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Information technology — Security techniques — Lightweight cryptography

Part 4:
Mechanisms using asymmetric techniques

Téchnologies de l'information — Techniques de sécurité — Cryptographie pour environnements contraints

Partie 4: Mécanismes basés sur les techniques asymétriques

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Foreword

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ISO/IEC 29192-4 was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC 27, *IT Security techniques*.

ISO/IEC 29192 consists of the following parts, under the general title *Information technology — Security techniques — Lightweight cryptography*:

— *Part 1: General*

— *Part 2: Block ciphers*

— *Part 3: Stream ciphers*

— *Part 4: Mechanisms using asymmetric techniques*

Further parts may follow.

Introduction

This part of ISO/IEC 29192 specifies three lightweight mechanisms based on asymmetric cryptography. The three mechanisms have different functionality, different supporting infrastructures, and different performance profiles.

— cryptoGPS is a lightweight asymmetric identification scheme; in the cryptographic literature such schemes are generally described as interactive proofs of knowledge. While there are many types of such scheme, the computational costs for the prover when using cryptoGPS are relatively low. This is particularly the case since cryptoGPS is well-suited to an implementation strategy using what is often referred to as "coupons". These are, essentially, the results given by a modest off-line pre-computation, with coupons being used by the prover at each invocation of the cryptoGPS scheme. The resultant scheme, with the role of the prover being taken by a computationally restricted device such as an RFID tag, offers very useful performance trade-offs.

— ALIKE is an asymmetric mechanism for authentication and key exchange. Based on a variant of RSA, ALIKE offers a unilateral authentication and an additional functionality, i.e. secure key establishment. ALIKE offers implementation advantages when compared to conventional asymmetric solutions such as RSA.

— The third mechanism is an identity-based signature scheme. Hence a trusted third party is involved in the computation of distinct signature keys. This scheme offers implementation advantages over many other schemes in the cryptographic literature.

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Information technology — Security techniques — Lightweight cryptography

Part 4:
Mechanisms using asymmetric techniques

1 Scope

This part of ISO/IEC 29192 specifies three lightweight mechanisms using asymmetric techniques:

— a unilateral authentication mechanism based on discrete logarithms on elliptic curves;

— an authenticated lightweight key exchange (ALIKE) mechanism for unilateral authentication and establishment of a session key;

— an identity-based signature mechanism.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 15946-1, *Information technology — Security techniques — Cryptographic techniques based on elliptic curves — Part 1: General*

ISO/IEC 29192-1, *Information technology — Security techniques — Lightweight cryptography — Part 1: General*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC 29192-1 and the following apply.

3.1
asymmetric cryptographic technique
cryptographic technique that uses two related operations: a public operation defined by a public data item, and a private operation defined by a private data item

Note 1 to entry: The two operations have the property that, given the public operation, it is computationally infeasible to derive the private operation.

[SOURCE: ISO/IEC 9798-5:2009, definition 2.3]

3.2
asymmetric pair
two related data items where the private data item defines a private operation and the public data item defines a public operation

[SOURCE: ISO/IEC 9798-5:2009, definition 2.5]

3.3
challenge
procedure parameter used in conjunction with secret parameters to produce a response

[SOURCE: ISO/IEC 9798-5:2009, definition 2.6]

3.4
claimant
entity whose identity can be authenticated, including the functions and the private data necessary to engage in authentication exchanges on behalf of a principal

[SOURCE: ISO/IEC 9798-5:2009, definition 2.7]

3.5
claimant parameter
public data item, number or bit string, specific to a given claimant within the domain

[SOURCE: ISO/IEC 9798-5:2009, definition 2.9]

3.6
collision-resistant hash-function
hash-function satisfying the following property: it is computationally infeasible to find any two distinct inputs which map to the same output

Note 1 to entry: computational feasibility depends on the specific security requirements and environment.

[SOURCE: ISO/IEC 10118-1:2000, definition 3.2]

3.7
coupon
pair of pre-computed numbers to be used only once

Note 1 to entry: One of the numbers shall be kept secret, and the other shall remain secret until the time of use.

[SOURCE: ISO/IEC 9798-5:2009, definition 2.8, modified]

3.8
domain
collection of entities operating under a single security policy

Note 1 to entry: For instance, public key certificates created either by a single certification authority, or by a collection of certification authorities using the same security policy.

[SOURCE: ISO/IEC 9798-5:2009, definition 2.11]

3.9
domain parameter
public key, or function, agreed and used by all entities within the domain

[SOURCE: ISO/IEC 9798-5:2009, definition 2.12]

3.10
entity authentication
corroboration that an entity is the one claimed

[SOURCE: ISO/IEC 9798-1:2010, definition 3.14]

3.11
exchange multiplicity parameter
number of exchanges of information involved in one instance of an authentication mechanism

[SOURCE: ISO/IEC 9798-5:2009, definition 2.15]

3.12
hash-function
function which maps strings of bits to fixed-length strings of bits, satisfying the following two properties:

— it is computationally infeasible to find for a given output, an input which maps to this output;

— it is computationally infeasible to find for a given input, a second input which maps to the same output

Note 1 to entry: Computational feasibility depends on the specific security requirements and environment.

[SOURCE: ISO/IEC 10118-1:2000, definition 3.5]

3.13
master secret key
secret data item

Note 1 to entry: Master secret key should only be used by the trusted server in accordance with the process of generation of signer private data.

3.14
private key
private data item of an asymmetric pair

Note 1 to entry: Private key shall be kept secret and should only be used by a claimant in accordance with an appropriate response formula, thereby establishing its identity.

[SOURCE: ISO/IEC 9798-5:2009, definition 2.21]

3.15
procedure parameter
transient public data item used in an instance of an authentication mechanism, e.g. a witness, challenge or response

[SOURCE: ISO/IEC 9798-5:2009, definition 2.22]

3.16
public key
public data item of an asymmetric pair, that can be made public and shall be used by every verifier for establishing the claimant's identity

[SOURCE: ISO/IEC 9798-5:2009, definition 2.23]

3.17
random number
time variant parameter whose value is unpredictable

[SOURCE: ISO/IEC 9798-1:2010, definition 3.29]

3.18
response
procedure parameter produced by the claimant, and processed by the verifier for checking the identity of the claimant

[SOURCE: ISO/IEC 9798-5:2009, definition 2.25]

3.19
secret parameter
number or bit string that does not appear in the public domain and is only used by a claimant

Note 1 to entry: For instance, a private key.

[SOURCE: ISO/IEC 9798-5:2009, definition 2.26]

3.20
sign
signature generation process that takes a message and a signing key of a signer to produce a signature

3.21
signer
entity with a unique bit string as an identity, including the functions and the private data necessary to engage in generation of a signature

3.22
signing key
secret data item given by the trusted server

Note 1 to entry: Signing key should only be used by a signer in accordance with the process of generation of a signature.

3.23
token
message consisting of data fields relevant to a particular communication and which contains information that has been produced using a cryptographic technique

[SOURCE: ISO/IEC 9798-5:2009, definition 2.27]

3.24
unilateral authentication
entity authentication which provides one entity with assurance of the other's identity but not vice versa

[SOURCE: ISO/IEC 9798-1:2010, definition 3.39]

3.25
verifier
entity including the functions necessary for engaging in authentication exchanges on behalf of an entity requiring an entity authentication or for engaging in verifying a signature of a given message and signer

[SOURCE: ISO/IEC 9798-5:2009, modified ─ Added the signature verification case]

3.26
verify
verification process that takes a message, a signature and an identity of a signer to output `accept` meaning the given signature is generated by the signer with the corresponding signing key, or `reject` otherwise

3.27
witness
procedure parameter that provides evidence of the claimant's identity to the verifier

[SOURCE: ISO/IEC 9798-5:2009, definition 2.31]

4   Symbols and abbreviated terms

For the purposes of this part of ISO/IEC 29192, the following symbols and abbreviated terms apply.

$\lvert A \rvert$	bit size of the number A if A is a non-negative integer (i.e. the unique integer i so that $2^{i-1} \le A < 2^{i}$ if $A > 0$, or 0 if $A = 0$, e.g. $\lvert 65\,537 \rvert = \lvert 2^{16} + 1 \rvert = 17$), or bit length of the bit string A if A is a bit string

NOTE   To represent a number A as a string of α bits with $\alpha > \lvert A \rvert$, $\alpha - \lvert A \rvert$ bits set to 0 are appended to the left of the $\lvert A \rvert$ bits.

$\lfloor A \rfloor$	the greatest integer that is less than or equal to the real number A
$A[i]$	the ith-bit of the number A, where $A[1]$ is the right-most bit and $A[\lvert A \rvert]$ is the left-most bit
$B \parallel C$	bit string resulting from the concatenation of data items B and C in the order specified. In cases where the result of concatenating two or more data items is input to a cryptographic algorithm as part of an authentication mechanism, this result shall be composed so that it can be uniquely resolved into its constituent data strings, i.e. so that there is no possibility of ambiguity in interpretation. This latter property could be achieved in a variety of different ways, depending on the application. For example, it could be guaranteed by

> (a) fixing the length of each of the substrings throughout the domain of use of the mechanism, or

> (b) encoding the sequence of concatenated strings using a method that guarantees unique decoding, e.g. using the distinguished encoding rules defined in ISO/IEC 8825-1 [18]

D	response (procedure parameter)
d	challenge (procedure parameter)
E	elliptic curve (domain parameter)
E_K	block cipher encryption function with key K
e	public exponent (domain parameter)
$f_0(u, x)$	$f_0(u, x) = 0 \parallel x \parallel \ldots \parallel 0 \parallel x \parallel 0 \parallel x^*$ where x^* represents the most significant bits of x (potentially no bits) required so that the length of $0 \parallel x \parallel \ldots \parallel 0 \parallel x \parallel 0 \parallel x^*$ is equal to u
$f_1(u, x)$	$f_1(u, x) = 1 \parallel x \parallel \ldots \parallel 1 \parallel x \parallel 1 \parallel x^*$ where x^* represents the most significant bits of x (potentially no bits) required so that the length of $1 \parallel x \parallel \ldots \parallel 1 \parallel x \parallel 1 \parallel x^*$ is equal to u
h	hash-function
$\lvert h \rvert$	bit length of the hash-code produced by the hash-function h
HE	padding function based on the block cipher E_K (domain parameter)
ID	binary string that represents the identity or identification information
L	bit length of the padding-code produced by the function HE (domain parameter)
m	message
N	composite modulus (domain parameter)
n	order of the base point P (domain parameter)
$[n]P$	multiplication operation that takes a positive integer n and a point P on the curve E as input and produces as output another point Q on the curve E, where $Q = [n]P = P + P + \ldots + P$ is the sum of n occurrences of P. The operation satisfies $[0]P = 0_E$ (the point at infinity), and $[-n]P = [n](-P)$

P	base point over the elliptic curve E (domain parameter)
$p_1, p_2 \dots$	prime factors of the modulus in ascending order, i.e. $p_1 < p_2 < \dots$ (secret parameters)
Q, Q_i	private key (secret parameter)
q	field size (domain parameter)
r	fresh random number or fresh string of random bits (secret parameter)
T	public point (domain parameter)
t	master secret key (secret parameter)
u	bit length of the key K in the block cipher encryption function E_K (domain parameter)
v	bit length of a block-message in the block cipher encryption E_K (domain parameter)
W	witness (procedure parameter)
w	security parameter (domain parameter)
$'X_1X_2 \dots'$	number whose hexadecimal representation is $X_1X_2 \dots$, where each X_i is equal to one of 0-9 and A-F
α	modulus size in bits, i.e. $2^{\alpha-1} \le \text{modulus} < 2^{\alpha}$, also denoted $\lvert \text{modulus} \rvert$ (domain parameter)
δ	length of fresh strings of random bits for representing challenges (domain parameter)
ρ	length of fresh strings of random bits for representing random numbers (domain parameter)
$\{a, b, c, \dots\}$	set containing the elements a, b, c, $\dots$

5   Unilateral authentication mechanism based on discrete logarithms on elliptic curves

5.1   General

This mechanism, cryptoGPS – also called GPS in the earlier cryptographic literature –, is due to Girault, Poupard, and Stern[6]. The revised name is now used so as to avoid confusion with the physical location service GPS. cryptoGPS is a zero-knowledge identification scheme that provides unilateral entity authentication. Several variants of cryptoGPS are specified in ISO/IEC 9798-5[21] and the version most suitable to constrained devices, along with some optimisations, is presented below.

5.2   Security requirements for the environment

The cryptoGPS mechanism enables a verifier to check that a claimant knows the elliptic curve discrete logarithm of a claimed public point with respect to a base point. A general framework for cryptographic techniques based on elliptic curves is given in ISO/IEC 15946-1.

NOTE 1   This mechanism implements the elliptic curve variant[5] of the cryptoGPS[6] scheme due to Girault, Poupard and Stern. It allows use of the so-called LHW (Low Hamming Weight) variant[4] particularly suitable for environments where the resources of the claimant are very low.

Within a given domain, the following requirements shall be satisfied.

a) Domain parameters that govern the operation of the mechanism shall be selected. The selected parameters shall be made available in a reliable manner to all entities within the domain.

b) Every claimant shall be equipped with the same elliptic curve E and a set of parameters, namely the field size q, a base point P over E, and n the order of point P. The curve and the set of parameters are either domain parameters or claimant parameters.

c) Each point P used as the base for elliptic curve discrete logarithms shall be such that, for any arbitrary point J of the curve, finding an integer k in [0, $n - 1$] (if one exists) such that $J = [k]P$ is computationally infeasible, where feasibility is defined by the context of use of the mechanism.

d) Every claimant shall be equipped with a private key.

e) Every verifier shall obtain an authentic copy of the public key corresponding to the claimant's private key.

NOTE 2   The exact means by which the verifier obtains a trusted copy of the public point specific to the claimant is beyond the scope of this part of ISO/IEC 29192. This may, for example, be achieved by the use of public-key certificates or by some other environment-dependent means.

f) Every verifier shall have the means to produce fresh strings of random bits. When coupons are not used, every claimant shall also have the means to produce fresh strings of random bits.

g) If the mechanism makes use of a hash-function, then all entities within the domain shall agree on a hash-function, e.g. one of the functions specified in ISO/IEC 10118-3 [23].

5.3   Key production

For claimant A, a fresh string shall be uniformly selected at random from the set {2, 3, …, $n - 2$}. The string represents the private key, denoted Q.

The number $\sigma = \lceil n \rceil$ gives the number of bits to be used to represent private keys.

Denoted $G(A)$, the public point for claimant A is set equal to either

a) The inverse of the multiplication of the base point P by the number Q.

$$G(A) = (x_G, y_G) = -[Q]P$$

NOTE 1   This version is the most suitable for constrained devices.

b) Or the multiplication of the base point P by the number Q.

$$G(A) = (x_G, y_G) = [Q]P$$

The challenges are selected from a set of integers S of cardinality Δ, where $2^{\delta-1} < \Delta \leq 2^{\delta}$. The length in bits of the greatest possible challenge is denoted by β. A value of δ from 8 to 40 is appropriate for most applications. Unless otherwise specified, the value of δ is set equal to 40. It is a domain parameter.

NOTE 2   The total number of possible challenges should be limited to 2^{40}. If this recommendation is not followed, then special care should be taken to prevent the verifier using the claimant as a signing oracle.

NOTE 3   When the set of challenges is the interval [0, $\Delta - 1$], then $\beta = \delta$.

NOTE 4   A challenge is said to be LHW (Low Hamming Weight) if there are at least $\sigma - 1$ zero bits between any two consecutive one bits in its binary representation.

NOTE 5   The definition of the public point $G(A)$ differs slightly from that defined in ISO/IEC 9798-5 [21]. This change allows more compact and efficient implementations of the resultant on-tag computation because the response formula is now an addition which is easier and more compact to implement than an integer subtraction.

5.4 Unilateral authentication mechanism

The bracketed letters in Figure 1 correspond to the steps of the mechanism, including the exchanges of information, described in detail below. The claimant is denoted by *A*. The verifier is denoted by *B*.
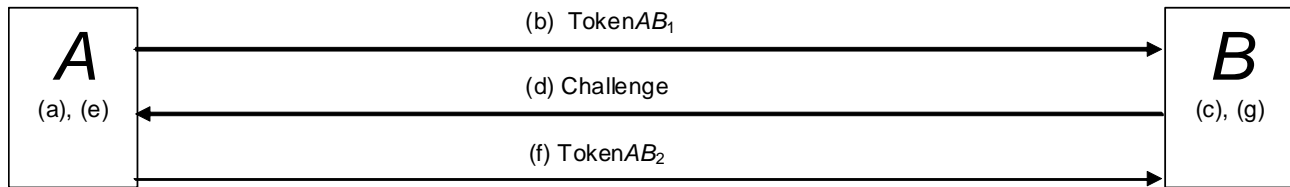
Figure 1 — Mechanism using a discrete logarithm with respect to elliptic curves

The claimant shall store a number δ, a base *P*, and a private key *Q* (as a string of σ bits). Unless otherwise specified, $\delta = 40$.

In the case of coupon use, in addition to a number δ and a private key *Q*, the claimant need only store a set of coupons and is not required to have a means to produce fresh strings of random bits. To be used only once, each coupon consists of a ρ-bit string (that need not be stored if it can be reproduced by a pseudo-random function, e.g. one of the functions specified in ISO/IEC 18031 [25]) and a witness.

In addition to a number δ and a number σ, the verifier shall be provided with a trusted copy of a public point *G*(*A*) and a trusted copy of the curve *E*, the base point *P* and the parameters *q* and *n*.

For each application of the mechanism, the following procedure shall be performed. The verifier *B* shall only accept the claimant *A* as valid if the procedure completes successfully.

a) For each authentication,

   1) either a coupon (*r*, *W*) is used.

   2) or a fresh string of ρ bits shall be uniformly selected at random. It shall be kept secret.

$$\rho = \sigma + \beta + 80$$

NOTE 1   If the fresh string of ρ bits is selected at random, then the probability that the leftmost 80 bits are all equal is negligible.

Denoted *r*, the number represented by the fresh string shall be converted into a witness, denoted *W*.

Witness formula: $W = \text{EC2OSP}_E([r]P, \text{fmt})$

with EC2OSP_E the function to convert a point on elliptic curve *E* to octet strings defined in ISO/IEC 15946-1 and fmt a format specifier, which is one of the symbolic values `compressed`, `uncompressed`, or `hybrid`.

NOTE 2   Under certain implementation circumstances some might prefer to use the witness formula $W = \text{EC2OSP}_E([r \bmod n]P, \text{fmt})$.

b) *A* sends Token*AB₁* to *B*. Token*AB₁* can be either witness *W* or a hash-code of *W* and *Text*, one of the following four hash variants.

The four hash variants are $h(W \| Text)$, $h(W \| h(Text))$, $h(h(W) \| Text)$, and $h(h(W) \| h(Text))$, where *h* is a hash-function and *Text* is an optional text field (it may be empty). If the text field is non-empty, then B shall have the means to recover the value of *Text*; this may require that A sends all or part of the text field with the token. How the text field is made available for use in applications is outside the scope of this part of ISO/IEC 29192. Annex A of ISO/IEC 9798-1 [20] gives information on the use of text fields. The hash variant is a domain parameter.

c) On receipt of TokenAB_1, a fresh string shall be uniformly selected at random from the set S.

d) B sends the fresh string as a challenge to A. The fresh string represents a number denoted d.

NOTE 3   If an LHW challenge is used, it can be transmitted in a compressed form to A who must have the means to retrieve the original challenge before step e)1).

e) On receipt of the challenge, the following computational steps are performed.

   1) If the challenge is not an element of S, then the procedure fails.

   2) A response D shall be computed from the random number r and the private key Q.

   Response formula is either:

   i) $D = r + d \times Q$ if $G(A) = -[Q]P$

NOTE 4   If the challenge received is an LHW challenge, the computation of D is reduced to a serial addition of r with a concatenation of copies of Q, separated by zero bits.

   or:

   ii) $D = r - d \times Q$ if $G(A) = [Q]P$

f) A sends TokenAB_2 to B. TokenAB_2 is the response D computed from step e)2).

g) On receipt of TokenAB_2, the following computational steps are performed.

   1) If the response D is not a string of ρ bits and/or if the leftmost 80 bits of D are all equal, then the procedure fails.

   2) Denoted W^*, a witness shall be computed.

   Verification formula: $W^* = \text{EC2OSP}_E([d]G(A) + [D]P, \text{fmt})$

NOTE 5   Under certain implementation circumstances some might prefer to use the verification formula $W = \text{EC2OSP}_E([d]G(A) + [D \bmod n]P, \text{fmt})$.

   3) If either witness W^* or a hash-code of W^* and Text (one of four hash variants) is identical to TokenAB_1 received in step b), then the procedure is successful. Otherwise the procedure fails.

NOTE 6   Other information may be sent with any exchange of the procedure. B may use such information to help compute the value of the optional Text field. For example, A may send information such as certificates with TokenAB_1.

6   Unilateral authenticated key exchange mechanism based on encryption

6.1   General

This mechanism, ALIKE, has been designed for contact-less transactions which are subject to very strong time limitations. In this protocol, a verifier (e.g. a reader or a terminal) authenticates a prover (e.g. a contact-less card) relative to a certification authority. Additionally, the prover and the verifier establish a session key for secure messaging. The originality of ALIKE is that it allows the use of low-cost readers (without Secure Access Module) while achieving strong time limitations. ALIKE is based on a public-key encryption scheme called RSA for paranoids [15] – a variant of RSA [13] – that enjoys very fast decryption. In ALIKE, the decryption is done by the prover (e.g. a contact-less card) where a cryptographic coprocessor is commonly available.

NOTE   ALIKE stands for Authenticated Lightweight Key Exchange. The previous name for ALIKE was SPAKE [3].The security proofs of ALIKE are available in [3].

6.2   Security requirements for the environment

The ALIKE mechanism enables a verifier to authenticate a claimant relative to a certification authority and to establish a session-key for secure messaging.

Within a given domain, the following requirements shall be satisfied.

a)   Domain parameters that govern the operation of the mechanism shall be selected. The selected parameters shall be made available in a reliable manner to all entities within the domain.

b)   Every claimant shall be equipped with distinct prime factors so that knowledge of their product, i.e. the modulus (a claimant parameter), shall not feasibly enable any entity to deduce them, where feasibility is defined by the context of use of the mechanism.

c)   All entities within the domain shall agree on a block cipher E_K, e.g. one of the algorithms specified in ISO/IEC 29192-2 [27] or in ISO/IEC 18033-3[26]. The key-size is denoted by u and the block-size is denoted by v. u and v shall be equal or greater than 128 bits and u shall be equal or greater than v. The maximum entropy of the secret key K of the block-cipher E_K is set to v - 1. The secret key K of length u is computed from a secret key x of length v - 1 using the functions $f_0(u, x)$ and $f_1(u, x)$.

NOTE   By virtue of the definition of $f_0(u, x)$ and $f_1(u, x)$, the first bit of the block cipher key is set either to 0 or 1. This guarantees the independence of the two different uses of the block cipher in the protocol.

d)   Every claimant and every verifier shall have the means to produce random numbers.

6.3   Key production

A number, denoted α, fixes the bit length of the modulus N, i.e. $2^{\alpha-1}$ < modulus < 2^{α}, in accordance with the context of use of the mechanism. It is a domain parameter. The bit length of the modulus shall be chosen such that the complexity estimation of the fastest factorization algorithms [8], [16] – whose running time depends on the size of the modulus N – is greater than the required level of security.

A non-negative integer, denoted w, shall be chosen such that $w > 2.v$. w is a security parameter and it is a domain parameter. w is also the bit length of p_1 and shall be chosen such that the complexity estimation of the fastest known algorithm [7] – whose running time depends on the size of $|p_1|$ – is greater than the required level of security.

Claimant A shall keep secret the two distinct large prime factors, denoted p_1 and p_2, of the modulus N. The prime factors p_1 and p_2 shall be chosen such that the modulus N is unbalanced with $|p_1| << |p_2|$.

a)   Generate two primes p_1 and p_2 such that

   1) $|p_1| = w$ and $\gcd(e, p_1 - 1) = 1$ where e is the public exponent. e shall be chosen large enough to avoid the Coppersmith attack [2] and compliant with the Shamir inferior bound [15]. The value $e = 11$ has some practical advantages.

   2) $|p_2| = \alpha - w$.

   3) $|p_1 \times p_2| = \alpha$.

b)   Compute $N = p_1 \times p_2$ and $t = e^{-1} \bmod (p_1 - 1)$. The public key is (N, e) and the private key is (p_1, t). The public key is certified by a certification authority.

Claimant A shall be equipped with private key $S_A = (p_1, t)$ and public key $P_A = (N, e)$ corresponding to the modulus N, see [15].

Claimant A shall be equipped with a certificate of the public key P_A, denoted σ.

NOTE   The exact means by which the claimant obtains a trusted copy of his public key is beyond the scope of this part of ISO/IEC 29192. This may, for example, be achieved by the use of public-key certificates or by some other environment-dependent means.

6.4   Unilateral authentication exchange

The bracketed letters in Figure 2 correspond to the steps of the mechanism, including the exchanges of information, described in detail below. The claimant is denoted A. The verifier is denoted B.
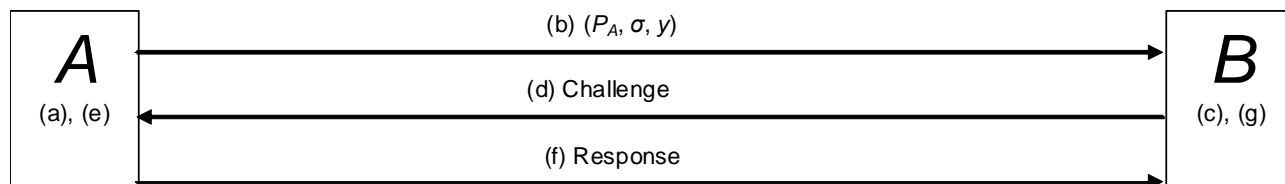

Figure 2 — ALIKE

The following procedure shall be performed. The verifier B shall only accept the claimant A as valid if the procedure completes successfully.

a)   A fresh number k of length $v-1$ shall be uniformly selected at random by the claimant. The block cipher is used to calculate a commitment y: $y = E_{f\_0(u,k)}(0)$

b) A sends (P_A, σ, y) to the verifier B.

c)   A fresh number r of length $v-1$ shall be uniformly selected at random by the verifier. The padding value $pad = E_{f\_1(u,r)}(0)$ is derived and the message $(r \mathbin{\|} pad)$ is encrypted with P_A. The result $d = (r \mathbin{\|} pad)^e \bmod N$ is the challenge.

d) B sends the challenge d to A.

e)   On receipt of the challenge, the following computational steps are performed.

   1)   If the size of the challenge is not equal to $\lvert N \rvert$, then the procedure fails.

   2) A uses the private key S_A to recover the plaintext, $d^{\,t} \bmod p_1$, and verify the consistency of the padding in the plaintext:

      i)   If the padding is not correct, then the procedure fails.

      ii)   The padding is removed to recover r.

   3)   A response D shall be computed by encrypting the number k using the block cipher, i.e. $D = E_{f\_0(u,\,r)}(0 \mathbin{\|} k)$

f) A sends the response D to B.

g)   On receipt of the response D, the verification process is performed.

   1) B verifies that σ is a trusted copy of the public key of the claimant A.

      iii)   If the verification fails, then the procedure fails.

      iv)   Else B recovers k' from the response D.

   2)   If $E_{f\_0(u,\,k')}(0) = y$, then the procedure is successful. Otherwise the procedure fails.

6.5   Session-key derivation

Optionally, a session-key could be established between the claimant *A* and the verifier *B* for secure messaging using the common secret (*r*, *k*).

7   Identity-based signature mechanism

7.1   General

An identity based cryptosystem, is an asymmetric cryptographic technology that allows a public key to be calculated from an identity and a set of public mathematical parameters and that allows for the corresponding private key to be calculated from an identity, a set of public mathematical parameters, and a domain-wide secret value. A user public key can be calculated by anyone who has the necessary public parameters; while a cryptographic secret is needed to calculate a user private key, and the calculation can only be performed by a trusted server that has this secret.

An Identity Based Signature (IBS) scheme under this framework is a signature scheme where the signature verification can be done without needing the verifier and the signer to interact with each other, either directly or through a proxy such as a directory or certificate server, before verifying the signatures. Other systems may require a connection to a server for each verification operation.

The scheme [9] described below is motivated by Bellare, Namprepre and Neven's identity-based identification scheme [1], which is actually based on Schnorr's identification scheme [14], but is further optimized. By using the technique specified in Annex B, the Identity Based Signature Mechanism stated in this section can become a very efficient mechanism for lightweight devices.

NOTE   The security proofs of the scheme described below are available in [9].

7.2   Security requirements for the environment

The IBS mechanism enables a verifier to check that a signer uses his signing key to produce a signature for a given message.

Within a given domain, the following requirements shall be satisfied.

a)   Domain parameters that govern the operation of the mechanism shall be selected. The selected parameters shall be made available in a reliable manner to all entities within the domain.

b)   Domain parameters shall include an elliptic curve *E* and a set of parameters, namely the base point *P* over *E*, and *n* the order of point *P*.

c)   Each point *P* used as the base for elliptic curve discrete logarithms shall be such that, for any arbitrary point *J* of the curve, finding a number *k* in [0, *n* − 1] (if one exists), so that $J = [k]P$ is computationally infeasible, where feasibility is defined by the context of use of the mechanism.

d)   Every signer and the trusted server shall have the means to produce random numbers.

e)   All entities within the domain shall agree on a collision-resistant hash-function, e.g. one of the functions specified in ISO/IEC 10118-3 [23].

f)   The trusted server shall uniformly select a fresh number *t* at random, which shall be non-zero and less than *n*, and compute the public point *T* which is set equal to the multiplication of the base point *P* by number *t*: $T = [t]P$

g)   The trusted server shall keep *t* as the master secret key and publish the curve *E*, the point *T*, the base point *P*, and the number *n* as the parameters.

7.3 Key production

Signer *A* shall ask the trusted server to generate his signing key. For each application of the mechanism, the following procedure shall be performed by the trusted sever.

The trusted server shall uniformly select a fresh number *r* at random, which shall be non-zero and less than *n* and compute the point $R = (x_R, y_R)$ which is set equal to the multiplication of the base point *P* by number *r*.

$$R = [r]P$$

a) A number *s* shall be computed from the random number *r* and the master secret key of the trusted server *t*.

$$s = r + h(x_R \| ID) \times t \bmod n$$

where *h* is a collision-resistant hash-function and *ID* is a binary string that represents the identity or identification information of the signer *A*.

b) The signing key for signer *A* shall be {*R, s*}.

NOTE   A correctly generated private key shall fulfill the following formula $[s]P = R + [h(x_R \| ID)]T$

7.4 Sign

To sign an arbitrary length message *m* with the signing key of the signer *A*, the following procedure shall be performed.

a) The signer shall uniformly select a fresh number *y* at random, which shall be non-zero and less than *n*.

b) Compute the point $Y = (x_Y, y_Y)$ which is set equal to the multiplication of the base point *P* by number *y*.

$$Y = [y]P$$

c) A number *z* shall be computed from the private key *R* and *s*.

$$z = y + h(x_Y \| x_R \| m) \times s \bmod n$$

d) The signature of signer *A* and the message *m* shall be {*Y, R, z*}.

7.5 Verify

To verify a signature {*Y, R, z*} of the signer *A* with identity *ID* for the message *m*, the verifier shall compute

$$c = h(x_Y \| x_R \| m)$$

and check if the following equality holds:

$$[z]P = Y + [c]R + [c \times h(x_R \| ID)]T$$

The verifier shall output `accept` if it holds, or `reject` otherwise.

Annex A
(normative)

Object identifiers

```
LightweightCryptography-4{
    iso(1) standard(0) lightweight-cryptography(29192)
    part4(4) asn1-module(0) algorithm-object-identifiers(0)}
    DEFINITIONS ::= BEGIN
EXPORTS ALL;


OID ::= OBJECT IDENTIFIER -- alias
-- Synonyms
is29192-4 OID ::= {iso(1) standard(0) lightweight-cryptography(29192) part4(4)}
mechanism OID ::= {is29192-4 mechanisms(1)}
-- Lightweight cryptographic mechanisms
lw-discrete-logarithms-ecc-CryptoGPS OID ::= {mechanism
    lw-discrete-logarithms-ecc-CryptoGPS(1)}
lw-authenticated-key-exchange-ALIKE OID ::= {mechanism
    lw-authenticated-key-exchange-ALIKE(2)}
lw-identity-based-signature-IBS OID ::= {mechanism
    lw-identity-based-signature-IBS(3)}


END -- LightweightCryptography-4
```

Annex B
(normative)

Memory-Computation Trade-Off Technique

The following technique (due to Liu et al. [9]) can be used to simplify the computation of an exponentiation or a scalar multiplication. Such operations are used in many ISO/IEC specified cryptographic mechanisms, in particular those based on discrete logarithm. For example, some of the signature mechanisms specified in ISO/IEC 14888-3 [24] and ISO/IEC 9796-3 [19], and the entity-authentication mechanisms in ISO/IEC 9798-5 [21] can be implemented in this way. By using this technique, the Identity Based Signature Mechanism stated in the section 7 can become a very efficient mechanism for lightweight devices.

The trade-off of this computation-facilitating technique is an increase in memory requirement.

Let E be an elliptic curve, P be the base point over E, and n be the order of point P.

For each number i from the set [0, $|n|$-1], the points Y_i are set equal to the scalar multiplication of the base point P by 2^i, i.e.

$$Y_i = [2^i]P$$

To compute $Y = [y]P$ for a non-zero number y which is less than n, the following procedure shall be performed:

a)   Set $Y = [0]P$

b)   For $i = 1$ to $|n|$ compute:

$$\text{If } y[i] = 1, \text{ then } Y = Y + Y_{i-1}$$

c)   Output Y

Annex C
(informative)

Numerical examples

C.1 cryptoGPS mechanism

C.1.1 Key production

The elliptic E curve for this example is curve P-192 defined in FIPS PUB 186-3 [17].

$$E: Y^2 = X^3 - 3X + b \text{ over } F_q$$

$q =$ FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFE FFFFFFFF FFFFFFFF

$b =$ 64210519 E59C80E7 0FA7E9AB 72243049 FEB8DEEC C146B9B1

Base point P over E.

$P =$ (x_P, y_P)
=   (188DA80E B03090F6 7CBF20EB 43A18800 F4FF0AFD 82FF1012,
    07192B95 FFC8DA78 631011ED 6B24CDD5 73F977A1 1E794811)

n is the order of point P.

$n =$ FFFFFFFF FFFFFFFF FFFFFFFF 99DEF836 146BC9B1 B4D22831

For hash-function h, this example makes use of SHA-256, i.e. the fourth hash-function specified in ISO/IEC 10118-3 [23].

The bit length is $\delta = 40$ for the challenges and $\sigma = |n| = 192$ bits.

C.1.2 Authentication exchange

Private key

$Q =$ 4F1DF03A A32DCA02 652E83E7 E5FF5259 D61F5563 B3A0FA10

Public point

In the first variant, the public point $G(A)$ is equal to the inverse of the multiplication of the base point P by the number Q.

$G(A) =$ $-[Q]P$
= (x_G, y_G)
=   (D753BF14 9529BC23 B1850A37 57C4D34A 0D686A95 C3B03855,
    1656B8CB 2896BFD4 BC8F94A8 F3708741 B954CC44 4FC3951A)

In the second variant, the public point $G(A)$ is equal to the multiplication of the base point P by the number Q.

$$
\begin{aligned}
G(A) &= [Q]G \\
&= (x_G, y_G) \\
&= (\text{D753BF14} \quad \text{9529BC23} \quad \text{B1850A37} \quad \text{57C4D34A} \quad \text{0D686A95} \quad \text{C3B03855,} \\
&\quad\ \text{E9A94734} \quad \text{D769402B} \quad \text{43706B57} \quad \text{0C8F78BD} \quad \text{46AB33BB} \quad \text{B03C6AE5})
\end{aligned}
$$

Step a

r is a fresh string of random bits of length $\rho = \sigma + \beta + 80 = 192 + 40 + 80 = 312$ bits.
W is the witness such that $W = \text{EC2OSP}_E([r]P, \texttt{uncompressed})$.

$r =$	05E8B1	E1121B08	FB9A0F58	FC1E932F	9CEFE94D	629BC223	40B5F04B
	554DCD2B	C812A76D	98F8BA3E				

$[r]P =$	(DAD48D02	4B83E223	4C0F5FFF	B51C15B7	1D52CF92	B35358CF,
	FFE42756	843D0DF8	F3166971	E8AF6E22	6FD381B0	A816720F)

$W =$	04	DAD48D02	4B83E223	4C0F5FFF	B51C15B7	1D52CF92	B35358CF
	FFE42756	843D0DF8	F3166971	E8AF6E22	6FD381B0	A816720F	

Step b

TokenAB_1 is equal to $h(W \,\|\, Text)$ where text field *Text* is empty. Hence Token$AB_1 = h(W)$.

$h(W) =$	0EB01E5E	32CA889D	099C8F6E	4CC3CB08	A3CD6008	C2849B43	0E07BCC7
	B5241843						

Step c, d

Verifier's challenge:

$d =$	2D	F0F5B4F2

Step e, f

In the first variant, the response to challenge, TokenAB_2, is $D = r + d \times Q.$

$D =$	5E8B1	E1121B08	FB9A0F67	2ED9CE48	044BD618	3242087C	ADDDA392
	F2CA1F36	FDD94248	E8485D5E				

In the second variant, the response to challenge, TokenAB_2, is $D = r - d \times Q.$

$D =$	5E8B1	E1121B08	FB9A0F4A	C9635817	3593FC82	92F57BC9	D38E3D03
	B7D17B20	924C0C92	49A9171E				

Step g

Verification:

$W^* =$	04	DAD48D02	4B83E223	4C0F5FFF	B51C15B7	1D52CF92	B35358CF
	FFE42756	843D0DF8	F3166971	E8AF6E22	6FD381B0	A816720F	

$h(W^*) =$	0EB01E5E	32CA889D	099C8F6E	4CC3CB08	A3CD6008	C2849B43	0E07BCC7
	B5241843						

Authentication is valid.

C.2 ALIKE mechanism

The parameters of ALIKE are chosen for 80 bit-security.

The bit size for the modulus N is 1280 bits and for p_1 is 352 bits.

The block cipher E_K is chosen, for instance, from ISO/IEC 29192-2[27] or ISO/IEC 18033-3[26]. In this example, it is AES with a key-size u of 128 bits.

NOTE   Since AES has a block size of 128 bits, u and v are equal in this example.

C.2.1 Key production

$e =$	0000000B						

$p_1 =$	DD30D446	E32767CF	E14885E7	44D077D0	89F82A87	37F53C4D	36AA9463
	7C250E7D	A516CA16	15C3B394	2B1CA791			

$p_2 =$	B544FE3B	FB7D54D3	FA19B2E6	275CD79E	B09CC643	44C03C6C	268F3624
	5989FECC	F44EC445	72A1F3C6	CD245A4D	4D17FDEC	0BF550D3	39C14EE8
	4893CF1A	1E9BAF91	341AC6A9	E8B337B1	6B13B3A0	DF31E1A5	E5D63E70
	0B93030D	BDAF9D6B	AFDBD696	6C1F09A0	95FA383C	32272D88	77A3F8FD

$N =$	p_1 x p_2						
$=$	9C9F22B8	C7999ED9	54E7F600	63D134AB	6AF4BA29	046C2048	C7C0BC70
	07686209	092D5B0B	BE6E2D88	2E76E9B2	D2A43371	29490102	2401CCE7
	A0143B96	13B1727B	BC704892	F22B9EE6	A0C1F377	03229588	2EAC4879
	3D88C4B3	800F5021	BAC0884C	A05EA932	38FD8D35	50F227C6	8DB51EFE
	A8051C08	8D475FC4	9A563C02	9616FDD0	650C5B66	ED2E1EFD	84732F70
	F6F1A24A	D5F88B5D	19864A5D	75F9124D			

$t =$	C9151E11	E5C6BB77	29E4D6D2	3E8EF88F	091026A9	78B0655D	7783CCB7
	8821B015	21B7A071	2B0F0058	27315283			

C.2.2 Authentication exchange

Step a, b

k is a fresh string of random bits of length $u - 1$ used to calculate the commitment y.

$k =$	6C64D272	0B770A23	D5700C0B	EBC63E5E

$y =$	$E_{f\_0(k)}(0)$			
$=$	E85D2E05	D4C6592B	E571EE71	9BA636E7

Step c, d

r is a fresh string of random bits of length $u - 1$.

$r =$	6E5707FA	1F9171C1	D802C92C	605A3FD1

$1 \| r =$	EE5707FA	1F9171C1	D802C92C	605A3FD1

$pad =$ $HE(r)$ where $HE(r)$ is equal to the $L = 128$ left-most bits of $E_{f\_1(r)}(0)$.

$pad =$	B8C940AE	B22FDB93	7A1FE295	1584A26C

Verifier's challenge:

$d =$ (r || pad) ^{e} mod N

=	18240256	E10CFD25	725AD87B	7EBAFB43	81988968	B7D35E4F	6D75A201
	6480DFA6	B5E4E78A	EDE764E7	49CB5880	4BFA2A81	088ECFB3	3903AA0F
	31E3CE42	C653CA28	4F418EED	F76D6914	D6B40C9B	205A00E5	6C8008AC
	13FFD2F1	CA57FB8A	B6B57001	A5E3B04D	BBE14BB5	D5200511	20F744E4
	9B87B87E	7F411F3D	4657E4AF	A26E6D0B	F4414095	816D90CD	06CF6EE5
	6C244F17	F30CDB58	C6226D80	AEDC70F4			

Step e, f

Response to challenge:

$D =$ $E_{f\_0(r)}(0 \,||\, k)$

=	01203402	350C0611	F34C71BF	59F9CC3E

Step g

Verification.

C.2.3 Session-key derivation

Optionally, a session-key s_k could be established.

$s_k =$ $r \oplus k$

=	0233D588	14E67BE2	0D72C527	8B9C018F

C.3 Identity-based signature mechanism

C.3.1 Key production

The elliptic curve for this example is

$$E: Y^2 = X^3 + aX + b \text{ over } F_q$$

with

$a =$	FFFFFFFF	FFFFFFFF	FFFFFFFF	FFFFFFFF	7FFFFFFC

$b =$	1C97BEFC	54BD7A8B	65ACF89F	81D4D4AD	C565FA45

$q =$	FFFFFFFF	FFFFFFFF	FFFFFFFF	FFFFFFFF	7FFFFFFF

Base point P over E.

$P =$ (x_P, y_P)
= (4A96B568 8EF57328 46646989 68C38BB9 13CBFC82,
23A62855 3168947D 59DCC912 04235137 7AC5FB32)

n is the order of point P.

$n =$	1	00000000	00000000	0001F4C8	F927AED3	CA752257

t is the master secret key.

$t =$ D21DF3A7   5787F180   5F00792F   9D8C317C   23FDF91B

T is the public point.

$T =$ (x_T, y_T)

$=$ (1B2F7E1F   831DF943   F82CFBE2   FF753A4C   9DF8040A,
        1FFE799A   563024AF   86652027   CEA9A60A   00E1FB73)

ID is the identification information of the signer. $|ID| = 8$ bits.

$ID =$ 01

r is a fresh number less than *n*.

$r =$ 8A29A77B   8826FC67   2ABEA882   FEAEE9C3   6E1A78C2

$R =$ $[r]P$
$=$ (x_R, y_R) with $|x_R| = |y_R| = 160$ bits
$=$ (1040E9BF   14546E1B   38FC74B5   31228C69   AF0BAED3,
        8DC50619   E3B28AEC   B8296F17   51466289   D32053F6)

For hash-function *h*, this example makes use of SHA-1, i.e. the third hash-function specified in ISO/IEC 10118-3 [23].

$s =$ $r + h(x_R \| ID) \times t \bmod n$
$=$ 49952E7E   4289DFA8   CE6ADB2F   55BA9C70   D89AA3C7

C.3.2 Sign

C.3.2.1   Example 1

m a message of 160 bits:

$m =$ 00000000   00000000   00000000   00000A73   199606B1

Step a

y is a fresh number less than *n*.

$y =$ 00000000   00000000   00000000   00000000   00000007

Step b

$Y =$ $[y]P$
$=$ (x_Y, y_Y) with $|x_Y| = |y_Y| = 160$ bits

$x_Y =$ 7A7F99D5   6472F619   577C4E8C   9B3A35E9   61472188

Step c, d

$z =$ $y + h(x_Y \| x_R \| m) \times s \bmod n$
$=$ 92D28A45   FFDE887E   C8D297A2   7FA02CB5   7DF2CBAF

C.3.2.2   Example 2

Message:

$m =$ 00000000   00000000   00000000   00000A79   19B70693

Step a

y is a fresh number less than n.

$y =$ 00000000   00000000   00000000   00000000   00000010

Step b

$Y =$ $[y]P$
$=$ (x_Y, y_Y)

$x_Y =$ B32F7DFA   2A82B99B   5CAC2772   AA6661BE   5F315034

Step c

$z =$ $y + h(x_Y \| x_R \| m) \times s \bmod n$
$=$ BB7A0E5A   805F67A6   CF00FF5A   0BF8B782   0803751E

C.3.3 Verify

C.3.3.1   Example 1

$c =$ $h(x_Y \| x_R \| m)$
$=$ 043969EF   9D9C6429   495139BD   8B37E086   FAA78FFB

$[z]P =$ $(x_{[z]P}, y_{[z]P})$ with

$x_{[z]P} =$ 88913D78   4FD959FF   91E14157   D44799FA   674B2717

C.3.3.2   Example 2

$c =$ $h(x_Y \| x_R \| m)$
$=$ F8228399   413773F9   EB23CCA0   DFD1D416   D50941B7

$[z]P =$ $(x_{[z]P}, y_{[z]P})$ with

$x_{[z]P} =$ E0B100B3   1CA6F0E7   251275A7   8B5F0BFB   C6207A29

Annex D
(informative)

Features

This annex describes lightweight properties of the algorithms described in this document and their compliance with the requirements in the part 1 of ISO/IEC 29192. In this Annex, the IBS mechanism is the mechanism described in Clause 7 implemented with the technique described in Annex B.

Table D.1 — Compliance of algorithms properties with the requirement of ISO/IEC 29192-1

		Algorithm name		
		cryptoGPS [5]	ALIKE [3]	IBS [9]
Constraints	Chip area	X		
	Energy consumption	X		X
	Code size and RAM size		X	X
	Communication bandwidth	X	X	X
	Execution time	X	X	

Table D.2 — cryptoGPS characteristics

	cryptoGPS [5]		
	Core computation [10]	Core computation [11]	Full module [12]
Security level [bits]	80	80	80
Chip area [GE]	317	431	2876
Authentication process [CLK]	1088	136	724
Energy [GE*CLK]	344 896	58 616	2 082 224
Technology [µm]	0,180	0,180	0,350
NOTE "Full module" includes the pseudo-random number generator together with the on-tag cryptoGPS computation while "core computation" refers solely to the on-tag cryptoGPS computation.			

Table D.3 — ALIKE characteristics

	ALIKE [3]	
	PICC [a] process	PCD [b] process
Security level [bits]	80	80
Crypto-coprocessor functionalities	Required for modular multiplication	Not required
Functions required	A random number generation. Two blocks cipher executions without specific side channel and fault attacks countermeasures. A modular exponentiation with small modulus ($\lvert p_1 \rvert$ = 352 bits)	A random number generation. Two blocks cipher executions A modular exponentiation with small exponent ($e \geq 11$, $\lvert N \rvert$ = 1 248 bits)
Non Volatile memory	To store RSA keys for ALIKE (88 bytes to compare to 400 bytes for classical RSA) and certificates	To store public key of CA
Code size	1.6 kbytes on 8051 core	
Data transferred with communication speed at 106.kb.s^{-1}	Incoming data 160 bytes ⇔ 15.40 ms	Incoming data 192 bytes ⇔ 18.8 ms
Internal process	From 4 to 15 faster than classical RSA according to component As example for 8051 core: 80 ms at 31MHz for CPU and 48 MHz for crypto-coprocessor	
[a] PICC: Proximity Integrated Circuit Card [b] PCD: Proximity Coupling Device		

Table D.4 — IBS characteristics

IBS [9]		
Security level [bits]		80
Code size and RAM size [Byte] This is based on TinyOS 1.0.15 on MicaZ	Online Sign only	flash = 54 308 RAM = 858
	Verify Only	flash = 55 374 RAM = 922
Execution time [ms]	Signature	896
	Verification	5 610
Energy consumption [μJ] This is based on MicaZ ATmel128L.	Online sign	12 370
	Verification	77 400
Communication bandwidth [bits]		480

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