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Encrypted Content-Encoding for HTTP
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Abstract

This memo introduces a content coding for HTTP that allows message payloads to be encrypted.

Note to Readers

Discussion of this draft takes place on the HTTP working group mailing list (ietf-http-wg@w3.org), which is archived at https://lists.w3.org/Archives/Public/ietf-http-wg/ .

Working Group information can be found at http://httpwg.github.io/ ; source code and issues list for this draft can be found at https://github.com/httpwg/http-extensions/labels/encryption .

Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

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1. Introduction

It is sometimes desirable to encrypt the contents of a HTTP message (request or response) so that when the payload is stored (e.g., with a HTTP PUT), only someone with the appropriate key can read it.

For example, it might be necessary to store a file on a server without exposing its contents to that server. Furthermore, that same

file could be replicated to other servers (to make it more resistant to server or network failure), downloaded by clients (to make it available offline), etc. without exposing its contents.

These uses are not met by the use of TLS [RFC5246], since it only encrypts the channel between the client and server.

This document specifies a content coding (Section 3.1.2 of [RFC7231]) for HTTP to serve these and other use cases.

This content coding is not a direct adaptation of message-based encryption formats - such as those that are described by [RFC4880], [RFC5652], [RFC7516], and [XMLENC] - which are not suited to stream processing, which is necessary for HTTP. The format described here cleaves more closely to the lower level constructs described in [RFC5116].

To the extent that message-based encryption formats use the same primitives, the format can be considered as sequence of encrypted messages with a particular profile. For instance, Appendix A explains how the format is congruent with a sequence of JSON Web Encryption [RFC7516] values with a fixed header.

This mechanism is likely only a small part of a larger design that uses content encryption. How clients and servers acquire and identify keys will depend on the use case. In particular, a key management system is not described.

1.1. Notational Conventions

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 [RFC2119].

Base64url encoding is defined in Section 2 of [RFC7515].

2. The "aes128gcm" HTTP Content Coding

The "aes128gcm" HTTP content coding indicates that a payload has been encrypted using Advanced Encryption Standard (AES) in Galois/Counter

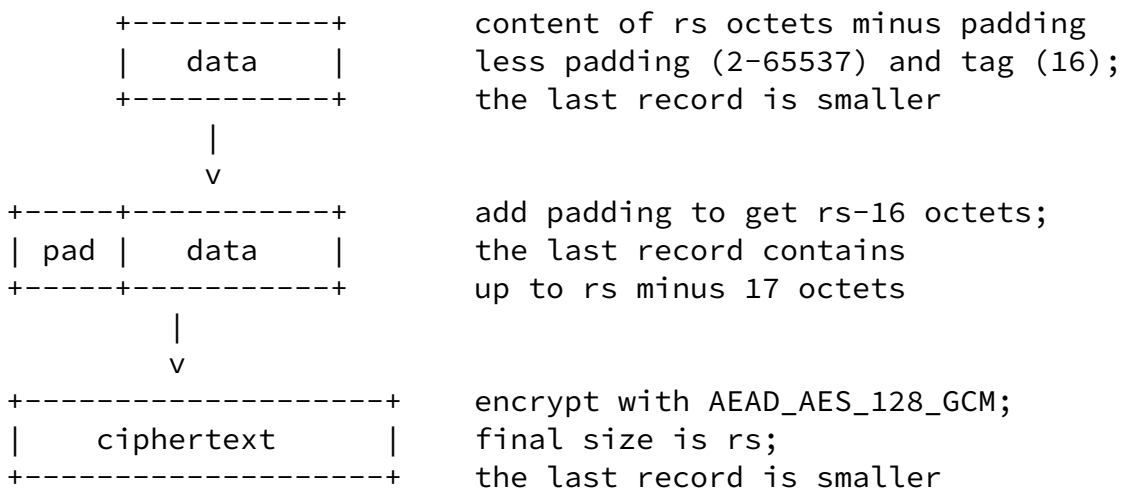
Mode (GCM) as identified as AEAD_AES_128_GCM in [RFC5116], Section 5.1. The AEAD_AES_128_GCM algorithm uses a 128 bit content encryption key.

Using this content coding requires knowledge of a key. How this key is acquired is not defined in this document.

The "aes128gcm" content coding uses a single fixed set of encryption primitives. Cipher suite agility is achieved by defining a new content coding scheme. This ensures that only the HTTP Accept-Encoding header field is necessary to negotiate the use of encryption.

The "aes128gcm" content coding uses a fixed record size. The final encoding consists of a header (see Section 2.1), zero or more fixed size encrypted records, and a partial record. The partial record MUST be shorter than the fixed record size.

The record size determines the length of each portion of plaintext that is enciphered, with the exception of the final record, which is necessarily smaller. The record size ("rs") is included in the content coding header (see Section 2.1).



AEAD_AES_128_GCM produces ciphertext 16 octets longer than its input plaintext. Therefore, the unencrypted content of each record is shorter than the record size by 16 octets. If the final record ends on a record boundary, the encoder MUST append a record that contains

contains only padding and is smaller than the full record size. A receiver MUST fail to decrypt if the final record ciphertext is less than 18 octets in size or equal to the record size. Valid records always contain at least a padding length of 2 octets and a 16 octet authentication tag.

Each record contains a 2 octet padding length and between 0 and 65535 octets of padding, inserted into a record before the content. The padding length is a two octet unsigned integer in network byte order; padding is that number of zero-valued octets. A receiver MUST fail to decrypt if any padding octet is non-zero, or a record has more padding than the record size can accommodate.

The nonce for each record is a 96-bit value constructed from the record sequence number and the input keying material. Nonce derivation is covered in Section 2.3.

The additional data passed to each invocation of AEAD_AES_128_GCM is a zero-length octet sequence.

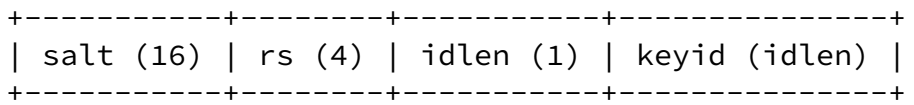
A consequence of this record structure is that range requests [RFC7233] and random access to encrypted payload bodies are possible at the granularity of the record size. Partial records at the ends of a range cannot be decrypted. Thus, it is best if range requests start and end on record boundaries. Note however that random access to specific parts of encrypted data could be confounded by the presence of padding.

Selecting the record size most appropriate for a given situation requires a trade-off. A smaller record size allows decrypted octets to be released more rapidly, which can be appropriate for applications that depend on responsiveness. Smaller records also reduce the additional data required if random access into the ciphertext is needed. Applications that depend on being able to pad by arbitrary amounts cannot increase the record size beyond 65537 octets.

Applications that don't depending on streaming, random access, or arbitrary padding can use larger records, or even a single record. A larger record size reduces the processing and data overheads.

2.1. Encryption Content Coding Header

The content coding uses a header block that includes all parameters needed to decrypt the content (other than the key). The header block is placed in the body of a message ahead of the sequence of records.



salt: The "salt" parameter comprises the first 16 octets of the "aes128gcm" content coding header. The same "salt" parameter value MUST NOT be reused for two different payload bodies that have the same input keying material; generating a random salt for every application of the content coding ensures that content encryption key reuse is highly unlikely.

rs: The "rs" or record size parameter contains an unsigned 32-bit integer in network byte order that describes the record size in octets. Note that it is therefore impossible to exceed the 2^36-31 limit on plaintext input to AEAD_AES_128_GCM. Values smaller than 19 are invalid.

keyid: The "keyid" parameter can be used to identify the keying material that is used. Recipients that receive a message are expected to know how to retrieve keys; the "keyid" parameter might

be input to that process. A "keyid" parameter SHOULD be a UTF-8 [RFC3629] encoded string, particularly where the identifier might need to appear in a textual form.

2.2. Content Encryption Key Derivation

In order to allow the reuse of keying material for multiple different HTTP messages, a content encryption key is derived for each message. The content encryption key is derived from the "salt" parameter using the HMAC-based key derivation function (HKDF) described in [RFC5869] using the SHA-256 hash algorithm [FIPS180-4].

The value of the "salt" parameter is the salt input to HKDF function. The keying material identified by the "keyid" parameter is the input keying material (IKM) to HKDF. Input keying material is expected to

be provided to recipients separately. The extract phase of HKDF therefore produces a pseudorandom key (PRK) as follows:

```
PRK = HMAC-SHA-256(salt, IKM)
```

The info parameter to HKDF is set to the ASCII-encoded string "Content-Encoding: aes128gcm" and a single zero octet:

```
cek_info = "Content-Encoding: aes128gcm" || 0x00
```

Note: Concatenation of octet sequences is represented by the "||" operator.

AEAD_AES_128_GCM requires a 16 octet (128 bit) content encryption key (CEK), so the length (L) parameter to HKDF is 16. The second step of HKDF can therefore be simplified to the first 16 octets of a single HMAC:

```
CEK = HMAC-SHA-256(PRK, cek_info || 0x01)
```

2.3. Nonce Derivation

The nonce input to AEAD_AES_128_GCM is constructed for each record. The nonce for each record is a 12 octet (96 bit) value that is produced from the record sequence number and a value derived from the input keying material.

The input keying material and salt values are input to HKDF with different info and length parameters.

The length (L) parameter is 12 octets. The info parameter for the nonce is the ASCII-encoded string "Content-Encoding: nonce", terminated by a a single zero octet:

```
nonce_info = "Content-Encoding: nonce" || 0x00
```

The result is combined with the record sequence number - using

exclusive or - to produce the nonce. The record sequence number (SEQ) is a 96-bit unsigned integer in network byte order that starts at zero.

Thus, the final nonce for each record is a 12 octet value:

```
NONCE = HMAC-SHA-256(PRK, nonce_info || 0x01) XOR SEQ
```

This nonce construction prevents removal or reordering of records. However, it permits truncation of the tail of the sequence (see Section 2 for how this is avoided).

3. Examples

This section shows a few examples of the encrypted content coding.

Note: All binary values in the examples in this section use base64url encoding [RFC7515]. This includes the bodies of requests. Whitespace and line wrapping is added to fit formatting constraints.

3.1. Encryption of a Response

Here, a successful HTTP GET response has been encrypted. This uses a record size of 4096 and no padding (just the 2 octet padding length), so only a partial record is present. The input keying material is identified by an empty string (that is, the "keyid" field in the header is zero octets in length).

The encrypted data in this example is the UTF-8 encoded string "I am the walrus". The input keying material is the value "B33e_VeFrOyIHwFTIfmesA" (in base64url). The content body contains a single record and is shown here using base64url encoding for presentation reasons.


```
HTTP/1.1 200 OK
```

```
Content-Type: application/octet-stream
Content-Length: 54
Content-Encoding: aes128gcm

sJvlboCWzB5jr8hI_q9cOQAAEAAANSmxkSVa0-MiNNuF77YHSs-iwaNe_OK0qfmO
c7NT5WSW
```

Note that the media type has been changed to "application/octet-stream" to avoid exposing information about the content. Alternatively (and equivalently), the Content-Type header field can be omitted.

Intermediate values for this example (all shown in base64):

```
salt (from header) = sJvlboCWzB5jr8hI_q9cOQ
PRK = MLAQxt_DHjM15cdlyU1oUnjq7TFlzToGTkdRmvvxVBw
CEK = v31u7VGV3soO3wNaMaIdhg
NONCE = XOaygzko98zjUFTJ
plaintext = AABJIGFtIHRoZSB3YWxydXM
```

3.2. Encryption with Multiple Records

This example shows the same message with input keying material of "BO3ZVPxUlnLORbVGMpbT1Q". In this example, the plaintext is split into records of 26 octets each (that is, the "rs" field in the header is 26). The first record includes a single octet of padding. This means that there are 7 octets of message in the first record, and 8 in the second. This causes the end of the content to align with a record boundary, forcing the creation of a third record that contains only two octets of the padding length.

```
HTTP/1.1 200 OK
Content-Length: 93
Content-Encoding: aes128gcm

uNCkWiNYzKTnBN9ji3-qWAAAABoCYTGHOqYFz-0in3dpb-VE2GfBngkaPy6bZus_
qLF79s6zQyTSsA0iLOKyd3JqVIwprNzVatRCWZGUx_qsFbJBCQu62RqQuR2d
```

4. Security Considerations

This mechanism assumes the presence of a key management framework that is used to manage the distribution of keys between valid senders and receivers. Defining key management is part of composing this mechanism into a larger application, protocol, or framework.

Implementation of cryptography - and key management in particular - can be difficult. For instance, implementations need to account for the potential for exposing keying material on side channels, such as might be exposed by the time it takes to perform a given operation. The requirements for a good implementation of cryptographic algorithms can change over time.

4.1. Key and Nonce Reuse

Encrypting different plaintext with the same content encryption key and nonce in AES-GCM is not safe [RFC5116]. The scheme defined here uses a fixed progression of nonce values. Thus, a new content encryption key is needed for every application of the content coding. Since input keying material can be reused, a unique "salt" parameter is needed to ensure a content encryption key is not reused.

If a content encryption key is reused - that is, if input keying material and salt are reused - this could expose the plaintext and the authentication key, nullifying the protection offered by encryption. Thus, if the same input keying material is reused, then the salt parameter MUST be unique each time. This ensures that the content encryption key is not reused. An implementation SHOULD generate a random salt parameter for every message; a counter could achieve the same result.

4.2. Data Encryption Limits

There are limits to the data that AEAD_AES_128_GCM can encipher. The maximum value for the record size is limited by the size of the "rs" field in the header (see Section 2.1), which ensures that the 2^36-31 limit for a single application of AEAD_AES_128_GCM is not reached [RFC5116]. In order to preserve a 2^-40 probability of indistinguishability under chosen plaintext attack (IND-CPA), the total amount of plaintext that can be enciphered MUST be less than 2^44.5 blocks of 16 octets [AEBounds].

If the record size is a multiple of 16 octets, this means 398 terabytes can be encrypted safely, including padding and overhead. However, if the record size is not a multiple of 16 octets, the total amount of data that can be safely encrypted is reduced because partial AES blocks are encrypted. The worst case is a record size of 19 octets, for which at most 74 terabytes of plaintext can be encrypted, of which at least two-thirds is padding.

4.3. Content Integrity

This mechanism only provides content origin authentication. The authentication tag only ensures that an entity with access to the content encryption key produced the encrypted data.

Any entity with the content encryption key can therefore produce content that will be accepted as valid. This includes all recipients of the same HTTP message.

Furthermore, any entity that is able to modify both the Encryption header field and the HTTP message body can replace the contents. Without the content encryption key or the input keying material, modifications to or replacement of parts of a payload body are not possible.

4.4. Leaking Information in Headers

Because only the payload body is encrypted, information exposed in header fields is visible to anyone who can read the HTTP message. This could expose side-channel information.

For example, the Content-Type header field can leak information about the payload body.

There are a number of strategies available to mitigate this threat, depending upon the application's threat model and the users' tolerance for leaked information:

1. Determine that it is not an issue. For example, if it is expected that all content stored will be "application/json", or another very common media type, exposing the Content-Type header field could be an acceptable risk.

2. If it is considered sensitive information and it is possible to determine it through other means (e.g., out of band, using hints in other representations, etc.), omit the relevant headers, and/or normalize them. In the case of Content-Type, this could be accomplished by always sending Content-Type: application/octet-

stream (the most generic media type), or no Content-Type at all.

3. If it is considered sensitive information and it is not possible to convey it elsewhere, encapsulate the HTTP message using the application/http media type (Section 8.3.2 of [RFC7230]), encrypting that as the payload of the "outer" message.

4.5. Poisoning Storage

This mechanism only offers encryption of content; it does not perform authentication or authorization, which still needs to be performed (e.g., by HTTP authentication [RFC7235]).

This is especially relevant when a HTTP PUT request is accepted by a server; if the request is unauthenticated, it becomes possible for a third party to deny service and/or poison the store.

4.6. Sizing and Timing Attacks

Applications using this mechanism need to be aware that the size of encrypted messages, as well as their timing, HTTP methods, URIs and so on, may leak sensitive information.

This risk can be mitigated through the use of the padding that this mechanism provides. Alternatively, splitting up content into segments and storing the separately might reduce exposure. HTTP/2 [RFC7540] combined with TLS [RFC5246] might be used to hide the size of individual messages.

Developing a padding strategy is difficult. A good padding strategy can depend on context. Common strategies include padding to a small set of fixed lengths, padding to multiples of a values, or padding to powers of 2. Even a good strategy can still cause size information to leak if processing activity of a recipient can be observed. This is especially true if the trailing records of a message contain only padding. Distributing non-padding data is recommended to avoid leaking size information.

5. IANA Considerations

5.1. The "aes128gcm" HTTP Content Coding

This memo registers the "aes128gcm" HTTP content coding in the HTTP Content Codings Registry, as detailed in Section 2.

- Name: aes128gcm
- Description: AES-GCM encryption with a 128-bit content encryption key
- Reference: this specification

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6.1. Normative References

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Appendix A. JWE Mapping

The "aes128gcm" content coding can be considered as a sequence of JSON Web Encryption (JWE) objects [RFC7516], each corresponding to a single fixed size record that includes leading padding. The following transformations are applied to a JWE object that might be expressed using the JWE Compact Serialization:

- The JWE Protected Header is fixed to the value { "alg": "dir", "enc": "A128GCM" }, describing direct encryption using AES-GCM with a 128-bit content encryption key. This header is not transmitted, it is instead implied by the value of the Content-Encoding header field.

- The JWE Encrypted Key is empty, as stipulated by the direct encryption algorithm.

- The JWE Initialization Vector ("iv") for each record is set to the exclusive or of the 96-bit record sequence number, starting at

zero, and a value derived from the input keying material (see Section 2.3). This value is also not transmitted.

- The final value is the concatenated header, JWE Ciphertext, and JWE Authentication Tag, all expressed without base64url encoding. The "." separator is omitted, since the length of these fields is known.

Thus, the example in Section 3.1 can be rendered using the JWE Compact Serialization as:

```
eyAiYWxnIjogImRpciIsICJlbmMiOiAiQTEyOEdDTSIgfQ..31iQYc1v4a36EgyJ.
NSmxkSVa0-MiNNuF77YHSs8.osGjXvzitKn5jnOzU-Vklg
```

Where the first line represents the fixed JWE Protected Header, an empty JWE Encrypted Key, and the algorithmically-determined JWE Initialization Vector. The second line contains the encoded body, split into JWE Ciphertext and JWE Authentication Tag.

Appendix B. Acknowledgements

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