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CBOR Object Signing and Encryption (COSE): AES-CTR and AES-CBC

Abstract

The Concise Binary Object Representation (CBOR) data format is designed for small code size and small message size. CBOR Object Signing and Encryption (COSE) is specified in RFC 9052 to provide basic security services using the CBOR data format. This document specifies the conventions for using AES-CTR and AES-CBC as Content Encryption algorithms with COSE.

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1. Introduction

This document specifies the conventions for using AES-CTR and AES-CBC as Content Encryption algorithms with the CBOR Object Signing and Encryption (COSE) [[RFC9052](#)] syntax. Encryption with COSE today uses Authenticated Encryption with Associated Data (AEAD) [[RFC5116](#)] algorithms, which provide both confidentiality and integrity protection. However, there are situations where another mechanism, such as a digital signature, is used to provide integrity. In these cases, an AEAD algorithm is not needed. The software manifest being defined by the IETF SUIT WG [[I-D.ietf-suit-manifest](#)] is one example where a digital signature is always present.

2. Conventions and Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [[RFC2119](#)] [[RFC8174](#)] when, and only when, they appear in all capitals, as shown here.

3. AES Modes of Operation

NIST has defined several modes of operation for Advanced Encryption Standard (AES) [[AES](#)] [[MODES](#)]. AES supports three key sizes: 128 bits, 192 bits, and 256 bits. AES has a block size of 128 bits (16 octets). Each of these modes has different characteristics. The

modes include: CBC (Cipher Block Chaining), CFB (Cipher FeedBack), OFB (Output FeedBack), and CTR (Counter).

Only AES Counter mode (AES-CTR) and AES Cipher Block Chaining (AES-CBC) are discussed in this document.

4. AES Counter Mode

When AES-CTR is used as a COSE Content Encryption algorithm, the encryptor generates a unique value that is communicated to the decryptor. This value is called an initialization vector (IV) in this document. The same IV and AES key combination **MUST NOT** be used more than once. The encryptor can generate the IV in any manner that ensures the same IV value is not used more than once with the same AES key.

When using AES-CTR, each AES encrypt operation generates 128 bits of key stream. AES-CTR encryption is the XOR of the key stream with the plaintext. AES-CTR decryption is the XOR of the key stream with the ciphertext. If the generated key stream is longer than the plaintext or ciphertext, the extra key stream bits are simply discarded. For this reason, AES-CTR does not require the plaintext to be padded to a multiple of the block size.

AES-CTR has many properties that make it an attractive COSE Content Encryption algorithm. AES-CTR uses the AES block cipher to create a stream cipher. Data is encrypted and decrypted by XORing with the key stream produced by AES encrypting sequential IV block values, called counter blocks. The first block of the key stream is the AES encryption of the IV, the second block of the key stream is the AES encryption of $(IV + 1) \bmod 2^{128}$, the third block of the key stream is the AES encryption of $(IV + 2) \bmod 2^{128}$, and so on. AES-CTR is easy to implement, and AES-CTR can be pipelined and parallelized. AES-CTR also supports key stream precomputation. Sending of the IV is the only source of expansion because the plaintext and ciphertext are the same size.

When used correctly, AES-CTR provides a high level of confidentiality. Unfortunately, AES-CTR is easy to use incorrectly. Being a stream cipher, reuse of the IV with the same key is catastrophic. An IV collision immediately leaks information about the plaintext. For this reason, it is inappropriate to use AES-CTR with static keys. Extraordinary measures would be needed to prevent reuse of an IV value with the static key across power cycles. To be safe, implementations **MUST** use fresh keys with AES-CTR.

AES-CTR keys may be obtained either from a key structure or from a recipient structure. Implementations encrypting and decrypting **MUST**

validate that the key type, key length, and algorithm are correct and appropriate for the entities involved.

With AES-CTR, it is trivial to use a valid ciphertext to forge other (valid to the decryptor) ciphertexts. Thus, it is equally catastrophic to use AES-CTR without a companion authentication and integrity mechanism. Implementations **MUST** use AES-CTR in conjunction with an authentication and integrity mechanism, such as a digital signature.

The instructions in Section 5.4 of [[RFC9052](#)] are followed for AES-CTR. Since AES-CTR cannot provide integrity protection for external additional authenticated data, the decryptor **MUST** ensure that no external additional authenticated data was supplied. See [Section 6](#).

4.1. AES-CTR COSE Key

When using a COSE key for the AES-CTR algorithm, the following checks are made:

- *The 'kty' field **MUST** be present, and it **MUST** be 'Symmetric'.

- *If the 'alg' field is present, it **MUST** match the AES-CTR algorithm being used.

- *If the 'key_ops' field is present, it **MUST** include 'encrypt' when encrypting.

- *If the 'key_ops' field is present, it **MUST** include 'decrypt' when decrypting.

In addition, the 'protected' header parameters encoded value **MUST** be a zero-length byte string.

4.2. AES-CTR COSE Algorithm Identifiers

The following table defines the COSE AES-CTR algorithm values. Note that these algorithms are being registered as "Deprecated" to avoid accidental use without a companion integrity protection mechanism.

Name	Value	Key Size	Description	Recommended
A128CTR	TBD1	128	AES-CTR w/ 128-bit key	Deprecated
A192CTR	TBD2	192	AES-CTR w/ 192-bit key	Deprecated
A256CTR	TBD3	256	AES-CTR w/ 256-bit key	Deprecated

Table 1

5. AES Cipher Block Chaining Mode

AES-CBC mode requires an 16 octet Initialization Vector (IV). Use of a randomly or pseudo-randomly generated IV ensures that the encryption of the same plaintext will yield different ciphertext.

AES-CBC performs an XOR of the IV with the first plaintext block before it is encrypted. For successive blocks, AES-CBC performs an XOR of previous ciphertext block with the current plaintext before it is encrypted.

AES-CBC requires padding of the plaintext; the padding algorithm specified in Section 6.3 of [\[RFC5652\]](#) **MUST** be used prior to encrypting the plaintext. This padding algorithm allows the decryptor to unambiguously remove the padding.

The simplicity of AES-CBC makes it an attractive COSE Content Encryption algorithm. The need to carry an IV and the need for padding lead to an increase in the overhead (when compared to AES-CTR). AES-CBC is much safer for use with static keys than AES-CTR. That said, as described in [\[RFC4107\]](#), the use of automated key management to generate fresh keys is greatly preferred.

AES-CBC does not provide integrity protection. Thus, an attacker can introduce undetectable errors if AES-CBC is used without a companion authentication and integrity mechanism. Implementations **MUST** use AES-CBC in conjunction with an authentication and integrity mechanism, such as a digital signature.

The instructions in Section 5.4 of [\[RFC9052\]](#) are followed for AES-CBC. Since AES-CBC cannot provide integrity protection for external additional authenticated data, the decryptor **MUST** ensure that no external additional authenticated data was supplied. See [Section 6](#).

5.1. AES-CBC COSE Key

When using a COSE key for the AES-CBC algorithm, the following checks are made:

- *The 'kty' field **MUST** be present, and it **MUST** be 'Symmetric'.

- *If the 'alg' field is present, it **MUST** match the AES-CBC algorithm being used.

- *If the 'key_ops' field is present, it **MUST** include 'encrypt' when encrypting.

- *If the 'key_ops' field is present, it **MUST** include 'decrypt' when decrypting.

In addition, the 'protected' header parameters encoded value **MUST** be a zero-length byte string.

5.2. AES-CBC COSE Algorithm Identifiers

The following table defines the COSE AES-CBC algorithm values. Note that these algorithms are being registered as "Deprecated" to avoid accidental use without a companion integrity protection mechanism.

Name	Value	Key Size	Description	Recommended
A128CBC	TBD4	128	AES-CBC w/ 128-bit key	Deprecated
A192CBC	TBD5	192	AES-CBC w/ 192-bit key	Deprecated
A256CBC	TBD6	256	AES-CBC w/ 256-bit key	Deprecated

Table 2

6. Implementation Considerations

COSE libraries that support either AES-CTR or AES-CBC and accept Additional Authenticated Data (AAD) as input should return an error if one of these non-AEAD content encryption algorithm is selected. This would ensure that a caller does not expect the AAD to be protected when the cryptographic algorithm is unable to do so.

7. IANA Considerations

IANA is requested to register six COSE algorithm identifiers for AES-CTR and AES-CBC in the COSE Algorithms Registry [[IANA](#)].

The information for the six COSE algorithm identifiers is provided in [Section 4.2](#) and [Section 5.2](#). Also, for all six entries, the "Capabilities" column should contain "[kty]", the "Change Controller" column should contain "IESG", and the "Reference" column should contain a reference to this document.

Ideally, the six values will be assigned in the -65534 to -261 range.

8. Security Considerations

This document specifies AES-CTR and AES-CBC for COSE, which are not authenticated encryption with additional data (AEAD) ciphers. The use of the ciphers is limited to special use cases where integrity and authentication is provided by another mechanism, such as firmware encryption.

Since AES has a 128-bit block size, regardless of the mode employed, the ciphertext generated by AES encryption becomes distinguishable from random values after 2^{64} blocks are encrypted with a single key. Implementations should change the key before before reaching this limit.

To avoid cross-protocol concerns, implementations **MUST NOT** use the same keying material with more than one mode. For example, the same keying material must not be used with AES-CTR and AES-CBC.

There are fairly generic precomputation attacks against all block cipher modes that allow a meet-in-the-middle attack against the key. These 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 AES-CTR and AES-CBC are 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.

When used properly, AES-CTR mode provides strong confidentiality. Unfortunately, it is very easy to misuse this counter mode. If counter block values are ever used for more than one plaintext with the same key, then the same key stream will be used to encrypt both plaintexts, and the confidentiality guarantees are voided.

What happens if the encryptor XORs the same key stream with two different plaintexts? Suppose two plaintext octet sequences P_1 , P_2 , P_3 and Q_1 , Q_2 , Q_3 are both encrypted with key stream K_1 , K_2 , K_3 . The two corresponding ciphertexts are:

$(P_1 \text{ XOR } K_1)$, $(P_2 \text{ XOR } K_2)$, $(P_3 \text{ XOR } K_3)$

$(Q_1 \text{ XOR } K_1)$, $(Q_2 \text{ XOR } K_2)$, $(Q_3 \text{ XOR } K_3)$

If both of these two ciphertext streams are exposed to an attacker, then a catastrophic failure of confidentiality results, since:

$(P_1 \text{ XOR } K_1) \text{ XOR } (Q_1 \text{ XOR } K_1) = P_1 \text{ XOR } Q_1$

$(P_2 \text{ XOR } K_2) \text{ XOR } (Q_2 \text{ XOR } K_2) = P_2 \text{ XOR } Q_2$

$(P_3 \text{ XOR } K_3) \text{ XOR } (Q_3 \text{ XOR } K_3) = P_3 \text{ XOR } Q_3$

Once the attacker obtains the two plaintexts XORed together, it is relatively straightforward to separate them. Thus, using any stream cipher, including AES-CTR, to encrypt two plaintexts under the same key stream leaks the plaintext.

Therefore, it is inappropriate to use AES-CTR with static keys. Extraordinary measures would be needed to prevent reuse of a counter block value with the static key across power cycles. To be safe, implementations **MUST** use fresh keys with AES-CTR.

Data forgery is trivial with AES-CTR mode. The demonstration of this attack is similar to the key stream reuse discussion above. If a known plaintext octet sequence P_1 , P_2 , P_3 is encrypted with key

stream K_1 , K_2 , K_3 , then the attacker can replace the plaintext with one of his own choosing. The ciphertext is:

$$(P_1 \text{ XOR } K_1), (P_2 \text{ XOR } K_2), (P_3 \text{ XOR } K_3)$$

The attacker simply XORs a selected sequence Q_1 , Q_2 , Q_3 with the ciphertext to obtain:

$$(Q_1 \text{ XOR } (P_1 \text{ XOR } K_1)), (Q_2 \text{ XOR } (P_2 \text{ XOR } K_2)), (Q_3 \text{ XOR } (P_3 \text{ XOR } K_3))$$

Which is the same as:

$$((Q_1 \text{ XOR } P_1) \text{ XOR } K_1), ((Q_2 \text{ XOR } P_2) \text{ XOR } K_2), ((Q_3 \text{ XOR } P_3) \text{ XOR } K_3)$$

Decryption of the attacker-generated ciphertext will yield exactly what the attacker intended:

$$(Q_1 \text{ XOR } P_1), (Q_2 \text{ XOR } P_2), (Q_3 \text{ XOR } P_3)$$

Accordingly, implementations **MUST** use AES-CTR in conjunction with an authentication and integrity mechanism, such as a digital signature.

AES-CBC does not provide integrity protection. Thus, an attacker can introduce undetectable errors if AES-CBC is used without a companion authentication mechanism. Accordingly, implementations **MUST** use of AES-CBC in conjunction with an authentication and integrity mechanism, such as a digital signature.

If an attacker is able to strip the authentication and integrity mechanism, then the attacker can replace it with their one of their own creation, even without knowing the plaintext. The usual defense against such an attack is an Authenticated Encryption with Associated Data (AEAD) [[RFC5116](#)] algorithm. Of course, neither AES-CTR nor AES-CBC is an AEAD. Thus, an implementation **SHOULD** provide integrity protection for the kid field to prevent undetected stripping of the the authentication and integrity mechanism; this prevents an attacker from altering the kid to trick the recipient into using a different key.

With AES-CBC mode, implementers **SHOULD** perform integrity checks prior to decryption to avoid padding oracle vulnerabilities [[Vaudenay](#)].

With the assignment of COSE algorithm identifiers for AES-CTR and AES-CBC in the COSE Algorithms Registry, an attacker can replace the COSE algorithm identifiers with one of these identifiers. Then, the attacker might be able to manipulate the ciphertext to learn some of the plaintext or extract the keying material used for authentication and integrity.

Since AES-GCM uses AES-CTR for encryption, an attacker can switch the algorithm identifier from AES-GCM to AES-CTR, and then strip the authentication tag to bypass the authentication and integrity, allowing the attacker to manipulate the ciphertext.

An attacker can switch the algorithm identifier from AES-GCM to AES-CBC, guess of 16 bytes of plaintext at a time, and checking each guess with padding oracle as discussed above.

9. Acknowledgements

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