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AMENDMENT 1
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**Information technology —
Security techniques — Encryption
algorithms —**

**Part 2:
Asymmetric ciphers**

AMENDMENT 1: FACE

*Technologies de l'information — Techniques de sécurité —
Algorithmes de chiffrement —*

Partie 2: Chiffres asymétriques

AMENDEMENT 1: FACE



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ISO copyright office
Ch. de Blandonnet 8 • CP 401
CH-1214 Vernier, Geneva, Switzerland
Tel. +41 22 749 01 11
Fax +41 22 749 09 47
copyright@iso.org
www.iso.org

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This document was prepared by ISO/IEC JTC 1, *Information technology*, Subcommittee SC 27, *IT Security techniques*.

A list of all parts in the ISO/IEC 18033 series can be found on the ISO website.

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Information technology — Security techniques — Encryption algorithms —

Part 2: Asymmetric ciphers

AMENDMENT 1: FACE

Introduction

Replace the Introduction with the following:

Introduction

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Scope NOTE

Replace:

- ECIES-HC; PSEC-HC; ACE-HC: generic hybrid ciphers based on ElGamal encryption;

with the following:

- ECIES-HC; PSEC-HC; ACE-HC; FACE-HC: generic hybrid ciphers based on ElGamal encryption;

8.1.2

Replace:

- *ECIES-KEM* (described in Clause 10.2),

- *PSEC-KEM* (described in Clause 10.3),
- *ACE-KEM* (described in Clause 10.4), and
- *RSA-KEM* (described in Clause 11.5).

with the following:

- *ECIES-KEM* (described in 10.2),
- *PSEC-KEM* (described in 10.3),
- *ACE-KEM* (described in 10.4),
- *FACE-KEM* (described in 10.5), and
- *RSA-KEM* (described in 11.5).

8.1.2

Replace NOTE 1 with the following:

NOTE 1 As a matter of convention, the corresponding generic hybrid ciphers built from these key encapsulation mechanisms via the generic hybrid construction in 8.3 should be called (respectively) *ECIES-HC*, *PSEC-HC*, *ACE-HC*, *RSA-HC*, and *FACE-HC*.

Clause 10

Add the following after “*ACE-KEM* is described in Clause 10.4”:

- *FACE-KEM* is described in 10.5.

Clause 10

Add the following after 10.4.4:

10.5 *FACE-KEM*

The key encapsulation mechanism *FACE-KEM* is described in 10.5.

NOTE *FACE-KEM* is based on a series of research papers (see References [43] to [46]).

10.5.1 System parameters

FACE-KEM is a family of key encapsulation mechanisms, parameterized by the following system parameters:

- Γ : a concrete group

$$\Gamma = (\mathcal{H}, \mathcal{G}, \mathbf{g}, \mu, \nu, \mathcal{E}, \mathcal{D}, \mathcal{E}', \mathcal{D}');$$
- *KDF*: a key derivation function, as described in 6.2;
- *Hash*: a cryptographic hash function, as described in 6.1;
- *CofactorMode*: one of two values: 0 or 1.
- *KeyLen*: a positive integer.

— *TagLen*: a positive integer.

Any combination of allowable system parameters (in 6.1.1, 6.2.1, 10.1.1) is allowed, except for the following restrictions:

— *Hash.len* shall be less than $\log_{256}\mu$.

— If $v = 1$, then *CofactorMode* shall be 0.

— If $v > 1$, then *CofactorMode* may be 1 provided $\gcd(\mu, v) = 1$.

NOTE The value of *CofactorMode* is used only by the decryption algorithm.

10.5.2 Key generation

The key generation algorithm *FACE-KEM.KeyGen* takes no input, and runs as follows.

a) Generate numbers a_1, a_2 uniformly at random from the range $[0..\mu)$.

b) Compute the group elements

$$\mathbf{g}_1 = a_1 \cdot \mathbf{g}, \mathbf{g}_2 = a_2 \cdot \mathbf{g}.$$

c) Generate numbers x_1, x_2, y_1, y_2 uniformly at random from the range $[0..\mu)$.

d) Compute the group elements

$$\mathbf{c} = x_1 \cdot \mathbf{g}_1 + x_2 \cdot \mathbf{g}_2, \mathbf{d} = y_1 \cdot \mathbf{g}_1 + y_2 \cdot \mathbf{g}_2.$$

e) Output the public key $\mathbf{g}_1, \mathbf{g}_2, \mathbf{c}, \mathbf{d}$.

f) Output the private key $x_1, x_2, y_1, y_2 \in [0..\mu)$.

10.5.3 Encryption

The encryption algorithm *FACE-KEM.Encrypt* takes as input a public key, consisting of

$$\mathbf{g}_1, \mathbf{g}_2, \mathbf{c}, \mathbf{d} \in \mathcal{G},$$

together with an encryption option *fmt* that specifies the format to be used for encoding group elements. It runs as follows.

a) Generate a number r uniformly at random from the range $[0..\mu)$.

b) Compute group elements

$$\mathbf{u}_1 = r \cdot \mathbf{g}_1, \mathbf{u}_2 = r \cdot \mathbf{g}_2.$$

c) Compute the octet strings

$$EU_1 = \mathcal{E}(\mathbf{u}_1, \text{fmt}), EU_2 = \mathcal{E}(\mathbf{u}_2, \text{fmt}).$$

d) Compute the integer

$$\alpha = \text{OS2IP}(\text{Hash.eval}(EU_1 \| EU_2)).$$

e) Compute the integer

$$r' = \alpha r \bmod \mu.$$

f) Compute the group element

$$\mathbf{v} = r \cdot \mathbf{c} + r' \cdot \mathbf{d}.$$

g) Set $EV = \mathcal{E}(\mathbf{v}, \text{fmt})$.

h) Set $Len = KeyLen + TagLen$.

i) Set $W = KDF(EV, Len)$.

j) Parse W as $W = \langle W_1, \dots, W_{Len} \rangle$ of Len octets.

k) Set $K = \langle W_1, \dots, W_{KeyLen} \rangle$ of $KeyLen$ octets.

l) Set $T = \langle W_{KeyLen+1}, \dots, W_{Len} \rangle$ of $TagLen$ octets.

m) Set $C_0 = EU_1 \| EU_2 \| T$.

n) Output the ciphertext C_0 and the secret key K .

10.5.4 Decryption

The decryption algorithm *FACE-KEM.Decrypt* takes as input a private key, consisting of

$$x_1, x_2, y_1, y_2 \in [0.. \mu),$$

and ciphertext C_0 . It runs as follows.

a) Parse C_0 as $C_0 = EU_1 \| EU_2 \| T$, where EU_1, EU_2 are octet strings such that for some (uniquely determined) group elements $\mathbf{u}_1, \mathbf{u}_2 \in \mathcal{H}$, $\mathbf{u}_1 = \mathcal{D}(EU_1)$, $\mathbf{u}_2 = \mathcal{D}(EU_2)$. This step **fails** if C_0 cannot be so parsed. Check that $\{EU_1, EU_2\}$ is a consistent set of valid encodings; if not, then **fail**.

b) If $CofactorMode = 0$ and $v > 1$: test if $\mathbf{u}_1 \in \mathcal{G}$ and $\mathbf{u}_2 \in \mathcal{G}$; if either $\mathbf{u}_1 \notin \mathcal{G}$ or $\mathbf{u}_2 \notin \mathcal{G}$, then **fail**.

c) If $CofactorMode = 0$, set

$$\hat{\mathbf{u}}_1 = \mathbf{u}_1, \hat{\mathbf{u}}_2 = \mathbf{u}_2;$$

$$\hat{x}_1 = x_1, \hat{x}_2 = x_2, \hat{y}_1 = y_1, \hat{y}_2 = y_2.$$

d) If $CofactorMode = 1$, set:

$$\hat{\mathbf{u}}_1 = v \cdot \mathbf{u}_1, \hat{\mathbf{u}}_2 = v \cdot \mathbf{u}_2;$$

$$\hat{x}_1 = v^{-1} x_1 \bmod \mu, \hat{x}_2 = v^{-1} x_2 \bmod \mu, \hat{y}_1 = v^{-1} y_1 \bmod \mu, \hat{y}_2 = v^{-1} y_2 \bmod \mu.$$

e) Compute the integer:

$$\alpha = OS2IP(\text{Hash.eval}(EU_1 \| EU_2)).$$

f) Compute the integers:

$$t_1 = \hat{x}_1 + \alpha \hat{y}_1 \bmod \mu, t_2 = \hat{x}_2 + \alpha \hat{y}_2 \bmod \mu.$$

g) Compute the group element:

$$\mathbf{v} = t_1 \cdot \hat{\mathbf{u}}_1 + t_2 \cdot \hat{\mathbf{u}}_2.$$

h) Set $EV = \mathcal{E}(\mathbf{v}, \text{fmt})$.

i) Set $Len = KeyLen + TagLen$.

j) Set $W = KDF(EV, Len)$.

k) Parse W as $L = \langle W_1, \dots, W_{Len} \rangle$ of Len octets.

l) Set $K = \langle W_1, \dots, W_{KeyLen} \rangle$ of $KeyLen$ octets.

m) Set $T_{dec} = \langle W_{KeyLen+1}, \dots, W_{Len} \rangle$ of $TagLen$ octets.

n) Test if $T_{dec} = T$; if not then **fail**.

o) Output the secret key K .

Annex A

Replace the title:

ASN.1 syntax for object identifiers

with the following:

Object identifiers

Annex A

Replace the first paragraph:

This annex gives ASN.1 syntax for object identifiers, public keys, and parameter structures to be associated with the algorithms specified in this part of ISO/IEC 18033.

with the following:

Annex A gives object identifiers, public keys, and parameter structures to be associated with the algorithms specified in this document.

Annex A

Replace:

```
-- Key encapsulation mechanisms --
id-kem-ecies OID ::= { id-kem ecies(1) }
id-kem-psec OID ::= { id-kem psec(2) }
id-kem-ace OID ::= { id-kem ace(3) }
id-kem-rsa OID ::= { id-kem rsa(4) }
```

with the following:

```
-- Key encapsulation mechanisms --
id-kem-ecies OID ::= { id-kem ecies(1) }
```

```
id-kem-psec OID ::= { id-kem psec(2) }
id-kem-ace OID ::= { id-kem ace(3) }
id-kem-rsa OID ::= { id-kem rsa(4) }
id-kem-face OID ::= { id-kem face(5) }
```

Annex A

Replace:

```
-- KEM information objects
KeyEncapsulationMechanism ::= AlgorithmIdentifier {{ KEMAlgorithms }}
KEMAlgorithms ALGORITHM ::= {
  { OID id-kem-ecies PARMS EciesKemParameters } |
  { OID id-kem-psec PARMS PsecKemParameters } |
  { OID id-kem-ace PARMS AceKemParameters } |
  { OID id-kem-rsa PARMS RsaKemParameters },
  ... -- Expect additional algorithms --
}
```

with the following:

```
-- KEM information objects
KeyEncapsulationMechanism ::= AlgorithmIdentifier {{ KEMAlgorithms }}
KEMAlgorithms ALGORITHM ::= {
  { OID id-kem-ecies PARMS EciesKemParameters } |
  { OID id-kem-psec PARMS PsecKemParameters } |
  { OID id-kem-ace PARMS AceKemParameters } |
  { OID id-kem-rsa PARMS RsaKemParameters } |
  { OID id-kem-face PARMS FaceKemParameters },
  ... -- Expect additional algorithms --
}
```

Annex A

Add the following before ~"-- DEM specifications":

```
-- FACE-KEM
-- all components of public key are elements of the group given in
-- FaceKemParameters
FaceKemPublicKey ::= SEQUENCE {
  g1 FieldElement,
  g2 FieldElement,
  c FieldElement,
  d FieldElement
}
FaceKemParameters ::= SEQUENCE {
  group Group OPTIONAL,
  keyDerivationFunction KeyDerivationFunction,
  hashFunction HashFunction,
  keyLength KeyLength,
  tagLength TagLength
}
--#####
```

Annex B

Add the following after B.15:

B.16 Security of *FACE-KEM*

The key encapsulation mechanism *FACE-KEM*, defined in 10.5, has the following security properties.

Recall that *FACE-KEM* is parameterized by a group Γ (see 10.1), a hash function *Hash* (see 6.1), and a key derivation *KDF* (see 6.2).

FACE-KEM can be proven secure against adaptive chosen ciphertext attack, assuming that the DDH problem (defined in B.8.2) is hard for group Γ . The security proof does not make use of the random oracle model. Instead, in the security proof, *Hash* is assumed to be secure against second preimage collision attacks, and *KDF* is assumed to transform the encoding of a random group element to a random octet string. For the security proof of *FACE-KEM*, see Reference [44] (indirect security reduction to the DDH problem), or Reference [46] (direct security reduction to the DDH problem).

Annex C

Replace all the following words in Annex C:

Test vector(s)

with the following:

Numerical example(s)

Annex C

Add the following after C.8.6:

C.9 Numerical examples for *FACE-KEM***C.9.1 Numerical examples over elliptic curve P224**

```

-----
FACE-KEM
-----
Kdf = Kdf2(Hash = Sha256(outlen = 20 octets))
Hash = Sha256(outlen = 20 octets)
CofactorMode = 0
KeyLen = TagLen = 16 (octets)
-----
Group = ECTModp-Group:
p = 0xffffffffffffffffffffffffffffffff000000000000000000000001
a = 0xfffffffffffffffffffffffffffffffffffffffffffffffffffffffffe
b = 0xb4050a850c04b3abf54132565044b0b7d7bfd8ba270b39432355ffb4
mu = 0xffffffffffffffffffffffffffffffff16a2e0b8f03e13dd29455c5c2a3d
nu = 0x01
g(x) = 0xb70e0cbd6bb4bf7f321390b94a03c1d356c21122343280d6115c1d21
g(y) = 0xbd376388b5f723fb4c22dfe6cd4375a05a07476444d5819985007e34
-----
Numbers to generate g1 and g2 in key generation
a1 = 0xdc32d5babd0d3753ca5f7ff8be59f4d6c49168b8f4c6e3b59317ba44
a2 = 0x81314bb3154af84a7489c95bb9fcc0edea88a8a0779497092677d46
-----
Public Key
g1(x) = 0x73e451f448f7c473e436f394de7ddf7a562af2f6cb0a1aa7d2d38f51
g1(y) = 0x892910a01bbd1a6c7995d79c29e72d21ed37112143ab55375bb9a29c
g2(x) = 0x57fc06cf338f547227f1275fe8c11055d73feba2a3eae9245c95d7c5

```

Numbers to generate g1 and g2 in key generation

a1 = 0x015897ecb2c932fabbb876e25442682b342fab391c

a2 = 0x0353cedb56d6129658a9c208427a79756979ffa1f2

Public Key

g1(x) = 0x05cf2e1de9dcf32160bef47df954851b52a226f463

g1(y) = 0x06c65878cff713a57fa53bbfc87497ac73067ed3aa

g2(x) = 0x034115a8459671a752b8be5926ac1f604983cc8e45

g2(y) = 0x06ba7e233b76dc98ab9adad1e320c62a29690e52c1

c(x) = 0x03cd12b6bf02ec9f36885a6d6d45eea5a2c6753c53

c(y) = 0x0464d1b820fb17f9b943c12fca6385d799b891d8b8

d(x) = 0x0682142c7a07e7e445ca2c48aca4e9d46bab195821

d(y) = 0x05067a81d6cb789c8bd443fe8e416c706eea7bb435

Private Key

x1 = 0x028d2d26a73f713d3f9d0d5b8ce30d76f4d151c902

x2 = 0xa9836a84a1583f601a2f9b2b2432a0aff42c84e8

y1 = 0x02140a3d998770496c5cbec836b6e8d38e47cc0575

y2 = 0x02f179878e0f7ef84d45966f119bc634d0f246beec

Trace for FACE-KEM.Encrypt

Encoding format = uncompressed_fmt

r = 0x010c6028d090fa88fdd82d281f640a5a3353387048

u1(x) = 0x02f0e6e40244de3232377911ea47cc95d73b4512c6

u1(y) = 0x9fa93f1fb1d81ba29db4d29071506eaaa0fa2def

u2(x) = 0x51d260249605e811007536a7ec3520d9e3a1566f

u2(y) = 0xdb2f64fee47dac599f3744e739fc3a45b21db7d2

EU1 = 0x0402f0e6e40244de3232377911ea47cc95d73b4512c6009fa93f1fb1d81ba29db4d29071506eaaa0fa2def

EU2 = 0x040051d260249605e811007536a7ec3520d9e3a1566f00db2f64fee47dac599f3744e739fc3a45b21db7d2

alpha = 0x36dlfacc466a738aaa09fe33e4cdf4983eb0c8d1

r_dash = 0x036f3c8b855b8d2d3b30f8f6748ea0229ec5a25c03

v(x) = 0x050dea8e376f2e31c714e59a07ec02d5d17df9a5e7

v(y) = 0x0140402b886f4969289ce1c31ccd82f9f492a41e9a

EV = 0x04050dea8e376f2e31c714e59a07ec02d5d17df9a5e70140402b886f4969289ce1c31ccd82f9f492a41e9a

W = 0x3ee707aec1ab5f0435d8e0e0c0d4d107f4343213cde66426b98a3ce7e91cf302

K = 0x3ee707aec1ab5f0435d8e0e0c0d4d107

T = 0xf4343213cde66426b98a3ce7e91cf302

C0 = 0x0402f0e6e40244de3232377911ea47cc95d73b4512c6009fa93f1fb1d81ba29db4d290715
06eaaa0fa2def040051d260249605e811007536a7ec3520d9e3a1566f00db2f64fee47dac59
9f3744e739fc3a45b21db7d2f4343213cde66426b98a3ce7e91cf302

C.9.3 Numerical examples over Zp group

FACE-KEM

Kdf = Kdf2(Hash = Sha256(outlen = 20 octets))

Hash = Sha256(outlen = 20 octets)

CofactorMode = 0

KeyLen = TagLen = 16 (octets)

Group=Modp-Group:

p =
0xa35178c0f9b33e25e6d473a41bcfc1c9bb38182821d16a25de75b75b81b71c4cb9f245590
976fc2c4d62dd2dfc2973dd6131cc84ccb0cd75d80b7e802bb7537b5c91ef4234989471e0dd
f6577e35b28140fc13f97c925a97d1bad5b9946a0bf80b097f5f106cf134a395b4af80b949e
7c1f02c3df831fec9fbf4c18b617b8513

g =
0x06bb7bb2b9c9218947602a11c58a91a39b28eaa73057765cfb1dc14e563f21d5209583a6f
68b4ac7d2d7a42e4cd6796437841c4746f27a098ef6a26455410003e54f25b3d252b8f35569
b0017496d60829609382a951fb19bf471a9674d8d4418df1563244ad709de93386e9d29ca66
e9bb6eal73009b8ald4502d7c7f461dd5

mu =
0x51a8bc607cd99f12f36a39d20de7e0e4dd9c0c1410e8b512ef3adbadc0db8e265cf922ac8
4bb7e1626b16e96fe14b9eeb098e642665866baec05bf4015dba9bdae48f7a11a4c4a38f06e
fb2bbf1ad940a07e09fcbe492d4be8dd6adcca3505fc0584bfaf8836789a51cada57c05ca4f
3e0f8161efc18ff64fdfa60c5b0bdc289

nu = 0x02

Numbers to generate g1 and g2 in key generation

a1 =
0x306e82cd2471c56a70a3522d2f51021d862ce87b1b55da895a4ed2dfa2bb7751e4472e320
2052413a250289387216fca1e5b7a140fdcb00ee01e20acc79fc0af0f33b87b025061db163b
f4c1b9f973bf73540281d9761f807644c35b35f0adbe9873ab9600f62fc37f0c7dff99cef3f
d6695ed5be70c0bc6e712710f520b310a

a2 =
0x06c4410333e2b6531346ed3e1e093aa15d8305e169655c0f6c42131c070f44eb98d46fde8
2ef858c8af1074cef1c22b612b9b27ea206ea60ebd82e57e67e80b562fb4a8f15cbcd1b7b5
70eb9b4ed9ecbce59271204e03411c64b7f849240ae83158a72274957d997e7e5489f352c0
b58b586d2cf278ae4abf2866902b75733

Public Key

g1 =
0x84e36daa032b03469efcacce74f5efe02aca71e5ea4499e0e9bfca4d4acdf94d52daa36ca
1b3cfde68f2fa22a0b4fe633e83a60f73bd4eac21e806dbc61c47fb71533890a24b83e3d5e7
a82a54e07fc06bf83fa90f08147ae587e12ad276bfcccc1f7d7c194fe45edc02806a84a46c1
efda06394ed4a49813a8d3b5541d42441