Message Encryption for Web Push
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Abstract

A message encryption scheme is described for the Web Push protocol. This scheme provides confidentiality and integrity for messages sent from an application server to a user agent.

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1. Introduction

The Web Push protocol [RFC8030] is an intermediated protocol by necessity. Messages from an application server are delivered to a user agent (UA) via a push service.

```
+-------+           +--------------+       +-------------+
|  UA   |           | Push Service |       | Application |
+-------+           +--------------+       +-------------+
        |                      |                      |
Setup   |                      |                      |<====================>
        |                      |                      |
Provide Subscription                          |
        |                      |     Push Message     |
        |<---------------------|                      |
PUSH MESSAGE                                       |
```

This document describes how messages sent using this protocol can be secured against inspection, modification and forgery by a push service.

Web Push messages are the payload of an HTTP message [RFC7230]. These messages are encrypted using an encrypted content encoding
This document describes how this content encoding is applied and describes a recommended key management scheme.

Multiple users of Web Push at the same user agent often share a central agent that aggregates push functionality. This agent can enforce the use of this encryption scheme by applications that use push messaging. An agent that only delivers messages that are properly encrypted strongly encourages the end-to-end protection of messages.

A web browser that implements the Web Push API [API] can enforce the use of encryption by forwarding only those messages that were properly encrypted.

1.1. Notational Conventions

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.

This document uses the terminology from [RFC8030], primarily user agent, push service, and application server.

2. Push Message Encryption Overview

Encrypting a push message uses elliptic-curve Diffie-Hellman (ECDH) [ECDH] on the P-256 curve [FIPS186] to establish a shared secret (see Section 3.1) and a symmetric secret for authentication (see Section 3.2).

A user agent generates an ECDH key pair and authentication secret that it associates with each subscription it creates. The ECDH public key and the authentication secret are sent to the application server with other details of the push subscription.

When sending a message, an application server generates an ECDH key pair and a random salt. The ECDH public key is encoded into the "keyid" parameter of the encrypted content coding header, the salt in the "salt" parameter of that same header (see Section 2.1 of [RFC8188]). The ECDH key pair can be discarded after encrypting the message.

The content of the push message is encrypted or decrypted using a content encryption key and nonce that is derived using all of these inputs and the process described in Section 3.
2.1. Key and Secret Distribution

The application using the subscription distributes the subscription public key and authentication secret to an authorized application server. This could be sent along with other subscription information that is provided by the user agent, such as the push subscription URI.

An application MUST use an authenticated, confidentiality protected communications medium for this purpose. In addition to the reasons described in [RFC8030], this ensures that the authentication secret is not revealed to unauthorized entities, which would allow those entities to generate push messages that will be accepted by the user agent.

Most applications that use push messaging have a pre-existing relationship with an application server that can be used for distribution of subscription data. An authenticated communication mechanism that provides adequate confidentiality and integrity protection, such as HTTPS [RFC2818], is sufficient.

3. Push Message Encryption

Push message encryption happens in four phases:

- A shared secret is derived using elliptic-curve Diffie-Hellman [ECDH] (Section 3.1).

- The shared secret is then combined with the authentication secret to produce the input keying material used in [RFC8188] (Section 3.3).

- A content encryption key and nonce are derived using the process in [RFC8188].

- Encryption or decryption follows according to [RFC8188].

The key derivation process is summarized in Section 3.4. Restrictions on the use of the encrypted content coding are described in Section 4.

3.1. Diffie-Hellman Key Agreement

For each new subscription that the user agent generates for an application, it also generates a P-256 [FIPS186] key pair for use in elliptic-curve Diffie-Hellman (ECDH) [ECDH].
When sending a push message, the application server also generates a new ECDH key pair on the same P-256 curve.

The ECDH public key for the application server is included as the "keyid" parameter in the encrypted content coding header (see Section 2.1 of [RFC8188]).

An application server combines its ECDH private key with the public key provided by the user agent using the process described in [ECDH]; on receipt of the push message, a user agent combines its private key with the public key provided by the application server in the "keyid" parameter in the same way. These operations produce the same value for the ECDH shared secret.

### 3.2. Push Message Authentication

To ensure that push messages are correctly authenticated, a symmetric authentication secret is added to the information generated by a user agent. The authentication secret is mixed into the key derivation process shown in Section 3.3.

A user agent MUST generate and provide a hard to guess sequence of 16 octets that is used for authentication of push messages. This SHOULD be generated by a cryptographically strong random number generator [RFC4086].

### 3.3. Combining Shared and Authentication Secrets

The shared secret produced by ECDH is combined with the authentication secret using the Hashed Message Authentication Code (HMAC)-based key derivation function (HKDF) [RFC5869]. This produces the input keying material used by [RFC8188].

The HKDF function uses SHA-256 hash algorithm [FIPS180-4] with the following inputs:

- **salt**: the authentication secret
- **IKM**: the shared secret derived using ECDH
- **info**: the concatenation of the ASCII-encoded string "WebPush: info" (this string is not NUL-terminated), a zero octet, and the user agent ECDH public key and the application server ECDH public key, both in the uncompressed point form defined in [X9.62]; that is:

\[
\text{key_info} = \text{"WebPush: info"} \ || \ 0x00 \ || \ ua_{public} \ || \ as_{public}
\]
L: 32 octets (i.e., the output is the length of the underlying SHA-256 HMAC function output)

3.4. Encryption Summary

This results in the final content encryption key and nonce generation using the following sequence, which is shown here in pseudocode with HKDF expanded into separate discrete steps using HMAC with SHA-256:

-- For a user agent:
  ecdh_secret = ECDH(ua_private, as_public)
  auth_secret = random(16)
  salt = <from content coding header>

-- For an application server:
  ecdh_secret = ECDH(as_private, ua_public)
  auth_secret = <from user agent>
  salt = random(16)

-- For both:

## Use HKDF to combine the ECDH and authentication secrets
# HKDF-Extract(salt=auth_secret, IKM=ecdh_secret)
PRK_key = HMAC-SHA-256(auth_secret, ecdh_secret)
# HKDF-Expand(PRK_key, key_info, L_key=32)
key_info = "WebPush: info" || 0x00 || ua_public || as_public
IKM = HMAC-SHA-256(PRK_key, key_info || 0x01)

## HKDF calculations from RFC 8188
# HKDF-Extract(salt, IKM)
PRK = HMAC-SHA-256(salt, IKM)
# HKDF-Expand(PRK, cek_info, L_cek=16)
cek_info = "Content-Encoding: aes128gcm" || 0x00
CEK = HMAC-SHA-256(PRK, cek_info || 0x01)[0..15]
# HKDF-Expand(PRK, nonce_info, L_nonce=12)
nonce_info = "Content-Encoding: nonce" || 0x00
NONCE = HMAC-SHA-256(PRK, nonce_info || 0x01)[0..11]

Note that this omits the exclusive OR of the final nonce with the record sequence number, since push messages contain only a single record (see Section 4) and the sequence number of the first record is zero.
4. Restrictions on Use of "aes128gcm" Content Coding

An application server MUST encrypt a push message with a single record. This allows for a minimal receiver implementation that handles a single record. An application server MUST set the "rs" parameter in the "aes128gcm" content coding header to a size that is greater than the sum of the lengths of the plaintext, the padding delimiter (1 octet), any padding, and the authentication tag (16 octets).

A push message MUST include the application server ECDH public key in the "keyid" parameter of the encrypted content coding header. The uncompressed point form defined in [X9.62] (that is, a 65 octet sequence that starts with a 0x04 octet) forms the entirety of the "keyid". Note that this means that the "keyid" parameter will not be valid UTF-8 as recommended in [RFC8188].

A push service is not required to support more than 4096 octets of payload body (see Section 7.2 of [RFC8030]). Absent header (86 octets), padding (minimum 1 octet), and expansion for AEAD_AES_128_GCM (16 octets), this equates to at most 3993 octets of plaintext.

An application server MUST NOT use other content encodings for push messages. In particular, content encodings that compress could result in leaking of push message contents. The Content-Encoding header field therefore has exactly one value, which is "aes128gcm". Multiple "aes128gcm" values are not permitted.

A user agent is not required to support multiple records. A user agent MAY ignore the "rs" field. If a record size is unchecked, decryption will fail with high probability for all valid cases. The padding delimiter octet MUST be checked, values other than 0x02 MUST cause the message to be discarded.

5. Push Message Encryption Example

The following example shows a push message being sent to a push service.
This example shows the ASCII encoded string, "When I grow up, I want to be a watermelon". The content body is shown here with line wrapping and URL-safe base64url [RFC4648] encoding to meet presentation constraints.

The keys used are shown below using the uncompressed form [X9.62] encoded using base64url.

Authentication Secret: BTBZMqHH6r4Tts7J_aSIgg
Receiver:
  private key: qIdXpw3UpT5VOmu_cF_v6ih07Aems3njxI-JWgLcM94
  public key: BCVxsr7N_eNgVRqvHtD0zTZsEc6-VV-JvLexhgUzORcx
  aZi6-AYWxvTBHm4bgyPjs7Vd8pZGH6SRpkNtoIAiw4
Sender:
  private key: yfWPiYE-n46HLnH0KqZOF1fJJU3MYrct3AEltAQ-oRw
  public key: BP4z9Ks6nGRTbVYI_c7VJSQ7Tbkgy27mlm1MoZIIgE163vCYLocImmWAm56TlzAC8wEqK6PBrU3j17A_yi195bQpu6cVPT
  pK4Mgk HF1CXztLVBST2Ks3oZbwuXpXLWyouBWLWGWQexSgSxsj_Qulcy4a-fN

Intermediate values for this example are included in Appendix A.

6. IANA Considerations

[[RFC EDITOR: please remove this section before publication.]] This document makes no request of IANA.

7. Security Considerations

The privacy and security considerations of [RFC8030] all apply to the use of this mechanism.

The security considerations of [RFC8188] describe the limitations of the content encoding. In particular, no HTTP header fields are protected by the content encoding scheme. A user agent MUST consider HTTP header fields to have come from the push service. Though header fields might be necessary for processing an HTTP response correctly, they are not needed for correct operation of the protocol. An application on the user agent that uses information from header...
fields to alter their processing of a push message is exposed to a
risk of attack by the push service.

The timing and length of communication cannot be hidden from the push
service. While an outside observer might see individual messages
intermixed with each other, the push service will see which
application server is talking to which user agent, and the
subscription that is used. Additionally, the length of messages
could be revealed unless the padding provided by the content encoding
scheme is used to obscure length.

The user agent and application MUST verify that the public key they
receive is on the P-256 curve. Failure to validate a public key can
allow an attacker to extract a private key. The appropriate
validation procedures are defined in Section 4.3.7 of [X9.62] and
alternatively in Section 5.6.2.6 of [KEYAGREEMENT]. This process
consists of three steps:

1. Verify that $Y$ is not the point at infinity (O),
2. Verify that for $Y = (x, y)$ both integers are in the correct
   interval,
3. Ensure that $(x, y)$ is a correct solution to the elliptic curve
   equation.

For these curves, implementers do not need to verify membership in
the correct subgroup.

In the event that this encryption scheme would need to be replaced, a
new content coding scheme could be defined. In order to manage
progressive deployment of the new scheme, the user agent can expose
information on the content coding schemes that it supports. The
supportedContentEncodings parameter of the Push API [API] is an
example of how this might be done.

8. References

8.1. Normative References

[ECDH] SECG, "Elliptic Curve Cryptography", SEC 1, 2000,
<http://www.secg.org/>.

[FIPS180-4] Department of Commerce, National, "NIST FIPS 180-4,
Secure Hash Standard", March 2012,
8.2. Informative References


Appendix A. Intermediate Values for Encryption

The intermediate values calculated for the example in Section 5 are shown here. The base64url values in these examples include whitespace that can be removed.

The following are inputs to the calculation:

Plaintext:  V2hlbiBJIGdyb3cgdXAsIEkgd2FudCB0byBiZSBhIHdhdGVybWVsb24

Application server public key (as_public):
BP4z9Ka6n6GTbVYL_c7VJSPQTBtkgcY27m1mMoZIIg
Dl16e3rVLoc1mnmYWAms67lzAC8wEqKK6PBru3jl7A8

Application server private key (as_private):  yfWPiYE-n46HLh0KqZOFlfJU3MYrct3AEltAQ-oRw

User agent public key (ua_public):  BCvxsr7N_eNgVRqvHtD0zTzsEc6-VV-JvLexhqUzORcx aOzi6-AYWxvTHhm4bjyPjs7Vd8p2GH6SRpkNtoIAiw4

User agent private key (ua_private):  qldXpw3UpT5VOmu_cf_v6ih07Aems3njjxI-JWgLcM94

Salt:  DGv6ra1nLgDCs1FRnbb1w

Authentication secret (auth_secret):  BTB2MqHH6r4Tts7J_aSIgg

Note that knowledge of just one of the private keys is necessary. The application server randomly generates the salt value, whereas salt is input to the receiver.

This produces the following intermediate values:

Shared ECDH secret (ecdh_secret):  kyrL1jII0HEZg3sM2ZWRHDB62YACZhhSlknJ672kSs
Pseudorandom key (PRK) for key combining (PRK_key):
Snr3JMxaHVDXHWJn5wdC52WjpCtd2EIEGBykDczW32k

Info for key combining (key_info): V2ViUHVzaDogaw5mbwAEJXGyvs3942BVG
q8e0PTNNmwr zr5VX4m8t7GgpTM5Fzfo7OLr4BhZe9MEebhuPI-OztV3
y1kYfJGMqQZ2ggCLDqT-M_SrDepxkU21WCP30lSUj0Ew
bZIHMtu5p2pTKGSCIA5Zent7wmC6HCJSfogJkuk5cwAv MBKliujwa7t45ewP

Input keying material for content encryption key derivation (IKM):
S41YMB_L0FuCe0q0WhDx813KgSyqU26kOyzWUsXYyr

PRK for content encryption (PRK): 09_eUZGrsvxChDCGRCdLiDXrReGOEVeSC
dCpBSJSc

Info for content encryption key derivation (cek_info):
Q29udGVudC1FbmNvZGluzzogYWVzMTI4Z2NtAA

Content encryption key (CEK): oIhVW04MRdy2XN9CiKLxTg

Info for content encryption nonce derivation (nonce_info):
Q29udGVudC1FbmNvZGluzzogbm9uY2UA

Nonce (NONCE): 4h_95k1XJ5E_qnoN

The salt, record size of 4096, and application server public key produce an 86 octet header of
DGv6rainl1YgDCS1FRnbzlwAAEABB8P4z
9KsN6nGRTbYV1_c7VJSPQ7Tkgycy27ml mlMo2IIgDl16e3vCYLocInmYWAmS6Tlz
AC8weEqKK6PBrj17A8.

The push message plaintext has the padding delimiter octet (0x02) appended to produce V2hlbiBJIGdyb3cgdXAsIEkgd2FudCB0
byBiZSBhIHdhgVybWVsb24C. The plaintext is then encrypted with AES-GCM, which emits ciphertext of
8pfeW0KbunFT06SuDRoJH9Q187S1Qurd
irN6Gcc7sfzIy1sqLgVi1VhjVkhuEos bI_0LpXMuGvnzQ.

The header and cipher text are concatenated and produce the result shown in Section 5.

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