                Using AES-CCM and AES-GCM Authenticated Encryption
                   in the Cryptographic Message Syntax (CMS)

Status of This Memo

   This document specifies an Internet standards track protocol for the
   Internet community, and requests discussion and suggestions for
   improvements. Please refer to the current edition of the "Internet
   Official Protocol Standards" (STD 1) for the standardization state
   and status of this protocol. Distribution of this memo is unlimited.

Abstract

   This document specifies the conventions for using the AES-CCM and the
   AES-GCM authenticated encryption algorithms with the Cryptographic
   Message Syntax (CMS) authenticated-enveloped-data content type.

1. Introduction

   This document specifies the conventions for using Advanced Encryption
   Standard-Counter with Cipher Block Chaining-Message Authentication
   Code (AES-CCM) and AES-Galois/Counter Mode (GCM) authenticated
   encryption algorithms as the content-authenticated-encryption
   algorithm with the Cryptographic Message Syntax [CMS] authenticated-
   enveloped-data content type [AuthEnv].

1.1. Terminology

   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].

1.2. ASN.1

   CMS values are generated using ASN.1 [X.208-88], which uses the Basic
   Encoding Rules (BER) [X.209-88] and the Distinguished Encoding Rules
   (DER) [X.509-88].

1.3. AES

   Dr. Joan Daemen and Dr. Vincent Rijmen, both from Belgium, developed
   the Rijndael block cipher algorithm, and they submitted it for
   consideration as the Advanced Encryption Standard (AES). Rijndael

was selected by the National Institute for Standards and Technology
(NIST), and it is specified in a U.S. Federal Information Processing
Standard (FIPS) Publication [AES]. NIST selected the Rijndael
algorithm for AES because it offers a combination of security,
performance, efficiency, ease of implementation, and flexibility.
Specifically, the algorithm performs well in both hardware and
software across a wide range of computing environments. Also, the
very low memory requirements of the algorithm make it very well
suited for restricted-space environments. The AES is widely used by
organizations, institutions, and individuals outside of the U.S.
Government.

The AES specifies three key sizes: 128, 192, and 256 bits.

1.4. AES-CCM

   The Counter with CBC-MAC (CCM) mode of operation is specified in
   [CCM]. CCM is a generic authenticated encryption block cipher mode.
   CCM is defined for use with any 128-bit block cipher, but in this
   document, CCM is used with the AES block cipher.

   AES-CCM has four inputs: an AES key, a nonce, a plaintext, and
   optional additional authenticated data (AAD). AES-CCM generates two
   outputs: a ciphertext and a message authentication code (also called
   an authentication tag).

   The nonce is generated by the party performing the authenticated
   encryption operation. Within the scope of any authenticated-
   encryption key, the nonce value MUST be unique. That is, the set of
   nonce values used with any given key MUST NOT contain any duplicate
   values. Using the same nonce for two different messages encrypted
   with the same key destroys the security properties.

   AAD is authenticated but not encrypted. Thus, the AAD is not
   included in the AES-CCM output. It can be used to authenticate
   plaintext packet headers. In the CMS authenticated-enveloped-data
   content type, authenticated attributes comprise the AAD.

1.5. AES-GCM

   The Galois/Counter Mode (GCM) is specified in [GCM]. GCM is a
   generic authenticated encryption block cipher mode. GCM is defined
   for use with any 128-bit block cipher, but in this document, GCM is
   used with the AES block cipher.

   AES-GCM has four inputs: an AES key, an initialization vector (IV), a
   plaintext content, and optional additional authenticated data (AAD).
   AES-GCM generates two outputs: a ciphertext and message

authentication code (also called an authentication tag). To have a
common set of terms for AES-CCM and AES-GCM, the AES-GCM IV is
referred to as a nonce in the remainder of this document.

The nonce is generated by the party performing the authenticated
encryption operation. Within the scope of any authenticated-
encryption key, the nonce value MUST be unique. That is, the set of
nonce values used with any given key MUST NOT contain any duplicate
values. Using the same nonce for two different messages encrypted
with the same key destroys the security properties.

AAD is authenticated but not encrypted. Thus, the AAD is not
included in the AES-GCM output. It can be used to authenticate
plaintext packet headers. In the CMS authenticated-enveloped-data
content type, authenticated attributes comprise the AAD.

2. Automated Key Management

The reuse of an AES-CCM or AES-GCM nonce/key combination destroys the
security guarantees. As a result, it can be extremely difficult to
use AES-CCM or AES-GCM securely when using statically configured
keys. For safety's sake, implementations MUST use an automated key
management system [KEYMGMT].

The CMS authenticated-enveloped-data content type supports four
general key management techniques:

   Key Transport: the content-authenticated-encryption key is
      encrypted in the recipient's public key;

   Key Agreement: the recipient's public key and the sender's
      private key are used to generate a pairwise symmetric key, then
      the content-authenticated-encryption key is encrypted in the
      pairwise symmetric key;

   Symmetric Key-Encryption Keys: the content-authenticated-
      encryption key is encrypted in a previously distributed
      symmetric key-encryption key; and

   Passwords: the content-authenticated-encryption key is encrypted
      in a key-encryption key that is derived from a password or
      other shared secret value.

All of these key management techniques meet the automated key
management system requirement as long as a fresh content-
authenticated-encryption key is generated for the protection of each
content. Note that some of these key management techniques use one
key-encryption key to encrypt more than one content-authenticated-

encryption key during the system life cycle. As long as fresh content-authenticated-encryption key is used each time, AES-CCM and AES-GCM can be used safely with the CMS authenticated-enveloped-data content type.

In addition to these four general key management techniques, CMS supports other key management techniques. See Section 6.2.5 of [CMS]. Since the properties of these key management techniques are unknown, no statement can be made about whether these key management techniques meet the automated key management system requirement. Designers and implementers must perform their own analysis if one of these other key management techniques is supported.

3. Content-Authenticated Encryption Algorithms

   This section specifies the conventions employed by CMS implementations that support content-authenticated encryption using AES-CCM or AES-GCM.

   Content-authenticated encryption algorithm identifiers are located in the AuthEnvelopedData EncryptedContentInfo contentEncryptionAlgorithm field.

   Content-authenticated encryption algorithms are used to encipher the content located in the AuthEnvelopedData EncryptedContentInfo encryptedContent field and to provide the message authentication code for the AuthEnvelopedData mac field. Note that the message authentication code provides integrity protection for both the AuthEnvelopedData authAttrs and the AuthEnvelopedData EncryptedContentInfo encryptedContent.

3.1. AES-CCM

   The AES-CCM authenticated encryption algorithm is described in [CCM]. A brief summary of the properties of AES-CCM is provided in Section 1.4.

   Neither the plaintext content nor the optional AAD inputs need to be padded prior to invoking AES-CCM.

There are three algorithm identifiers for AES-CCM, one for each AES
key size:

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

id-aes128-CCM OBJECT IDENTIFIER ::= { aes 7 }

id-aes192-CCM OBJECT IDENTIFIER ::= { aes 27 }

id-aes256-CCM OBJECT IDENTIFIER ::= { aes 47 }
```

With all three AES-CCM algorithm identifiers, the AlgorithmIdentifier
parameters field MUST be present, and the parameters field must
contain a CCMParameter:

```
CCMParameters ::= SEQUENCE {
  aes-nonce         OCTET STRING (SIZE(7..13)),
  aes-ICVlen        AES-CCM-ICVlen DEFAULT 12 }

AES-CCM-ICVlen ::= INTEGER (4 | 6 | 8 | 10 | 12 | 14 | 16)
```

The aes-nonce parameter field contains 15-L octets, where L is the
size of the length field. With the CMS, the normal situation is for
the content-authenticated-encryption key to be used for a single
content; therefore, L=8 is RECOMMENDED. See [CCM] for a discussion
of the trade-off between the maximum content size and the size of the
nonce. Within the scope of any content-authenticated-encryption key,
the nonce value MUST be unique. That is, the set of nonce values
used with any given key MUST NOT contain any duplicate values.

The aes-ICVlen parameter field tells the size of the message
authentication code. It MUST match the size in octets of the value
in the AuthEnvelopedData mac field. A length of 12 octets is
RECOMMENDED.

3.2. AES-GCM

The AES-GCM authenticated encryption algorithm is described in [GCM].
A brief summary of the properties of AES-CCM is provided in Section
1.5.

Neither the plaintext content nor the optional AAD inputs need to be
padded prior to invoking AES-GCM.

There are three algorithm identifiers for AES-GCM, one for each AES
key size:

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

id-aes128-GCM OBJECT IDENTIFIER ::= { aes 6 }

id-aes192-GCM OBJECT IDENTIFIER ::= { aes 26 }

id-aes256-GCM OBJECT IDENTIFIER ::= { aes 46 }
```

With all three AES-GCM algorithm identifiers, the AlgorithmIdentifier
parameters field MUST be present, and the parameters field must
contain a GCMParameter:

```
GCMParameters ::= SEQUENCE {
  aes-nonce        OCTET STRING, -- recommended size is 12 octets
  aes-ICVlen       AES-GCM-ICVlen DEFAULT 12 }

AES-GCM-ICVlen ::= INTEGER (12 | 13 | 14 | 15 | 16)
```

The aes-nonce is the AES-GCM initialization vector. The algorithm
specification permits the nonce to have any number of bits between 1
and 2^{64}. However, the use of OCTET STRING within GCMParameters
requires the nonce to be a multiple of 8 bits. Within the scope of
any content-authenticated-encryption key, the nonce value MUST be
unique, but need not have equal lengths. A nonce value of 12 octets
can be processed more efficiently, so that length is RECOMMENDED.

The aes-ICVlen parameter field tells the size of the message
authentication code. It MUST match the size in octets of the value
in the AuthEnvelopedData mac field. A length of 12 octets is
RECOMMENDED.

4. Security Considerations

   AES-CCM and AES-GCM make use of the AES block cipher in counter mode
   to provide encryption. When used properly, counter mode provides
   strong confidentiality. Bellare, Desai, Jokipii, and Rogaway show in
   [BDJR] that the privacy guarantees provided by counter mode are at
   least as strong as those for Cipher Block Chaining (CBC) mode when
   using the same block cipher.

   Unfortunately, it is easy to misuse counter mode. If counter block
   values are ever used for more than one encryption operation with the
   same key, then the same key stream will be used to encrypt both
   plaintexts, and the confidentiality guarantees are voided.

Fortunately, the CMS AuthEnvelopedData provides all the tools needed
to avoid misuse of counter mode. Automated key management is
discussed in Section 2.

There are fairly generic precomputation attacks against the use of
any block cipher in counter mode that allow a meet-in-the-middle
attack against the key [H][B][MF]. AES-CCM and AES-GCM both make use
of counter mode for encryption. These precomputation attacks require
the creation and searching of huge tables of ciphertext associated
with known plaintext and known keys. Assuming that the memory and
processor resources are available for a precomputation attack, then
the theoretical strength of any block cipher in counter mode is
limited to $2^{(n/2)}$ bits, where n is the number of bits in the key.
The use of long keys is the best countermeasure to precomputation
attacks. Use of an unpredictable nonce value in the counter block
significantly increases the size of the table that the attacker must
compute to mount a successful precomputation attack.

Implementations must randomly generate content-authenticated-
encryption keys. The use of inadequate pseudo-random number
generators (PRNGs) to generate cryptographic keys can result in
little or no security. An attacker may find it much easier to
reproduce the PRNG environment that produced the keys, and then
searching the resulting small set of possibilities, rather than brute
force searching the whole key space. The generation of quality
random numbers is difficult. RFC 4086 [RANDOM] offers important
guidance in this area.

5. References

5.1. Normative References

   [AES]   NIST, FIPS PUB 197, "Advanced Encryption Standard (AES)",
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   [CCM]   Whiting, D., Housley, R., and N. Ferguson, "Counter with
                  CBC-MAC (CCM)", RFC 3610, September 2003.

   [CMS]   Housley, R., "Cryptographic Message Syntax (CMS)", RFC
                  3852, July 2004.

   [GCM]   Dworkin, M., "NIST Special Publication 800-38D:
                  Recommendation for Block Cipher Modes of Operation:
                  Galois/Counter Mode (GCM) and GMAC." , U.S. National
                  Institute of Standards and Technology
                  http://csrc.nist.gov/publications/nistpubs/800-38D/SP-
                  800-38D.pdf

   [STDWORDS] Bradner, S., "Key words for use in RFCs to Indicate
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   [X.209-88] CCITT. Recommendation X.209: Specification of Basic
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               1988.

   [X.509-88] CCITT. Recommendation X.509: The Directory-
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5.2. Informative References

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   [B]   Biham, E., "How to Forge DES-Encrypted Messages in 2^28
               Steps", Technion Computer Science Department Technical
               Report CS0884, 1996.

   [BDJR]   Bellare, M, Desai, A., Jokipii, E., and P. Rogaway, "A
               Concrete Security Treatment of Symmetric Encryption:
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               Annual Symposium on Foundations of Computer Science,
               1997.

   [H]   Hellman, M. E., "A cryptanalytic time-memory trade-off",
               IEEE Transactions on Information Theory, July 1980, pp.
               401-406.

   [KEYMGMT]   Bellovin, S. and R. Housley, "Guidelines for
               Cryptographic Key Management", BCP 107, RFC 4107, June
               2005.

   [MF]   McGrew, D., and S. Fluhrer, "Attacks on Additive
               Encryption of Redundant Plaintext and Implications on
               Internet Security", The Proceedings of the Seventh Annual
               Workshop on Selected Areas in Cryptography (SAC 2000),
               Springer-Verlag, August, 2000.

   [RANDOM]   Eastlake, D., 3rd, Schiller, J., and S. Crocker,
               "Randomness Requirements for Security", BCP 106, RFC
               4086, June 2005.

Appendix: ASN.1 Module

```
   CMS-AES-CCM-and-AES-GCM
       { iso(1) member-body(2) us(840) rsadsi(113549) pkcs(1)
         pkcs-9(9) smime(16) modules(0) cms-aes-ccm-and-gcm(32) }

   DEFINITIONS IMPLICIT TAGS ::= BEGIN

   -- EXPORTS All

   -- Object Identifiers

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

   id-aes128-CCM OBJECT IDENTIFIER ::= { aes 7 }

   id-aes192-CCM OBJECT IDENTIFIER ::= { aes 27 }

   id-aes256-CCM OBJECT IDENTIFIER ::= { aes 47 }

   id-aes128-GCM OBJECT IDENTIFIER ::= { aes 6 }

   id-aes192-GCM OBJECT IDENTIFIER ::= { aes 26 }

   id-aes256-GCM OBJECT IDENTIFIER ::= { aes 46 }


   -- Parameters for AigorithmIdentifier

   CCMParameters ::= SEQUENCE {
     aes-nonce          OCTET STRING (SIZE(7..13)),
     aes-ICVlen         AES-CCM-ICVlen DEFAULT 12 }

   AES-CCM-ICVlen ::= INTEGER (4 | 6 | 8 | 10 | 12 | 14 | 16)

   GCMParameters ::= SEQUENCE {
     aes-nonce          OCTET STRING, -- recommended size is 12 octets
     aes-ICVlen         AES-GCM-ICVlen DEFAULT 12 }

   AES-GCM-ICVlen ::= INTEGER (12 | 13 | 14 | 15 | 16)

   END
```

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