

Internet Engineering Task Force (IETF)
Request for Comments: 5990
Category: Standards Track
ISSN: 2070-1721

J. Randall
Randall Consulting
B. Kaliski
EMC
J. Brainard
RSA
S. Turner
IECA
September 2010

Use of the RSA-KEM Key Transport Algorithm in the Cryptographic Message Syntax (CMS)

Abstract

The RSA-KEM Key Transport Algorithm is a one-pass (store-and-forward) mechanism for transporting keying data to a recipient using the recipient's RSA public key. ("KEM" stands for "key encapsulation mechanism".) This document specifies the conventions for using the RSA-KEM Key Transport Algorithm with the Cryptographic Message Syntax (CMS). The ASN.1 syntax is aligned with an expected forthcoming change to American National Standard (ANS) X9.44.

Status of This Memo

This is an Internet Standards Track document.

This document is a product of the Internet Engineering Task Force (IETF). It represents the consensus of the IETF community. It has received public review and has been approved for publication by the Internet Engineering Steering Group (IESG). Further information on Internet Standards is available in Section 2 of RFC 5741.

Information about the current status of this document, any errata, and how to provide feedback on it may be obtained at <http://www.rfc-editor.org/info/rfc5990>.

Copyright Notice

Copyright (c) 2010 IETF Trust and the persons identified as the document authors. All rights reserved.

This document is subject to BCP 78 and the IETF Trust's Legal Provisions Relating to IETF Documents (<http://trustee.ietf.org/license-info>) in effect on the date of publication of this document. Please review these documents carefully, as they describe your rights and restrictions with respect to this document. Code Components extracted from this document must include Simplified BSD License text as described in Section 4.e of the Trust Legal Provisions and are provided without warranty as described in the Simplified BSD License.

Table of Contents

| | |
|--|----|
| 1. Introduction | 3 |
| 1.1. Conventions Used in This Document | 4 |
| 2. Use in CMS | 4 |
| 2.1. Underlying Components | 4 |
| 2.2. RecipientInfo Conventions | 5 |
| 2.3. Certificate Conventions | 5 |
| 2.4. SMIMECapabilities Attribute Conventions | 6 |
| 3. Security Considerations | 7 |
| 4. IANA Considerations | 9 |
| 5. Acknowledgements | 9 |
| 6. References | 10 |
| 6.1. Normative References | 10 |
| 6.2. Informative References | 11 |
| Appendix A. RSA-KEM Key Transport Algorithm | 12 |
| A.1. Underlying Components | 12 |
| A.2. Sender's Operations | 12 |
| A.3. Recipient's Operations | 13 |
| Appendix B. ASN.1 Syntax | 15 |
| B.1. RSA-KEM Key Transport Algorithm | 16 |
| B.2. Selected Underlying Components | 18 |
| B.2.1. Key Derivation Functions | 18 |
| B.2.2. Symmetric Key-Wrapping Schemes | 19 |
| B.3. ASN.1 Module | 20 |
| B.4. Examples | 25 |

1. Introduction

The RSA-KEM Key Transport Algorithm is a one-pass (store-and-forward) mechanism for transporting keying data to a recipient using the recipient's RSA public key.

Most previous key transport algorithms based on the RSA public-key cryptosystem (e.g., the popular PKCS #1 v1.5 algorithm [PKCS1]) have the following general form:

1. Format or "pad" the keying data to obtain an integer m .
2. Encrypt the integer m with the recipient's RSA public key:

$$c = m^e \bmod n$$

3. Output c as the encrypted keying data.

The RSA-KEM Key Transport Algorithm takes a different approach that provides higher security assurance, by encrypting a `random` integer with the recipient's public key, and using a symmetric key-wrapping scheme to encrypt the keying data. It has the following form:

1. Generate a random integer z between 0 and $n-1$.
2. Encrypt the integer z with the recipient's RSA public key:

$$c = z^e \bmod n$$

3. Derive a key-encrypting key KEK from the integer z .
4. Wrap the keying data using KEK to obtain wrapped keying data WK.
5. Output c and WK as the encrypted keying data.

This different approach provides higher security assurance because (a) the input to the underlying RSA operation is effectively a random integer between 0 and $n-1$, where n is the RSA modulus, so it does not have any structure that could be exploited by an adversary, and (b) the input is independent of the keying data so the result of the RSA decryption operation is not directly available to an adversary. As a result, the algorithm enjoys a "tight" security proof in the random oracle model. (In other padding schemes, such as PKCS #1 v1.5, the input has structure and/or depends on the keying data, and the provable security assurances are not as strong.) The approach is also architecturally convenient because the public-key operations are

separate from the symmetric operations on the keying data. Another benefit is that the length of the keying data is bounded only by the symmetric key-wrapping scheme, not the size of the RSA modulus.

The RSA-KEM Key Transport Algorithm in various forms is being adopted in several draft standards as well as in American National Standard (ANS) X9.44 [ANS-X9.44]. It has also been recommended by the New European Schemes for Signatures, Integrity, and Encryption (NESSIE) project [NESSIE]. Originally, [ANS-X9.44] specified a different object identifier to identify the RSA-KEM Key Transport Algorithm. [ANS-X9.44] used `id-ac-generic-hybrid`, while this document uses `id-rsa-kem`. These OIDs are used in the `KeyTransportInfo` field to indicate the key encryption algorithm, in certificates to allow recipients to restrict their public keys for use with RSA-KEM only, and in SMIME Capability attributes to allow recipients to advertise their support for RSA-KEM. Legacy implementations that wish to interoperate with [ANS-X9.44] should consult that specification for more information on `id-ac-generic-hybrid`.

For completeness, a specification of the algorithm is given in Appendix A of this document; ASN.1 syntax is given in Appendix B.

NOTE: The term "KEM" stands for "key encapsulation mechanism" and refers to the first three steps of the process above. The formalization of key transport algorithms (or more generally, asymmetric encryption schemes) in terms of key encapsulation mechanisms is described further in research by Victor Shoup leading to the development of the ISO/IEC 18033-2 standard [SHOUP].

1.1. Conventions Used in This Document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [STDWORDS].

2. Use in CMS

The RSA-KEM Key Transport Algorithm MAY be employed for one or more recipients in the CMS enveloped-data content type (Section 6 of [CMS]), where the keying data processed by the algorithm is the CMS content-encryption key.

2.1. Underlying Components

A CMS implementation that supports the RSA-KEM Key Transport Algorithm MUST support at least the following underlying components:

- o For the key derivation function, KDF3 (see [ANS-X9.44]) based on SHA-256 (see [FIPS-180-3]). KDF3 is an instantiation of the Concatenation Key Derivation Function defined in [NIST-SP800-56A].
- o For the key-wrapping scheme, AES-Wrap-128, i.e., the AES Key Wrap with a 128-bit key-encrypting key (see [AES-WRAP]).

An implementation **SHOULD** also support KDF2 (see [ANS-X9.44]) based on SHA-1 (this function is also specified as the key derivation function in [ANS-X9.63]). The Camellia key wrap algorithm (see [CAMELLIA]) **SHOULD** be supported if Camellia is supported as a content-encryption cipher. The Triple-DES Key Wrap (see [3DES-WRAP]) **SHOULD** also be supported if Triple-DES is supported as a content-encryption cipher.

It **MAY** support other underlying components. When AES or Camellia is used, the data block size is 128 bits and the key size can be 128, 192, or 256 bits, while Triple-DES requires a data block size of 64 bits and a key size of 112 or 168 bits.

2.2. RecipientInfo Conventions

When the RSA-KEM Key Transport Algorithm is employed for a recipient, the RecipientInfo alternative for that recipient **MUST** be KeyTransRecipientInfo. The algorithm-specific fields of the KeyTransRecipientInfo value **MUST** have the following values:

- o keyEncryptionAlgorithm.algorithm **MUST** be id-rsa-kem (see Appendix B);
- o keyEncryptionAlgorithm.parameters **MUST** be a value of type GenericHybridParameters, identifying the RSA-KEM key encapsulation mechanism (see Appendix B);
- o encryptedKey **MUST** be the encrypted keying data output by the algorithm, where the keying data is the content-encryption key (see Appendix A).

2.3. Certificate Conventions

The conventions specified in this section augment RFC 5280 [PROFILE].

A recipient who employs the RSA-KEM Key Transport Algorithm **MAY** identify the public key in a certificate by the same AlgorithmIdentifier as for the PKCS #1 v1.5 algorithm, i.e., using the rsaEncryption object identifier [PKCS1]. The fact that the user will accept RSA-KEM with this public key is not indicated by the use

of this identifier. This MAY be signaled by the use of the appropriate SMIME Capabilities either in a message or in the certificate.

If the recipient wishes only to employ the RSA-KEM Key Transport Algorithm with a given public key, the recipient MUST identify the public key in the certificate using the id-rsa-kem object identifier (see Appendix B). When the id-rsa-kem algorithm identifier appears in the SubjectPublicKeyInfo algorithm field, the encoding SHALL omit the parameters field from AlgorithmIdentifier. That is, the AlgorithmIdentifier SHALL be a SEQUENCE of one component, the object identifier id-rsa-kem.

Regardless of the AlgorithmIdentifier used, the RSA public key is encoded in the same manner in the subject public key information. The RSA public key MUST be encoded using the type RSAPublicKey type:

```
RSAPublicKey ::= SEQUENCE {  
    modulus          INTEGER, -- n  
    publicExponent   INTEGER  -- e  
}
```

Here, the modulus is the modulus n , and publicExponent is the public exponent e . The Distinguished Encoding Rules (DER)-encoded RSAPublicKey is carried in the subjectPublicKey BIT STRING within the subject public key information.

The intended application for the key MAY be indicated in the key usage certificate extension (see [PROFILE], Section 4.2.1.3). If the keyUsage extension is present in a certificate that conveys an RSA public key with the id-rsa-kem object identifier as discussed above, then the key usage extension MUST contain the following value:

keyEncipherment

dataEncipherment SHOULD NOT be present. That is, a key intended to be employed only with the RSA-KEM Key Transport Algorithm SHOULD NOT also be employed for data encryption or for authentication such as in signatures. Good cryptographic practice employs a given RSA key pair in only one scheme. This practice avoids the risk that vulnerability in one scheme may compromise the security of the other, and may be essential to maintain provable security.

2.4. SMIMECapabilities Attribute Conventions

RFC 3851 [MSG], Section 2.5.2 defines the SMIMECapabilities signed attribute (defined as a SEQUENCE of SMIMECapability SEQUENCES) to be used to specify a partial list of algorithms that the software

announcing the SMIMECapabilities can support. When constructing a signedData object, compliant software MAY include the SMIMECapabilities signed attribute announcing that it supports the RSA-KEM Key Transport Algorithm.

The SMIMECapability SEQUENCE representing the RSA-KEM Key Transport Algorithm MUST include the id-rsa-kem object identifier (see Appendix B) in the capabilityID field and MUST include a GenericHybridParameters value in the parameters field identifying the components with which the algorithm is to be employed.

The DER encoding of a SMIMECapability SEQUENCE is the same as the DER encoding of an AlgorithmIdentifier. Example DER encodings for typical sets of components are given in Appendix B.4.

3. Security Considerations

The RSA-KEM Key Transport Algorithm should be considered for new CMS-based applications as a replacement for the widely implemented RSA encryption algorithm specified originally in PKCS #1 v1.5 (see [PKCS1] and Section 4.2.1 of [CMSALGS]), which is vulnerable to chosen-ciphertext attacks. The RSA Encryption Scheme - Optimal Asymmetric Encryption Padding (RSAES-OAEP) Key Transport Algorithm has also been proposed as a replacement (see [PKCS1] and [CMS-OAEP]). RSA-KEM has the advantage over RSAES-OAEP of a tighter security proof, but the disadvantage of slightly longer encrypted keying data.

The security of the RSA-KEM Key Transport Algorithm described in this document can be shown to be tightly related to the difficulty of either solving the RSA problem or breaking the underlying symmetric key-wrapping scheme, if the underlying key derivation function is modeled as a random oracle, and assuming that the symmetric key-wrapping scheme satisfies the properties of a data encapsulation mechanism [SHOUP]. While in practice a random-oracle result does not provide an actual security proof for any particular key derivation function, the result does provide assurance that the general construction is reasonable; a key derivation function would need to be particularly weak to lead to an attack that is not possible in the random oracle model.

The RSA key size and the underlying components should be selected consistent with the desired symmetric security level for an application. Several security levels have been identified in the NIST FIPS PUB 800-57 [NIST-GUIDELINE]. For brevity, the first three levels are mentioned here:

- o 80-bit security. The RSA key size SHOULD be at least 1024 bits, the hash function underlying the KDF SHOULD be SHA-1 or above, and the symmetric key-wrapping scheme SHOULD be AES Key Wrap, Triple-DES Key Wrap, or Camellia Key Wrap.
- o 112-bit security. The RSA key size SHOULD be at least 2048 bits, the hash function underlying the KDF SHOULD be SHA-224 or above, and the symmetric key-wrapping scheme SHOULD be AES Key Wrap, Triple-DES Key Wrap, or Camellia Key Wrap.
- o 128-bit security. The RSA key size SHOULD be at least 3072 bits, the hash function underlying the KDF SHOULD be SHA-256 or above, and the symmetric key-wrapping scheme SHOULD be AES Key Wrap or Camellia Key Wrap.

Note that the AES Key Wrap or Camellia Key Wrap MAY be used at all three of these levels; the use of AES or Camellia does not require a 128-bit security level for other components.

Implementations MUST protect the RSA private key and the content-encryption key. Compromise of the RSA private key may result in the disclosure of all messages protected with that key. Compromise of the content-encryption key may result in disclosure of the associated encrypted content.

Additional considerations related to key management may be found in [NIST-GUIDELINE].

The security of the algorithm also depends on the strength of the random number generator, which SHOULD have a comparable security level. For further discussion on random number generation, please see [RANDOM].

Implementations SHOULD NOT reveal information about intermediate values or calculations, whether by timing or other "side channels", or otherwise an opponent may be able to determine information about the keying data and/or the recipient's private key. Although not all intermediate information may be useful to an opponent, it is preferable to conceal as much information as is practical, unless analysis specifically indicates that the information would not be useful.

Generally, good cryptographic practice employs a given RSA key pair in only one scheme. This practice avoids the risk that vulnerability in one scheme may compromise the security of the other, and may be essential to maintain provable security. While RSA public keys have often been employed for multiple purposes such as key transport and digital signature without any known bad interactions, for increased

security assurance, such combined use of an RSA key pair is NOT RECOMMENDED in the future (unless the different schemes are specifically designed to be used together).

Accordingly, an RSA key pair used for the RSA-KEM Key Transport Algorithm SHOULD NOT also be used for digital signatures. (Indeed, the Accredited Standards Committee X9 (ASC X9) requires such a separation between key establishment key pairs and digital signature key pairs.) Continuing this principle of key separation, a key pair used for the RSA-KEM Key Transport Algorithm SHOULD NOT be used with other key establishment schemes, or for data encryption, or with more than one set of underlying algorithm components.

Parties MAY formalize the assurance that one another's implementations are correct through implementation validation, e.g., NIST's Cryptographic Module Validation Program (CMVP).

4. IANA Considerations

Within the CMS, algorithms are identified by object identifiers (OIDs). With one exception, all of the OIDs used in this document were assigned in other IETF documents, in ISO/IEC standards documents, by the National Institute of Standards and Technology (NIST), and in Public-Key Cryptography Standards (PKCS) documents. The two exceptions are the ASN.1 module's identifier (see Appendix B.3) and id-rsa-kem that are both assigned in this document. The module object identifiers are defined in an arc delegated by the former company RSA Data Security Inc. to the S/MIME Working Group. When the S/MIME Working Group closes, this arc and its registration procedures will be transferred to IANA.

5. Acknowledgements

This document is one part of a strategy to align algorithm standards produced by ASC X9, ISO/IEC JTC1 SC27, NIST, and the IETF. We would like to thank the members of the ASC X9F1 working group for their contributions to drafts of ANS X9.44, which led to this specification.

Our thanks to Russ Housley as well for his guidance and encouragement. We also appreciate the helpful direction we've received from Blake Ramsdell and Jim Schaad in bringing this document to fruition. A special thanks to Magnus Nystrom for his assistance on Appendix B. Thanks also to Bob Griffin and John Linn for both editorial direction and procedural guidance.

6. References

6.1. Normative References

- [3DES-WRAP] Housley, R., "Triple-DES and RC2 Key Wrapping", RFC 3217, December 2001.
- [AES-WRAP] Schaad, J. and R. Housley, "Advanced Encryption Standard (AES) Key Wrap Algorithm", RFC 3394, September 2002.
- [ANS-X9.44] ASC X9F1 Working Group. American National Standard X9.44: Public Key Cryptography for the Financial Services Industry -- Key Establishment Using Integer Factorization Cryptography. 2007.
- [ANS-X9.63] American National Standard X9.63-2002: Public Key Cryptography for the Financial Services Industry: Key Agreement and Key Transport Using Elliptic Curve Cryptography.
- [CAMELLIA] Moriai, S. and A. Kato, "Use of the Camellia Encryption Algorithm in Cryptographic Message Syntax (CMS)", RFC 3657, January 2004.
- [CMS] Housley, R., "Cryptographic Message Syntax (CMS)", RFC 5652, September 2009.
- [CMSALGS] Housley, R., "Cryptographic Message Syntax (CMS) Algorithms", RFC 3370, August 2002.
- [FIPS-180-3] National Institute of Standards and Technology (NIST). FIPS 180-3: Secure Hash Standard. October 2008.
- [MSG] Ramsdell, B. and S. Turner, "Secure/Multipurpose Internet Mail Extensions (S/MIME) Version 3.2 Message Specification", RFC 5751, January 2010.
- [PROFILE] Cooper, D., Santesson, S., Farrell, S., Boeyen, S., Housley, R., and W. Polk, "Internet X.509 Public Key Infrastructure Certificate and Certificate Revocation List (CRL) Profile", RFC 5280, May 2008.
- [STDWORDS] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, March 1997.

6.2. Informative References

- [AES-WRAP-PAD] Housley, R. and M. Dworkin, "Advanced Encryption Standard (AES) Key Wrap with Padding Algorithm", RFC 5649, September 2009.
- [CMS-OAEP] Housley, R., "Use of the RSAES-OAEP Key Transport Algorithm in Cryptographic Message Syntax (CMS)", RFC 3560, July 2003.
- [NESSIE] NESSIE Consortium. Portfolio of Recommended Cryptographic Primitives. February 2003. <http://www.cryptoneessie.org/>.
- [NIST-GUIDELINE] National Institute of Standards and Technology. Special Publication 800-57: Recommendation for Key Management - Part 1: General (Revised). March 2007. <http://csrc.nist.gov/publications/index.html>.
- [NIST-SP800-56A] National Institute of Standards and Technology. Special Publication 800-56A: Recommendation for Pair-Wise Key Establishment Schemes Using Discrete Logarithm Cryptography (Revised). March 2007. <http://csrc.nist.gov/publications/index.html>.
- [PKCS1] Jonsson, J. and B. Kaliski, "Public-Key Cryptography Standards (PKCS) #1: RSA Cryptography Specifications Version 2.1", RFC 3447, February 2003.
- [RANDOM] Eastlake 3rd, D., Schiller, J., and S. Crocker, "Randomness Requirements for Security", BCP 106, RFC 4086, June 2005.
- [SHOUP] Shoup, V. A Proposal for an ISO Standard for Public Key Encryption. Version 2.1, December 20, 2001. <http://eprint.iacr.org/2001/112>.

Appendix A. RSA-KEM Key Transport Algorithm

The RSA-KEM Key Transport Algorithm is a one-pass (store-and-forward) mechanism for transporting keying data to a recipient using the recipient's RSA public key.

With this type of algorithm, a sender encrypts the keying data using the recipient's public key to obtain encrypted keying data. The recipient decrypts the encrypted keying data using the recipient's private key to recover the keying data.

A.1. Underlying Components

The algorithm has the following underlying components:

- o KDF, a key derivation function, which derives keying data of a specified length from a shared secret value;
- o Wrap, a symmetric key-wrapping scheme, which encrypts keying Data using a key-encrypting key.

In the following, `kekLen` denotes the length in bytes of the key-encrypting key for the underlying symmetric key-wrapping scheme.

In this scheme, the length of the keying data to be transported **MUST** be among the lengths supported by the underlying symmetric key-wrapping scheme. (Both the AES and Camellia Key Wraps, for instance, require the length of the keying data to be a multiple of 8 bytes, and at least 16 bytes.) Usage and formatting of the keying data (e.g., parity adjustment for Triple-DES keys) is outside the scope of this algorithm. With some key derivation functions, it is possible to include other information besides the shared secret value in the input to the function. Also, with some symmetric key-wrapping schemes, it is possible to associate a label with the keying data. Such uses are outside the scope of this document, as they are not directly supported by CMS.

A.2. Sender's Operations

Let (n,e) be the recipient's RSA public key (see [PKCS1] for details), and let K be the keying data to be transported.

Let $nLen$ denote the length in bytes of the modulus n , i.e., the least integer such that $2^{\{8*nLen\}} > n$.

The sender performs the following operations:

1. Generate a random integer z between 0 and $n-1$ (see note), and convert z to a byte string Z of length $nLen$, most significant byte first:

$z = \text{RandomInteger}(0, n-1)$

$Z = \text{IntegerToString}(z, nLen)$

2. Encrypt the random integer z using the recipient's public key (n, e) , and convert the resulting integer c to a ciphertext C , a byte string of length $nLen$:

$c = z^e \bmod n$

$C = \text{IntegerToString}(c, nLen)$

3. Derive a key-encrypting key KEK of length $kekLen$ bytes from the byte string Z using the underlying key derivation function:

$KEK = \text{KDF}(Z, kekLen)$

4. Wrap the keying data K with the key-encrypting key KEK using the underlying key-wrapping scheme to obtain wrapped keying data WK :

$WK = \text{Wrap}(KEK, K)$

5. Concatenate the ciphertext C and the wrapped keying data WK to obtain the encrypted keying data EK :

$EK = C \parallel WK$

6. Output the encrypted keying data EK .

NOTE: The random integer z MUST be generated independently at random for different encryption operations, whether for the same or different recipients.

A.3. Recipient's Operations

Let (n, d) be the recipient's RSA private key (see [PKCS1]; other private key formats are allowed), and let EK be the encrypted keying data.

Let $nLen$ denote the length in bytes of the modulus n .

The recipient performs the following operations:

1. Separate the encrypted keying data EK into a ciphertext C of length nLen bytes and wrapped keying data WK:

$$C \parallel WK = EK$$

If the length of the encrypted keying data is less than nLen bytes, output "decryption error", and stop.

2. Convert the ciphertext C to an integer c, most significant byte first. Decrypt the integer c using the recipient's private key (n,d) to recover an integer z (see note):

$$c = \text{StringToInteger}(C)$$
$$z = c^d \bmod n$$

If the integer c is not between 0 and n-1, output "decryption error", and stop.

3. Convert the integer z to a byte string Z of length nLen, most significant byte first (see note):

$$Z = \text{IntegerToString}(z, nLen)$$

4. Derive a key-encrypting key KEK of length kekLen bytes from the byte string Z using the underlying key derivation function (see note):

$$KEK = \text{KDF}(Z, kekLen)$$

5. Unwrap the wrapped keying data WK with the key-encrypting key KEK using the underlying key-wrapping scheme to recover the keying data K:

$$K = \text{Unwrap}(KEK, WK)$$

If the unwrapping operation outputs an error, output "decryption error", and stop.

6. Output the keying data K.

NOTE: Implementations SHOULD NOT reveal information about the integer z and the string Z, nor about the calculation of the exponentiation in Step 2, the conversion in Step 3, or the key derivation in Step 4, whether by timing or other "side channels". The observable behavior of the implementation SHOULD be the same at

these steps for all ciphertexts *C* that are in range. (For example, IntegerToString conversion should take the same amount of time regardless of the actual value of the integer *z*.) The integer *z*, the string *Z*, and other intermediate results **MUST** be securely deleted when they are no longer needed.

Appendix B. ASN.1 Syntax

The ASN.1 syntax for identifying the RSA-KEM Key Transport Algorithm is an extension of the syntax for the "generic hybrid cipher" in ANS X9.44 [ANS-X9.44]. The syntax for the scheme is given in Appendix B.1. The syntax for selected underlying components including those mentioned above is given in Appendix B.2.

The following object identifier prefixes are used in the definitions below:

```
is18033-2 OID ::= { iso(1) standard(0) is18033(18033) part2(2) }

nistAlgorithm OID ::= {
    joint-iso-itu-t(2) country(16) us(840) organization(1)
    gov(101) csor(3) nistAlgorithm(4)
}

pkcs-1 OID ::= {
    iso(1) member-body(2) us(840) rsadsi(113549) pkcs(1) pkcs-1(1)
}

x9-44 OID ::= { iso(1) identified-organization(3) tc68(133)
    country(16) x9(840) x9Standards(9) x9-44(44) }

x9-44-components OID ::= { x9-44 components(1) }
```

NullParms is a more descriptive synonym for NULL when an algorithm identifier has null parameters:

```
NullParms ::= NULL
```

The material in this Appendix is based on ANS X9.44.

B.1. RSA-KEM Key Transport Algorithm

The object identifier for the RSA-KEM Key Transport Algorithm is `id-rsa-kem`, which is defined in this document as:

```
id-rsa-kem OID ::= {  
    iso(1) member-body(2) us(840) rsadsi(113549) pkcs(1)  
    pkcs-9(9) smime(16) alg(3) 14  
}
```

When `id-rsa-kem` is used in an `AlgorithmIdentifier`, the parameters **MUST** employ the `GenericHybridParameters` syntax. The parameters **MUST** be absent when used in the `SubjectPublicKeyInfo` field. The syntax for `GenericHybridParameters` is as follows:

```
GenericHybridParameters ::= {  
    kem KeyEncapsulationMechanism,  
    dem DataEncapsulationMechanism  
}
```

The fields of type `GenericHybridParameters` have the following meanings:

- o `kem` identifies the underlying key encapsulation mechanism, which in this case is also denoted as RSA-KEM.

The object identifier for RSA-KEM (as a key encapsulation mechanism) is `id-kem-rsa` as:

```
id-kem-rsa OID ::= {  
    is18033-2 key-encapsulation-mechanism(2) rsa(4)  
}
```

The associated parameters for `id-kem-rsa` have type `RsaKemParameters`:

```
RsaKemParameters ::= {  
    keyDerivationFunction KeyDerivationFunction,  
    keyLength              KeyLength  
}
```


The fields of type `RsaKemParameters` have the following meanings:

- * `keyDerivationFunction` identifies the underlying key derivation function. For alignment with ANS X9.44, it **MUST** be KDF2 or KDF3. However, other key derivation functions **MAY** be used with CMS. Please see Appendix B.2.1 for the syntax for KDF2 and KDF3.

```
KeyDerivationFunction ::=
    AlgorithmIdentifier {{KDFAlgorithms}}
```

```
KDFAlgorithms ALGORITHM ::= {
    kdf2 | kdf3,
    ... -- implementations may define other methods
}
```

- * `keyLength` is the length in bytes of the key-encrypting key, which depends on the underlying symmetric key-wrapping scheme.

```
KeyLength ::= INTEGER (1..MAX)
```

- o `dem` identifies the underlying data encapsulation mechanism. For alignment with ANS X9.44, it **MUST** be an X9-approved symmetric key-wrapping scheme. However, other symmetric key-wrapping schemes **MAY** be used with CMS. Please see Appendix B.2.2 for the syntax for the AES, Triple-DES, and Camellia Key Wraps.

```
DataEncapsulationMechanism ::=
    AlgorithmIdentifier {{DEMAgorithms}}
```

```
DEMAgorithms ALGORITHM ::= {
    X9-SymmetricKeyWrappingSchemes,
    Camellia-KeyWrappingSchemes,
    ... -- implementations may define other methods
}
```

```
X9-SymmetricKeyWrappingSchemes ALGORITHM ::= {
    aes128-Wrap | aes192-Wrap | aes256-Wrap | tdes-Wrap,
    ... -- allows for future expansion
}
```

```
Camellia-KeyWrappingSchemes ALGORITHM ::= {
    Camellia128-Wrap | Camellia192-Wrap | Camellia256-Wrap
}
```

B.2. Selected Underlying Components

B.2.1. Key Derivation Functions

The object identifier for KDF2 (see [ANS-X9.44]) is:

```
id-kdf-kdf2 OID ::= { x9-44-components kdf2(1) }
```

The associated parameters identify the underlying hash function. For alignment with ANS X9.44, the hash function **MUST** be an ASC X9-approved hash function. However, other hash functions **MAY** be used with CMS.

```
kdf2 ALGORITHM ::= { OID id-kdf-kdf2 PARMS KDF2-HashFunction }
```

```
KDF2-HashFunction ::= AlgorithmIdentifier {{KDF2-HashFunctions}}
```

```
KDF2-HashFunctions ALGORITHM ::= {  
    X9-HashFunctions,  
    ... -- implementations may define other methods  
}
```

```
X9-HashFunctions ALGORITHM ::= {  
    sha1 | sha224 | sha256 | sha384 | sha512,  
    ... -- allows for future expansion  
}
```

The object identifier for SHA-1 is:

```
id-sha1 OID ::= {  
    iso(1) identified-organization(3) oiw(14) secsig(3)  
    algorithms(2) sha1(26)  
}
```

The object identifiers for SHA-224, SHA-256, SHA-384, and SHA-512 are

```
id-sha224 OID ::= { nistAlgorithm hashAlgs(2) sha224(4) }  
id-sha256 OID ::= { nistAlgorithm hashAlgs(2) sha256(1) }  
id-sha384 OID ::= { nistAlgorithm hashAlgs(2) sha384(2) }  
id-sha512 OID ::= { nistAlgorithm hashAlgs(2) sha512(3) }
```

There has been some confusion over whether the various SHA object identifiers have a NULL parameter, or no associated parameters. As also discussed in [PKCS1], implementations **SHOULD** generate algorithm identifiers without parameters and **MUST** accept algorithm identifiers either without parameters, or with NULL parameters.

```

sha1    ALGORITHM ::= { OID id-sha1    } -- NULLParms MUST be
sha224  ALGORITHM ::= { OID id-sha224  } -- accepted for these
sha256  ALGORITHM ::= { OID id-sha256  } -- OIDs
sha384  ALGORITHM ::= { OID id-sha384  } -- ""
sha512  ALGORITHM ::= { OID id-sha512  } -- ""

```

The object identifier for KDF3 (see [ANS-X9.44]) is:

```
id-kdf-kdf3 OID ::= { x9-44-components kdf3(2) }
```

The associated parameters identify the underlying hash function. For alignment with the draft ANS X9.44, the hash function MUST be an ASC X9-approved hash function. However, other hash functions MAY be used with CMS.

```

kdf3 ALGORITHM ::= { OID id-kdf-kdf3  PARMS KDF3-HashFunction }
KDF3-HashFunction ::= AlgorithmIdentifier { KDF3-HashFunctions }
KDF3-HashFunctions ALGORITHM ::= {
    X9-HashFunctions,
    ... -- implementations may define other methods
}

```

B.2.2. Symmetric Key-Wrapping Schemes

The object identifiers for the AES Key Wrap depend on the size of the key-encrypting key. There are three object identifiers (see [AES-WRAP]):

```

id-aes128-Wrap OID ::= { nistAlgorithm aes(1) aes128-Wrap(5) }
id-aes192-Wrap OID ::= { nistAlgorithm aes(1) aes192-Wrap(25) }
id-aes256-Wrap OID ::= { nistAlgorithm aes(1) aes256-Wrap(45) }

```

These object identifiers have no associated parameters.

```

aes128-Wrap ALGORITHM ::= { OID id-aes128-Wrap }
aes192-Wrap ALGORITHM ::= { OID id-aes192-Wrap }
aes256-Wrap ALGORITHM ::= { OID id-aes256-Wrap }

```

The object identifier for the Triple-DES Key Wrap (see [3DES-WRAP]) is:

```

id-alg-CMS3DESwrap OBJECT IDENTIFIER ::= {
    iso(1) member-body(2) us(840) rsadsi(113549) pkcs(1) pkcs-9(9)
    smime(16) alg(3) 6
}

```

This object identifier has a NULL parameter.

```
tdes-Wrap ALGORITHM ::=
  { OID id-alg-CMS3DESwrap  PARMS NullParms }
```

NOTE: ASC X9 has not yet incorporated AES Key Wrap with Padding [AES-WRAP-PAD] into ANS X9.44. When ASC X9.44 adds AES Key Wrap with Padding, this document will also be updated.

The object identifiers for the Camellia Key Wrap depend on the size of the key-encrypting key. There are three object identifiers:

```
id-camellia128-Wrap OBJECT IDENTIFIER ::=
  { iso(1) member-body(2) 392 200011 61 security(1)
    algorithm(1) key-wrap-algorithm(3)
    camellia128-wrap(2) }
```

```
id-camellia192-Wrap OBJECT IDENTIFIER ::=
  { iso(1) member-body(2) 392 200011 61 security(1)
    algorithm(1) key-wrap-algorithm(3)
    camellia192-wrap(3) }
```

```
id-camellia256-Wrap OBJECT IDENTIFIER ::=
  { iso(1) member-body(2) 392 200011 61 security(1)
    algorithm(1) key-wrap-algorithm(3)
    camellia256-wrap(4) }
```

These object identifiers have no associated parameters.

```
camellia128-Wrap ALGORITHM ::= { OID id-camellia128-Wrap }
camellia192-Wrap ALGORITHM ::= { OID id-camellia192-Wrap }
camellia256-Wrap ALGORITHM ::= { OID id-camellia256-Wrap }
```

B.3. ASN.1 Module

```
CMS-RSA-KEM
  { iso(1) member-body(2) us(840) rsadsi(113549) pkcs(1)
    pkcs-9(9) smime(16) modules(0) cms-rsa-kem(21) }
```

```
DEFINITIONS ::=
```

```
BEGIN
```

```
-- EXPORTS ALL
```

```
-- IMPORTS None
```

```
-- Useful types and definitions
```

```
OID ::= OBJECT IDENTIFIER -- alias

-- Unless otherwise stated, if an object identifier has associated
-- parameters (i.e., the PARMS element is specified), the
-- parameters field shall be included in algorithm identifier
-- values. The parameters field shall be omitted if and only if
-- the object identifier does not have associated parameters
-- (i.e., the PARMS element is omitted), unless otherwise stated.

ALGORITHM ::= CLASS {
    &id    OBJECT IDENTIFIER UNIQUE,
    &Type  OPTIONAL
}
WITH SYNTAX { OID &id [PARMS &Type] }

AlgorithmIdentifier { ALGORITHM:IOSet } ::= SEQUENCE {
    algorithm    ALGORITHM.&id( {IOSet} ),
    parameters   ALGORITHM.&Type( {IOSet}{@algorithm} ) OPTIONAL
}

NullParms ::= NULL

-- ISO/IEC 18033-2 arc

iso18033-2 OID ::= { iso(1) standard(0) iso18033(18033) part2(2) }

-- NIST algorithm arc

nistAlgorithm OID ::= {
    joint-iso-itu-t(2) country(16) us(840) organization(1)
    gov(101) csor(3) nistAlgorithm(4)
}

-- PKCS #1 arc

pkcs-1 OID ::= {
    iso(1) member-body(2) us(840) rsadsi(113549) pkcs(1) pkcs-1(1)
}

-- RSA-KEM Key Transport Algorithm

id-rsa-kem OID ::= {
    iso(1) member-body(2) us(840) rsadsi(113549) pkcs(1)
    pkcs-9(9) smime(16) alg(3) 14
}
```

```
GenericHybridParameters ::= SEQUENCE {
    kem   KeyEncapsulationMechanism,
    dem   DataEncapsulationMechanism
}

KeyEncapsulationMechanism ::= AlgorithmIdentifier {{KEMAlgorithms}}

KEMAlgorithms ALGORITHM ::= { kem-rsa, ... }

kem-rsa ALGORITHM ::= { OID id-kem-rsa PARMS RsaKemParameters }

id-kem-rsa OID ::= {
    is18033-2 key-encapsulation-mechanism(2) rsa(4)
}

RsaKemParameters ::= SEQUENCE {
    keyDerivationFunction KeyDerivationFunction,
    keyLength              KeyLength
}

KeyDerivationFunction ::= AlgorithmIdentifier {{KDFAlgorithms}}

KDFAlgorithms ALGORITHM ::= {
    kdf2 | kdf3,
    ... -- implementations may define other methods
}

KeyLength ::= INTEGER (1..MAX)

DataEncapsulationMechanism ::= AlgorithmIdentifier {{DEMAgorithms}}

DEMAgorithms ALGORITHM ::= {
    X9-SymmetricKeyWrappingSchemes |
    Camellia-KeyWrappingSchemes,
    ... -- implementations may define other methods
}

X9-SymmetricKeyWrappingSchemes ALGORITHM ::= {
    aes128-Wrap | aes192-Wrap | aes256-Wrap | tdes-Wrap,
    ... -- allows for future expansion
}

X9-SymmetricKeyWrappingScheme ::=
    AlgorithmIdentifier {{ X9-SymmetricKeyWrappingSchemes }}
```

```
Camellia-KeyWrappingSchemes ALGORITHM ::= {
    camellia128-Wrap | camellia192-Wrap | camellia256-Wrap,
    ... -- allows for future expansion
}

Camellia-KeyWrappingScheme ::=
    AlgorithmIdentifier {{ Camellia-KeyWrappingSchemes }}

-- Key Derivation Functions

id-kdf-kdf2 OID ::= { x9-44-components kdf2(1) }

-- Base arc

x9-44 OID ::= {
    iso(1) identified-organization(3) tc68(133) country(16) x9(840)
    x9Standards(9) x9-44(44)
}

x9-44-components OID ::= { x9-44 components(1) }

kdf2 ALGORITHM ::= { OID id-kdf-kdf2  PARMS KDF2-HashFunction }

KDF2-HashFunction ::= AlgorithmIdentifier {{ KDF2-HashFunctions }}

KDF2-HashFunctions ALGORITHM ::= {
    X9-HashFunctions,
    ... -- implementations may define other methods
}

id-kdf-kdf3 OID ::= { x9-44-components kdf3(2) }

kdf3 ALGORITHM ::= { OID id-kdf-kdf3  PARMS KDF3-HashFunction }

KDF3-HashFunction ::= AlgorithmIdentifier {{ KDF3-HashFunctions }}

KDF3-HashFunctions ALGORITHM ::= {
    X9-HashFunctions,
    ... -- implementations may define other methods
}

-- Hash Functions

X9-HashFunctions ALGORITHM ::= {
    sha1 | sha224 | sha256 | sha384 | sha512,
    ... -- allows for future expansion
}
```

```
id-sha1 OID ::= {
    iso(1) identified-organization(3) oiw(14) secsig(3)
    algorithms(2) sha1(26)
}

id-sha224 OID ::= { nistAlgorithm hashAlgs(2) sha224(4) }
id-sha256 OID ::= { nistAlgorithm hashAlgs(2) sha256(1) }
id-sha384 OID ::= { nistAlgorithm hashAlgs(2) sha384(2) }
id-sha512 OID ::= { nistAlgorithm hashAlgs(2) sha512(3) }

sha1 ALGORITHM ::= { OID id-sha1 } -- NullParms MUST be
sha224 ALGORITHM ::= { OID id-sha224 } -- accepted for these
sha256 ALGORITHM ::= { OID id-sha256 } -- OIDs
sha384 ALGORITHM ::= { OID id-sha384 } -- ""
sha512 ALGORITHM ::= { OID id-sha512 } -- ""

-- Symmetric Key-Wrapping Schemes

id-aes128-Wrap OID ::= { nistAlgorithm aes(1) aes128-Wrap(5) }
id-aes192-Wrap OID ::= { nistAlgorithm aes(1) aes192-Wrap(25) }
id-aes256-Wrap OID ::= { nistAlgorithm aes(1) aes256-Wrap(45) }
aes128-Wrap ALGORITHM ::= { OID id-aes128-Wrap }
aes192-Wrap ALGORITHM ::= { OID id-aes192-Wrap }
aes256-Wrap ALGORITHM ::= { OID id-aes256-Wrap }

id-alg-CMS3DESwrap OBJECT IDENTIFIER ::= {
    iso(1) member-body(2) us(840) rsadsi(113549) pkcs(1) pkcs-9(9)
    smime(16) alg(3) 6
}

tDES-Wrap ALGORITHM ::= { OID id-alg-CMS3DESwrap PARMS NullParms }

id-camellia128-Wrap OBJECT IDENTIFIER ::=
{ iso(1) member-body(2) 392 200011 61 security(1)
  algorithm(1) key-wrap-algorithm(3)
  camellia128-wrap(2) }
```



```

id-camellia192-Wrap OBJECT IDENTIFIER ::=
  { iso(1) member-body(2) 392 200011 61 security(1)
    algorithm(1) key-wrap-algorithm(3)
    camellia192-wrap(3) }

id-camellia256-Wrap OBJECT IDENTIFIER ::=
  { iso(1) member-body(2) 392 200011 61 security(1)
    algorithm(1) key-wrap-algorithm(3)
    camellia256-wrap(4) }

camellia128-Wrap ALGORITHM ::= { OID id-camellia128-Wrap }
camellia192-Wrap ALGORITHM ::= { OID id-camellia192-Wrap }
camellia256-Wrap ALGORITHM ::= { OID id-camellia256-Wrap }

END

```

B.4. Examples

As an example, if the key derivation function is KDF3 based on SHA-256 and the symmetric key-wrapping scheme is the AES Key Wrap with a 128-bit KEK, the AlgorithmIdentifier for the RSA-KEM Key Transport Algorithm will have the following value:

```

SEQUENCE {
  id-rsa-kem,
  SEQUENCE {
    SEQUENCE {
      id-kem-rsa,
      SEQUENCE {
        SEQUENCE {
          id-kdf-kdf3,
          SEQUENCE {
            id-sha256 -- SHA-256; no parameters (preferred)
          },
          16 -- KEK length in bytes
        },
        SEQUENCE {
          id-aes128-Wrap -- data encapsulation mechanism
            -- AES-128 Wrap; no parameters
        }
      }
    }
  }
}

```

This AlgorithmIdentifier value has the following DER encoding:

```

30 47
 06 0b 2a 86 48 86 f7 0d 01 09 10 03 0e      -- id-rsa-kem
 30 38
   30 29
    06 07 28 81 8c 71 02 02 04                -- id-kem-rsa
    30 1e
     30 19
      06 0a 2b 81 05 10 86 48 09 2c 01 02      -- id-kdf-kdf3
      30 0b
       06 09 60 86 48 01 65 03 04 02 01      -- id-sha256
       02 01 10                              -- 16 bytes
 30 0b
   06 09 60 86 48 01 65 03 04 01 05          -- id-aes128-Wrap

```

The DER encodings for other typical sets of underlying components are as follows:

- o KDF3 based on SHA-384, AES Key Wrap with a 192-bit KEK

```

30 47 06 0b 2a 86 48 86 f7 0d 01 09 10 03 0e 30
38 30 29 06 07 28 81 8c 71 02 02 04 30 1e 30 19
06 0a 2b 81 05 10 86 48 09 2c 01 02 30 0b 06 09
60 86 48 01 65 03 04 02 02 02 01 18 30 0b 06 09
60 86 48 01 65 03 04 01 19

```

- o KDF3 based on SHA-512, AES Key Wrap with a 256-bit KEK

```

30 47 06 0b 2a 86 48 86 f7 0d 01 09 10 03 0e 30
38 30 29 06 07 28 81 8c 71 02 02 04 30 1e 30 19
06 0a 2b 81 05 10 86 48 09 2c 01 02 30 0b 06 09
60 86 48 01 65 03 04 02 03 02 01 20 30 0b 06 09
60 86 48 01 65 03 04 01 2d

```

- o KDF2 based on SHA-1, Triple-DES Key Wrap with a 128-bit KEK (two-key Triple-DES)

```

30 45 06 0b 2a 86 48 86 f7 0d 01 09 10 03 0e 30
36 30 25 06 07 28 81 8c 71 02 02 04 30 1a 30 15
06 0a 2b 81 05 10 86 48 09 2c 01 01 30 07 06 05
2b 0e 03 02 1a 02 01 10 30 0d 06 0b 2a 86 48 86
f7 0d 01 09 10 03 06

```

Authors' Addresses

James Randall
Randall Consulting
55 Sandpiper Drive
Dover, NH 03820
USA

EMail: jdrandall@comcast.net

Burt Kaliski
EMC
176 South Street
Hopkinton, MA 01748
USA

EMail: burt.kaliski@emc.com

John Brainard
RSA, The Security Division of EMC
174 Middlesex Turnpike
Bedford, MA 01730
USA

EMail: jbrainard@rsa.com

Sean Turner
IECA, Inc.
3057 Nutley Street, Suite 106
Fairfax, VA 22031
USA

EMail: turners@ieca.com