<b>4</b>
<b>3</b>	<b>Foundations</b>	<b>7</b>
3.1	Public key criptograpy . . . . .	10
3.2	Public key algorithm . . . . .	10
3.3	Diffie-Hellman (DH) . . . . .	11
<b>4</b>	<b>Message Integrity</b>	<b>11</b>
4.1	SHA-3 . . . . .	12
<b>5</b>	<b>Integrity and Secrecy</b>	<b>12</b>
5.1	Authenticated Encryption . . . . .	13
<b>6</b>	<b>Definitions of authentication</b>	<b>14</b>
<b>7</b>	<b>Esercizi</b>	<b>17</b>

# 1 Introduzione

Security Principles:

- security in depth: there must be more layers in security;
- security by design: you design the system to be secure;
- security by default: the security feature are turned on even if you don't want to;
- least privilege: when someone operates in the system, that program must have the minimum permission to allow the basic work;
- need-to-know: which data can be accessed by a program or by a human, a program must operate only on the sufficient data it needs;

Security properties:

**Peer authentication** When a person tries to perform an operation on system it has to prove its identity to the system, but even the system has to authenticate itself to the accessing user, this is called mutual authentication (when both peers have to authenticate).

**Data authentication** Non-repudiation: undeniable proof of the data creator; there needs to be several facets:

- authentication;
- integrity of the data;
- identification;
- ...

**Authorization (access control)** Someone has to give you the Authorization to perform some kind of action.

**Privacy (communication)** Someone listening to a conversation means to violate the privacy.

**Privacy (data, actions, position)** Keeping some data encrypted inside a disk to protect them from someone accessing them. By law the internet provider are required to keep track of all the visited websites up to some years in the past, those can be accessed in case of an investigation. The internet provider needs to keep track at any time of the position of the connected device.

**Integrity (data modification)** The manager of the network can in some way modify the data shared by the systems, it can also cancel some parts of the data or filtering specific ones.

**Replay attack** If the data is encrypted they can no longer be modified by an external actor. The data cannot be changed but it can be send more than once, a **replay attack**. This can be solved by giving an ID to every transaction.

**Data protection:**

- data in transit: data must be secured while travelling between systems;
- data at rest: even when the data is parked on the disk is not modified in any way;
- data at work: data at some point is copied in the RAM to perform some kind of action, and if an external program modifies them inside the RAM it will be never known;

**Basic Problems** Networks are insecure:

- most of the communication are in clear;
- LANs operate in broadcast;
- geographical connections are not made through end-to-end dedicated lines but through shared lines and third-party routers;
- weak user authentication;
- there is no server authentication;
- the software contains many bugs;

## 2 Some classes of attacks

**IP spoofing** : creating an IP packet that contains a different address, typically the level 3 and level 2 address. It's a technique to hide someone's identity. The attacks are: data forging a packet in someone else's name, or corrupting them. The countermeasures are: to never use an address-based authentication.

**Packet sniffing** : the ability to read the packets addressed to another network node, this is very to do in broadcast area networks (all intranet networks are broadcast). This attack allows to read the payload of the packets sniffed, the countermeasures are: to don't use broadcast networks (not possible), to encrypt the payload of the packets.

**Denial-of-Service (DoS)** : keeping an host busy so that it cannot perform any other relevant action. Some examples are:

- mail or log saturation;
- ping flooding;
- SYN attack

The purpose of the attack is to block the use of a system. There are no countermeasures, the only possibility is to monitor.

**Distributed Dos** The attacker is using many computers (deamons, zombie, ...), usually infected with a malware, those machines contrlled by another master are called **Botnet**. To control the machines the attacker may uses encrypted channels, using a CC structure (Command and Control).

Attack: some of the deamons are turned into masters contrlling all the deamons, the attacker unplugs from the network avoidnd being monitored, some time later the masters give the command to the deamons and they start attacking all the vectim.

**Shadow/fake server** There are two kind of tecnique to fake a server:

- being in the same network (sniffing packet), if I (the attacker) respond to the user faster than the server, now your connection is opened with me, now the victim exchanges informatios with the attacker;
- creating a fake DNS to my own versions of the servers, providing wrong services, capturing data;

The countermeasures are: server authentications.

**Connection hijacking (MITM, Data Spoofing)** The attacker takes phisycal control of some node, becoming a **Man In The Middle**, letting the comunications of two cominacotrs get through my node, reading all the traffic, being able to perform any action. The countermeasures: even if the channel is already opennd and the peers are already identified, the attackers can still take control of the comunications, to prevent this kind of attaks there needs to be some kind of authentication inside of the packets, even then also serializations is needed, beacause the attacker can swap the order of the packets.

**Trojan** A trojan is program containing a malicious payload. The networks are becoming more protected but terminals are becoming more vulnerable (smartphone, smartTV, IOT, ...). The attacker could trick the user into download an extension, or pirated copies of games, this programs could contain things like keyloggers. This attacks are colled:

- MATE: Man At The End;
- MITB: Man In The Browser;

**Zues** Also known as Zbot, this malware is installed on millions of devices, it can be used to:

- perform keylogging or form grabbing;
- to load other malware, like CryptoLocker ransomware;

It was very difficult to discover.

**Software Bugs** Bugs in a software are exploitable, thanks to them DoS can be performed.

### **Virus & Co. (malware)**

- virus: damages the target and replicates itself thanks to humans, requires involuntary complicity;
- worm replicates itself sucking all the available resources and propagating;
- trojan: a vector for malware;
- backdoor: entry point not known but the developers;
- rootkit: something installed in the computer that provides root access to the attacker, remaining unnoticed;
- PUA: Potentially Unwanted Applications, some applications not very dangerous but performing annoying operations;

**Ransomware** It's a kind of malware that is oriented on getting a ransom, typically performed by encrypting the disk or changing passwords. The only way of unlocking the device is to reset it, or

### **Social Engineering :**

- phishing:
- psychological pressure: asking for help, or impersonating a person of interest imposing to perform some action;

**Fake Mail** It can be possible to take an old email (send to the victim), copying it and changing the attachment with a malware.

Important classes of attacks:

- Stuxnet (2010): new king of attack, it was a worm + virus for Windows, it was the first time to attempt to damage a SCADA system. It contained in itself an attack based on a known vulnerability (patched), a known vulnerability (not patched), and 2 zero-day vulnerability. This malware was used to destroy a nuclear plant in Iran (in fact in Iran the spread was 51%), destroying most of the machines, the facility was isolated from internet, the only way it could have accessed it was via USB, the malware spread thanks to shared disks and old software with bugs, the malware also used digital signature validate by Microsoft;
- Mirai: it was a cyberworm exploiting IOT vulnerabilities, transforming the victim in botnets for a large scale attack. All these devices were because they have little to none protection. The software was compiled with static libraries, cross compiled and also open source. It also observes the victim before contacting the C&C, if it detects some security protection it contacts a fake C&C.

#### The pillars of security

- Planning;
- Avoidance;
- Detection;
- Investigation;

## 3 Foundations

**Cryptography** It's a mathematical algorithm that consists in: a clear message gets encrypted with a key, send to the receiver, that will decrypt the message with a second key to read the original message.

- message in clear: called: **plain text** or **P**;
- encrypted message: called **ciphertext** or **C**;

**Kerchoff's principle:**

- the keys need to be secret;
- the keys are managed by a trusted system;

- the keys needs to be of adequate lenght;

If this three priciples are met then the ecription and decryption algorithms can be public.

### Security through obscurity (STO)

**Secret key/symmetric cryptography** The key is shared

$$C = enc(K, P) \text{ or } C = PK$$

$$P = dec(K, C) = enc^{-1}(K, C)$$

The main problem of symmetric cryptography is how to share the shared key.

DES is an **obsolete** symmetric algorithm with 64 bit block and 56 bit key. AES is a **state of the art** symmetric algorithm that uses 128 bit block and 128-192-256 bit key.

**The XOR function** If the input is random the output has the same probability (the 0:1 have 50% probability of outcome).

**DES** It used 64 bits as a key but only 56 bits were for the key, the other 8 bit were parity bits, this algorithm was created to run fast on hardware.

**Triple DES (3DES)** 3DES works with 2 keys, following the algorithm:

$$C' = enc(K_1, P) \ C'' = dec(K_2, C') \ C = enc(K_1, C'')$$

3DES with 3 keys:

$$C' = enc(K_1, P) \ C'' = dec(K_2, C') \ C = enc(K_3, C'')$$

The reason why it's not good to encrypt twice with the same algorithm, the reason is beacause of the attack **meet-in-the-middle**, which allows to decrypt the data with  $2^{n+1}$  attempts if the keys are n-bit long, this is not a good enough improvemnt for the incresed volume of work added, or worse if the algorithm is part of a group there could exist a  $K_3$ :

$$enc(K_2, enc(K_1, P)) = enc(K_3, P)$$



**Meet-in-the-middle attack** Hypothesis:

- n-bit key;
- known P and C such that  $C = \text{enc}(K_2, \text{enc}(K_1, P))$ ;

Note:

- $\exists M$  such that  $M = \text{enc}(K_1, P)$  and  $C = \text{enc}(K_2, M)$ ;

Actions:

- compute  $2^n$  for  $X_i = \text{enc}(K_i, P)$ ;
- compute  $2^n$  for  $Y_j = \text{dec}(K_j, C)$ ;
- if  $X_i$  and  $Y_j$  are matched then  $K_i$  and  $K_j$  are found;
- false positives can be discarded with other  $(P, C)$  couples;

**Application of block algorithms** How a block algorithm is applied to a data quantity different from the algorithm's block size?

- ECB (Electronic Code Book): if we have to encrypt some data, we simply split the data in equal size blocks and encrypt every block with the same key, this is very insecure, for example an attacker could swap two ciphertext, also if there is a known plaintext the attacker could find the matching key and then decrypt all the ciphertext;
- CBC (Cipher Block Chaining): we also split the data, we take every block, and before encrypting the block we xor it with the previous encrypted block, for the initial block we use a IV (Initialization Vector,  $C_0$ ), for this reason the first block is the most vulnerable. In decryption to recover the plain text, the decrypted block will need to be xor-ed with the previous block (property of the xor function);

**Padding with explicit length**

- Schneier: the last byte has the value of bytes of padding, the other bytes are null;
- SSL/TLS: the bytes of padding are all at the value as the length of the padding;

If the data is an exact multiple of the block length, then the padding will have to be added in anyhow, if that is the case the last block will be entirely of padding.

**Ciphertext stealing (CTS)** CTS permits to use any block algorithm without requiring any padding to be added.

**CTR (Counter mode)**

**AES = rijndael** It can have 3 possible key length (128/192/256) and a block size of 128 bit.

### 3.1 Public key cryptography

It is an asymmetric algorithm, it means that the keys are different, one is used to encrypt and the other one is for decrypt, that is why they are called **key-pair**. They take a lot of time to compute, this is why it is used to encrypt small quantities of data, usually used to share symmetric keys.

The keys are called **public key** (SK) and a **private key** (PK), one encrypts the other decrypts, both of them can be interchangeable so we must chose which one of them must be public and which one must be kept secret.

**Digital signature** The idea of digital signature: the asymmetric keys provides a way of signing messages, if I encrypt my data with my private key, anybody else can decrypt that data the public key, this works because this only works with key-pair, and because the key used to encrypt is private nobody else know it, and the decryption only with the respective public key.

**Confidentiality without shared secrets** To share secret messages with someone: I can encrypt the data with the public key, sending the message to the receiver I am sure that nobody else can read the message, and when it reaches the receiver it can decrypt the message with his private key.

### 3.2 Public key algorithm

**RSA** It is based on the factorization of the product of two prime numbers, it can be used for both digital signature and confidentiality.

**DSA (Digital Signature Algorithm)** It is based on taking power, logarithm of the result, it can only be used for the digital signature.

Both DSA and RSA are going deprecated.

**Certificate** How to bind a public key to the identity of the person? To avoid this kind of problem a **public-key certificate** has been created.

**Secret key exchange** One way of sharing keys between two users is to encrypt the symmetric key with the public key of the receivers, the receiver can then decrypt the symmetric key with his private key and then both of them can start sharing messages with symmetric keys. This is the base of secret communications nowadays. This is still not secure because the sender can choose the password and share it with somebody else.

### 3.3 Diffie-Hellman (DH)

There are some common parameters know. Sender  $A = g^x \bmod p$ ; Receiver  $B = g^y \bmod p$ . Then A and B are shared,

This algorithm is not a good algorithm in the case of a man-in-the-middle attack, this can be rendered more secure with a certification.

**DH, RSA and quantum computing** Quantum computer pose a threat to those kind of algorithm, there is a quantum algorithm called **Shor's algorithm** that can factorize a number in  $O(N^3)$  time.

**Elliptic Curve Cryptography** Instead of using modular arithmetic but we take computation on a plane that represent the graph of an elliptic curve, this kind of algorithm is more secure than RSA or DSA, in fact the keys are shorter.

- **ECDSA**: digital signature;
- **ECDH**: for key agreement;
- **ECMQV**: authenticated key agreement;

## 4 Message Integrity

Even if something has been encrypted it does not mean it cannot be damaged. The normal way of computing data integrity is to create a **digest**. A digest is always of a fixed length, and it is created with a mathematical algorithm, in cybersecurity a digest is always created with a **cryptographic hash function**. The structure of a hash function is always the same: it splits the data in blocks and in computing a new block it reuses the previous block. The families of the hash functions are:

- sha-2: sha-256, sha-512, ..., good enough, but they are based on the algorithm of sha-1 which has already been attacked;
- sha-3: most secure;

An important part of the hash function is create less **collisions** possible, a collision occurs when two different messages create two identical digests.

## 4.1 SHA-3

The selected sha-3 algorithm was **Keccak**, it has simple implementation and it has very good performance on a variety of very different hardware.

**KDF** The hash functions are also used for **deriving passwords** (**KDF** Key Derivation Function). The KDF is composed of:

- P = password;
- S = salt;
- I = number of iteration;

The password is derived in following way: (da ricontrollare)

$$\text{hash}_{I\text{-times}}(P||S)$$

MAC, MIC, MID ...

**keyed-digest HMAC** A hmac is a function to compute the digest, with HMAC the Hash function needs to be specified like: HMAC-SHA256.

**CBC-MAC** CBC can also be used to create the digest of some data, you discard all the block except for the last one, in this way all the previous blocks are used.

## 5 Integrity and Secrecy

We use:

- K1: symmetric encryption;
- K2: key-digest

How do you use the two keys?

1. authenticate and encrypt:
2. authenticate then encrypt:
- 3.

Combining authentication and integrity is not good. The solution is **Authenticated Encryption (AE)**.

## 5.1 Authenticated Encryption

da finire

- peer authentication:
- data origin authentication:
- confidentiality:
- integrity:
- authorization:
- non-repudiation:
- availability:
- accountability:

## 6 Definitions of authentication

Usually an "actor" needs to be handled authentication, called authN (or authC), the authorization is given authZ.

knowledge: something the user knows; ownership: something the user possesses (like a bank card chip); inherence: something the user is; This can also be applied to hardware and software.

Risks for those: The risk of knowledge (e.g. passwords): how to protect known passwords. ownership (e.g. smartphone): for example owning a smartphone with a malware that can read some data, or it could be stolen, ... inherence (e.g. biometrics): counterfeiting (the fingerprint can be reproduced) and privacy, this is why inherence must only be used locally;

Nowadays systems are getting more and more complex, digital authentication model (NIST SP800.63B) an applicant when trying to enroll and proving his identity, the CPS (credential service provider) gives you authenticator enrollment/issuance, so it becomes a subscriber, a relying party (like SPID) takes an authenticated session from a subscriber.

Or a claimant can rely on a relying party (like SPID), a that communicates with a verifier (like [isp.polito.it](http://isp.polito.it)), when the relying party instates ..... da finire .....

Authentication protocol, is protocol that runs between a verifier and a client, the user has a UserID and a secret associated with the UID, the verifier contains a UID with a the result of a function that takes the SUID,  $\{ \text{UID} : f(\text{SUID}) \}$ , 1. user: authentication request; 2. user: UID 3. verifier: proof request; 4. user: proof =  $F(\text{SUID})$

1. Reusable password as SUID: user: has a PIUD, verifier has  $(\text{UID} : H(\text{PIUD}))$  the client creates and transmits the password, the server needs to verify the proof: 1.

1. password in clear text 2. proof = password ?

2. 1. server knows the digest of a password 2.  $f(\text{proof}) = H(\text{PIUD})$  ?

The only advantage is that is simple to handle for a user, the cons are: some passwords are easy to discover, the user has to remember lots of passwords.

password best practices: 1. alpha char (up + lower) + number + special char; 2. they need to be long; 3. never use dictionary words 4. frequently changed 5. don't use passwords

server side: 1. never store the password in clear 2. store a digest of a password 3. dictionary attack: to protect from this attack a salt needs to be inserted 4. using a protected store accessible by one password

Dictionary attack: Hypothesis: the attacker knows the hash algo and all the digests the attacker uses a large dictionary of words, and stores the digest associated with each word. After the precomputation the attacker,  $HP = \text{hash of unknown password } w = \text{lookup} (DB, HP)$  if we the attacker finds a match then he found the original password.

To defeat this attack a salt needs to be used for every UID, the salt is a random long number generated by the verifier the verifier stores  $HP = \text{hash} ( \text{pwd} \text{ --- salt}$

), { UID, HP(UID), salt(UID) }. The reason why this is effective is because the dictionary attack is based on precomputation, if the data gets stolen it will take a lot of time to recompute all the hashes, and by the time the attacker found a match the password may have been changed, also every UID has a different salt.

Originally linux stored passwords in /etc/passwd with a DES hash function, since that file needs to be world-readable (UID, GID, home shell, ..) they have been moved to /etc/shadow (it's not readable by normal users). (see crypt(5)) they are stored as \$id\$salt\$hashedpwd

example mysql stores username and password in the "user" table, it stores the passwd = p with sha1(sha1(p)) (very bad). sha1("Superman!!!") = sha1(sha1("Superman!!!"))

Strong (peer) authN we consider strong authentication for ECB (European Central Bank), stated that password must not be used for money transaction operations. Authentication should be based on two or ways, the elements should not be related, non-reusable, strong authentication procedure.

PICIDSS (v3.2): requires multifactor authentication, for accessing into the cardholder data environment (one exception is via using a console),

an example of multifactor is when picking money from an ATM (card chip + password).

Challenge-response authentication (CRA) The most strong kind of authentication, the claimant has a key Kc, the verifier contains a Kv associated with an ID. 1. cla: ID 2. ver: challenge 3. cla: response = f(challenge, Kc) 4. ver: response == g(challenge, Kv) ? the key is not transmitted (protected from sniffing), the challenge must not be repeatable, usually is a random nonce (number used only once), the function f must not be invertible (someone sniffing could invert the function from the nonce and find the key),

symmetric CRA, uses a hash function instead of encryption, but Kc must be known in cleartext to the verifier (there are attacks against  $ID : K$  table at the verifier), SCRAM (Salted CRA Mechanism) to use CRA to its full potential we can combine it with asymmetric encryption the claimant has a ID.SK 1. claimant: cert(ID, ID.PK) 2. ver: C = enc(ID.PK, R) 3. cla: response = dec(ID.SK, C) 4. ver: valid(ID) && response == R ?

R is random number Asymmetric CRA is the strongest mechanism known, it's implemented for peer authentication (client and server). The problems are: slow, PKI (trusted root, name constrain, revocation), avoid, the table does not contain any information (it requires integrity).

One-time passwords (OTP) the user has got a list of passwords, each password is usable only one time, when the user tries to authenticate sends a password to the server, the server contains a SUID that is associated to the password,

this is immune to authentication subject .... finish ....

if the user needs to have all the passwords already precomputed (banks give passwords card). On intelligent and trusted hardware there are applications that can generate passwords ad-hoc.

Time-based OTP the user has a passwords with a count down timer associated with it, if the time expires the password is no more valid, 1. ver: authN request 2. cla: ID,  $X = p(\dots)$

the passwords cannot be precomputed, and claimant and verifier need to be synchronized (need to have the same time), the server checks that the time slot is correct  $X == p(\text{ID}, t) \text{ --- } X == p(\text{ID}, t-1) \text{ --- } X == p(\text{ID}, t+1)$ , usually hours and minutes are used, In order to avoid replay attacks the authentication is one per timeslot. It is based on time, so it can be attacked with a time attack (servers get time via NTP servers (Network Time Protocol)) causing DoS, also the device can get the time from mobile network vulnerable to a femtocell attack, also obtaining DoS, but if a future time slot is used by the attacker he can sniff the network and the use the password himselft in that time slot.

Event-Based OTP Time-base OTP is not enough when trying to make more request in the same time slot, this is based on a counter that is advanced every time an operation is performed.  $p(\text{ID}, C) = h(C, \text{SID})$  requires local computation, it need OTP pre-computation also by an attacker who temporarily have access to

Out-of-Band OTP It allows to avoid local computation of the OTP, cla: UID, PUID when the cla tries to authenticate he gives to the OTP a UID and a PUID, than the verifier sends on out of band (outside of the current channel like a SMS) a OTP, the number has to be set before.

the channel must be secure OOB channel is text/SMS message, this are not very secure because they are based on SS7 (insecure protocol). other times the message is sent via a PUSH message

Multi authN

Biometric Biometrics always take into consideration two factors: \* FAR = false acceptance rate \* FRR = false rejection rate they are tightly coupled with the cost of the device

HOTP the HMAC is used. K: shared secret key C: counter (monotonic positive integer) h: hash function (sha1 by default) sel: function to select 4 byte string  $\text{HOTP}(K, C) = \text{sel}(\text{HMAC-h}(K, C)) \& 0x7FFFFFFF$  The mask is used to set the MSB=0 to set the number to be positive

Used for Eventbased OPT

TOTP as HOTP but the counter is the number of intervals TS elapsed since a fixed origin  $T_0$   $C = (T - T_0) / TS$  RFC-6238  $T_0 = \text{unix epoch}$   $T = \text{unixtime}(\text{now})$   $Ts = 30 \text{ seconds}$   $C = \text{floor}(\text{unixtime}(\text{now}) / 30)$

Google authenticator supports HOTP and TOTP the key is provided in base 32 C is provided as uint\_64  $\text{sel}(X)$  offset = 4 LSB of X return  $X[\text{offset} \dots \text{offset}+3]$  TS = 30 seconds N = 6 if the generated code is contains less than 6 bytes then its left padded with zeros

FIDO Fast IDentity Online Defined: biometric auth = passwordless user experience 2-factor authN = 2nd factor user experience

based on personal devices capable of asymmetric crypto



UAF U2F ASM

used on many websites to authenticate like google, twitter, aws, ...

## 7 Esercizi

- Symmetric:

alg-keylen-

- Hash functions:

– B = data blob;

– D = digest;

$D = h\text{-alg}(B)$

- Keyed digest:

$D = kd(K, B)$  or  $D = mac(K, B)$   $D = \text{keyed-digest-alg}(K, B) \implies \text{hmac-sha-1}(K, B)$

- Asymmetric encryption:

$C = \text{asymm-enc}(PK, P) \implies \text{rsa-2048-enc}(Alice.PK, P)$

- Basic operation:

– random();

– save();

– send();

– receive();

– "——" or "+" concatenate;

- Extract value from certificates (PKC = public key certificate):

get-hashalg(PKC), get-pubkey(PKC)

1.

```
1 IV = random()
2 C = aes-128-cbc-enc(K, P, IV)
3 Alice.send(IV, C)
4 Bob.receive(IV, C)
5 P = aes-128-cbc-dec(K, C, IV)
```

2. Alice wants to write data P protected on disk, size of data must not be increased, key must be generated:

```
1 Alice passwd
2 salt = random()
3 IV = random()
4 K = h-sha-512(passwd || salt)
5 D = hmac-sha-512(passwd || salt)
6 C = aes-256-cbc-cts-enc(K, P, IV)
7 writes(C, D, IV, salt)
```

3. alice wants to send bob a message P protected for integrity and authentication, they share symm key K

```
1 alice
2 h = hmac-sha-256(K, P || "hmac-sha-256")
3 Alice.send("hmac-sha-256", h, P)
4 Bob.receive("hmac-sha-256", h, P)
5 h' = hmac-sha-256(K, P || "hmac-sha-256")
6 if h != h' FAIL
```

4. Alice wants to send bob a digitally signed message P, alice has Key Pair, alice send OOB PK

```
1 S = rsa-2048-enc(Alice.SK, h-sha512(P))
2 Alice.send(P, S, "rsa-2048", "h-sha512(P))
3 Bob.receive(P, S, "rsa-2048", "h-sha512(P))
4 digest = rsa-2048-dec(Alice.PK, S)
5 if digest == h-sha512(P) then SIGNATURE VERIFIED
```