JOSE Working Group
Internet-Draft
Intended status: Standards Track
Expires: October 27, 2013

M. Jones
Microsoft
J. Bradley
Ping Identity
N. Sakimura
NRI

April 25, 2013

JSON Web Signature (JWS)
draft-ietf-jose-json-web-signature-10

Abstract

JSON Web Signature (JWS) is a means of representing content secured with digital signatures or Message Authentication Codes (MACs) using JavaScript Object Notation (JSON) data structures. Cryptographic algorithms and identifiers for use with this specification are described in the separate JSON Web Algorithms (JWA) specification. Related encryption capabilities are described in the separate JSON Web Encryption (JWE) specification.

Status of this Memo

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

Internet-Drafts are working documents of the Internet Engineering Task Force (IETF). Note that other groups may also distribute working documents as Internet-Drafts. The list of current Internet-Drafts is at http://datatracker.ietf.org/drafts/current/.

Internet-Drafts are draft documents valid for a maximum of six months and may be updated, replaced, or obsoleted by other documents at any time. It is inappropriate to use Internet-Drafts as reference material or to cite them other than as "work in progress."

This Internet-Draft will expire on October 27, 2013.

Copyright Notice

Copyright (c) 2013 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 4
1.1. Notational Conventions 4
2. Terminology 4
3. JSON Web Signature (JWS) Overview 6
3.1. Example JWS 6
4. JWS Header 7
4.1. Reserved Header Parameter Names 8
4.1.1. "alg" (Algorithm) Header Parameter 8
4.1.2. "jku" (JWK Set URL) Header Parameter 8
4.1.3. "jwk" (JSON Web Key) Header Parameter 9
4.1.4. "x5u" (X.509 URL) Header Parameter 9
4.1.5. "x5t" (X.509 Certificate Thumbprint) Header Parameter 9
4.1.6. "x5c" (X.509 Certificate Chain) Header Parameter . . . 9
4.1.7. "kid" (Key ID) Header Parameter 10
4.1.8. "typ" (Type) Header Parameter 10
4.1.9. "cty" (Content Type) Header Parameter 10
4.1.10. "crit" (Critical) Header Parameter 11
4.2. Public Header Parameter Names 11
4.3. Private Header Parameter Names 11
5. Producing and Consuming JWSs 11
5.1. Message Signing or MACing 12
5.2. Message Signature or MAC Validation 13
5.3. String Comparison Rules 14
6. Securing JWSs with Cryptographic Algorithms 14
7. JSON Serialization 15
7.1. Example JWS-JS 15
8. Implementation Considerations 17
9. IANA Considerations 17
9.1. JSON Web Signature and Encryption Header Parameters Registry 17
9.1.1. Registration Template 18
9.1.2. Initial Registry Contents 18
9.2. JSON Web Signature and Encryption Type Values Registry . . 19
9.2.1. Registration Template 19
9.2.2. Initial Registry Contents 20
9.3. Media Type Registration 20
9.3.1. Registry Contents 20
10. Security Considerations 21

10.1. Cryptographic Security Considerations 21
10.2. JSON Security Considerations 23
10.3. Unicode Comparison Security Considerations 23
11. References 23
11.1. Normative References 23
11.2. Informative References 25
Appendix A. JWS Examples 26
A.1. Example JWS using HMAC SHA-256 26
A.1.1. Encoding 26
A.1.2. Decoding 28
A.1.3. Validating 28
A.2. Example JWS using RSA SHA-256 28
A.2.1. Encoding 28
A.2.2. Decoding 32
A.2.3. Validating 32
A.3. Example JWS using ECDSA P-256 SHA-256 33
A.3.1. Encoding 33
A.3.2. Decoding 35
A.3.3. Validating 35
A.4. Example JWS using ECDSA P-521 SHA-512 36
A.4.1. Encoding 36
A.4.2. Decoding 38
A.4.3. Validating 38
A.5. Example Plaintext JWS 39
Appendix B. "x5c" (X.509 Certificate Chain) Example 40
Appendix C. Notes on implementing base64url encoding without padding 41
Appendix D. Possible Compact Serialization for Multiple Signatures 42
Appendix E. Acknowledgements 43
Appendix F. Document History 44
Authors' Addresses 48

1. Introduction

JSON Web Signature (JWS) is a compact format for representing content secured with digital signatures or Message Authentication Codes (MACs) intended for space constrained environments such as HTTP Authorization headers and URI query parameters. It represents this content using JavaScript Object Notation (JSON) [RFC4627] based data structures. The JWS cryptographic mechanisms provide integrity protection for arbitrary sequences of octets.

Cryptographic algorithms and identifiers for use with this specification are described in the separate JSON Web Algorithms (JWA) [JWA] specification. Related encryption capabilities are described in the separate JSON Web Encryption (JWE) [JWE] specification.

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 Key words for use in RFCs to Indicate Requirement Levels [RFC2119].

2. Terminology

JSON Web Signature (JWS) A data structure representing a digitally signed or MACed message. The structure represents three values: the JWS Header, the JWS Payload, and the JWS Signature.

JSON Text Object A UTF-8 [RFC3629] encoded text string representing a JSON object; the syntax of JSON objects is defined in Section 2.2 of [RFC4627].

JWS Header A JSON Text Object that describes the digital signature or MAC operation applied to create the JWS Signature value.

JWS Payload The sequence of octets to be secured -- a.k.a., the message. The payload can contain an arbitrary sequence of octets.

JWS Signature A sequence of octets containing the cryptographic material that ensures the integrity of the JWS Header and the JWS Payload. The JWS Signature value is a digital signature or MAC value calculated over the JWS Signing Input using the parameters specified in the JWS Header.

Base64url Encoding The URL- and filename-safe Base64 encoding described in RFC 4648 [RFC4648], Section 5, with the (non URL-safe) '=' padding characters omitted, as permitted by Section 3.2. (See Appendix C for notes on implementing base64url encoding without padding.)

Encoded JWS Header Base64url encoding of the JWS Header.

Encoded JWS Payload Base64url encoding of the JWS Payload.

Encoded JWS Signature Base64url encoding of the JWS Signature.

JWS Signing Input The concatenation of the Encoded JWS Header, a period ('.') character, and the Encoded JWS Payload.

Header Parameter Name The name of a member of the JWS Header.

Header Parameter Value The value of a member of the JWS Header.

JWS Compact Serialization A representation of the JWS as the concatenation of the Encoded JWS Header, the Encoded JWS Payload, and the Encoded JWS Signature in that order, with the three strings being separated by two period ('.') characters. This results in a compact, URL-safe representation.

JWS JSON Serialization A representation of the JWS as a JSON structure containing Encoded JWS Header, Encoded JWS Payload, and Encoded JWS Signature values. Unlike the JWS Compact Serialization, the JWS JSON Serialization enables multiple digital signatures and/or MACs to be applied to the same content. This representation is neither compact nor URL-safe.

Collision Resistant Namespace A namespace that allows names to be allocated in a manner such that they are highly unlikely to collide with other names. For instance, collision resistance can be achieved through administrative delegation of portions of the namespace or through use of collision-resistant name allocation functions. Examples of Collision Resistant Namespaces include: Domain Names, Object Identifiers (OIDs) as defined in the ITU-T X.660 and X.670 Recommendation series, and Universally Unique IDentifiers (UUIDs) [RFC4122]. When using an administratively delegated namespace, the definer of a name needs to take reasonable precautions to ensure they are in control of the portion of the namespace they use to define the name.

StringOrURI A JSON string value, with the additional requirement that while arbitrary string values MAY be used, any value containing a ":" character MUST be a URI [RFC3986]. StringOrURI values are compared as case-sensitive strings with no transformations or canonicalizations applied.

3. JSON Web Signature (JWS) Overview

JWS represents digitally signed or MACed content using JSON data structures and base64url encoding. Three values are represented in a JWS: the JWS Header, the JWS Payload, and the JWS Signature. In the Compact Serialization, the three values are base64url-encoded for transmission, and represented as the concatenation of the encoded strings in that order, with the three strings being separated by two period ('.') characters. A JSON Serialization for this information is also defined in Section 7.

The JWS Header describes the signature or MAC method and parameters employed. The JWS Payload is the message content to be secured. The JWS Signature ensures the integrity of both the JWS Header and the JWS Payload.

3.1. Example JWS

The following example JWS Header declares that the encoded object is a JSON Web Token (JWT) [JWT] and the JWS Header and the JWS Payload are secured using the HMAC SHA-256 algorithm:

```
{"typ":"JWT",
 "alg":"HS256"}
```

Base64url encoding the octets of the UTF-8 representation of the JWS Header yields this Encoded JWS Header value:

```
eyJ0eXAiOiJKV1QiLA0KICJhbGciOiJIUzI1NiJ9
```

The following is an example of a JSON object that can be used as a JWS Payload. (Note that the payload can be any content, and need not be a representation of a JSON object.)

```
{"iss":"joe",
 "exp":1300819380,
 "http://example.com/is_root":true}
```

Base64url encoding the octets of the UTF-8 representation of the JSON object yields the following Encoded JWS Payload (with line breaks for display purposes only):

```
eyJpc3MiOiJqb2UiLA0KICJleHAiOjEzMDA4MTkzODAsDQogImh0dHA6Ly9leGFt
cGxlLmNvbS9pc19yb290Ijp0cnVlfQ
```

Computing the HMAC of the octets of the ASCII [USASCII] representation of the JWS Signing Input (the concatenation of the Encoded JWS Header, a period ('.') character, and the Encoded JWS Payload) with the HMAC SHA-256 algorithm using the key specified in Appendix A.1 and base64url encoding the result yields this Encoded JWS Signature value:

```
dBjftJeZ4CVP-mB92K27uhbUJU1p1r_wW1gFWFOEjXk
```

Concatenating these values in the order Header.Payload.Signature with period ('.') characters between the parts yields this complete JWS representation using the JWS Compact Serialization (with line breaks for display purposes only):

```
eyJ0eXAiOiJKV1QiLA0KICJhbGciOiJIUzI1NiJ9
.
eyJpc3MiOiJqb2UiLA0KICJleHAiOjEzMDA4MTkzODAsDQogImh0dHA6Ly9leGFt
cGxlLmNvbS9pc19yb290Ijp0cnVlfQ
.
dBjftJeZ4CVP-mB92K27uhbUJU1p1r_wW1gFWFOEjXk
```

This computation is illustrated in more detail in Appendix A.1.

4. JWS Header

The members of the JSON object represented by the JWS Header describe the digital signature or MAC applied to the Encoded JWS Header and the Encoded JWS Payload and optionally additional properties of the JWS. The Header Parameter Names within this object MUST be unique; JWSs with duplicate Header Parameter Names MUST be rejected.

Implementations are required to understand the specific header parameters defined by this specification that are designated as "MUST be understood" and process them in the manner defined in this specification. All other header parameters defined by this specification that are not so designated MUST be ignored when not understood. Unless listed as a critical header parameter, per Section 4.1.10, all other header parameters MUST be ignored when not understood.

There are three classes of Header Parameter Names: Reserved Header Parameter Names, Public Header Parameter Names, and Private Header Parameter Names.

4.1. Reserved Header Parameter Names

The following Header Parameter Names are reserved with meanings as defined below. All the names are short because a core goal of this specification is for the resulting representations using the JWS Compact Serialization to be compact.

Additional reserved Header Parameter Names MAY be defined via the IANA JSON Web Signature and Encryption Header Parameters registry Section 9.1. As indicated by the common registry, JWSs and JWEs share a common header parameter space; when a parameter is used by both specifications, its usage must be compatible between the specifications.

4.1.1. "alg" (Algorithm) Header Parameter

The "alg" (algorithm) header parameter identifies the cryptographic algorithm used to secure the JWS. The algorithm specified by the "alg" value MUST be supported by the implementation and there MUST be a key for use with that algorithm associated with the party that digitally signed or MACed the content or the JWS MUST be rejected. "alg" values SHOULD either be registered in the IANA JSON Web Signature and Encryption Algorithms registry [JWA] or be a value that contains a Collision Resistant Namespace. The "alg" value is a case sensitive string containing a StringOrURI value. Use of this header parameter is REQUIRED. This header parameter MUST be understood by implementations.

A list of defined "alg" values can be found in the IANA JSON Web Signature and Encryption Algorithms registry [JWA]; the initial contents of this registry are the values defined in Section 3.1 of the JSON Web Algorithms (JWA) [JWA] specification.

4.1.2. "jku" (JWK Set URL) Header Parameter

The "jku" (JWK Set URL) header parameter is a URI [RFC3986] that refers to a resource for a set of JSON-encoded public keys, one of which corresponds to the key used to digitally sign the JWS. The keys MUST be encoded as a JSON Web Key Set (JWK Set) [JWK]. The protocol used to acquire the resource MUST provide integrity protection; an HTTP GET request to retrieve the certificate MUST use TLS [RFC2818] [RFC5246]; the identity of the server MUST be validated, as per Section 3.1 of HTTP Over TLS [RFC2818]. Use of this header parameter is OPTIONAL.

4.1.3. "jwk" (JSON Web Key) Header Parameter

The "jwk" (JSON Web Key) header parameter is the public key that corresponds to the key used to digitally sign the JWS. This key is represented as a JSON Web Key [JWK]. Use of this header parameter is OPTIONAL.

4.1.4. "x5u" (X.509 URL) Header Parameter

The "x5u" (X.509 URL) header parameter is a URI [RFC3986] that refers to a resource for the X.509 public key certificate or certificate chain [RFC5280] corresponding to the key used to digitally sign the JWS. The identified resource MUST provide a representation of the certificate or certificate chain that conforms to RFC 5280 [RFC5280] in PEM encoded form [RFC1421]. The certificate containing the public key corresponding to the key used to digitally sign the JWS MUST be the first certificate. This MAY be followed by additional certificates, with each subsequent certificate being the one used to certify the previous one. The protocol used to acquire the resource MUST provide integrity protection; an HTTP GET request to retrieve the certificate MUST use TLS [RFC2818] [RFC5246]; the identity of the server MUST be validated, as per Section 3.1 of HTTP Over TLS [RFC2818]. Use of this header parameter is OPTIONAL.

4.1.5. "x5t" (X.509 Certificate Thumbprint) Header Parameter

The "x5t" (X.509 Certificate Thumbprint) header parameter provides a base64url encoded SHA-1 thumbprint (a.k.a. digest) of the DER encoding of the X.509 certificate [RFC5280] corresponding to the key used to digitally sign the JWS. Use of this header parameter is OPTIONAL.

If, in the future, certificate thumbprints need to be computed using hash functions other than SHA-1, it is suggested that additional related header parameters be defined for that purpose. For example, it is suggested that a new "x5t#S256" (X.509 Certificate Thumbprint using SHA-256) header parameter could be defined by registering it in the IANA JSON Web Signature and Encryption Header Parameters registry Section 9.1.

4.1.6. "x5c" (X.509 Certificate Chain) Header Parameter

The "x5c" (X.509 Certificate Chain) header parameter contains the X.509 public key certificate or certificate chain [RFC5280] corresponding to the key used to digitally sign the JWS. The certificate or certificate chain is represented as an array of certificate value strings. Each string is a base64 encoded ([RFC4648] Section 4 -- not base64url encoded) DER [ITU.X690.1994]

PKIX certificate value. The certificate containing the public key corresponding to the key used to digitally sign the JWS MUST be the first certificate. This MAY be followed by additional certificates, with each subsequent certificate being the one used to certify the previous one. The recipient MUST verify the certificate chain according to [RFC5280] and reject the JWS if any validation failure occurs. Use of this header parameter is OPTIONAL.

See Appendix B for an example "x5c" value.

4.1.7. "kid" (Key ID) Header Parameter

The "kid" (key ID) header parameter is a hint indicating which key was used to secure the JWS. This parameter allows originators to explicitly signal a change of key to recipients. Should the recipient be unable to locate a key corresponding to the "kid" value, they SHOULD treat that condition as an error. The interpretation of the "kid" value is unspecified. Its value MUST be a string. Use of this header parameter is OPTIONAL.

When used with a JWK, the "kid" value can be used to match a JWK "kid" parameter value.

4.1.8. "typ" (Type) Header Parameter

The "typ" (type) header parameter is used to declare the type of this object. The type value "JWS" is used to indicate that this object is a JWS using the JWS Compact Serialization. The type value "JWS-JS" is used to indicate that this object is a JWS using the JWS JSON Serialization. The "typ" value is a case sensitive string. Use of this header parameter is OPTIONAL.

MIME Media Type [RFC2046] values MAY be used as "typ" values.

"typ" values SHOULD either be registered in the IANA JSON Web Signature and Encryption Type Values registry Section 9.2 or be a value that contains a Collision Resistant Namespace.

4.1.9. "cty" (Content Type) Header Parameter

The "cty" (content type) header parameter is used to declare the type of the secured content (the Payload). For example, the JSON Web Token (JWT) [JWT] specification uses the "cty" value "JWT" to indicate that the Payload is a JSON Web Token (JWT). The "cty" value is a case sensitive string. Use of this header parameter is OPTIONAL.

The values used for the "cty" header parameter come from the same

value space as the "typ" header parameter, with the same rules applying.

4.1.10. "crit" (Critical) Header Parameter

The "crit" (critical) header parameter is array listing the names of header parameters that are present in the JWS Header that MUST be understood and processed by the implementation or if not understood, MUST cause the JWS to be rejected. This list MUST NOT include header parameters defined by this specification, duplicate names, or names that do not occur as header parameters within the JWS. Use of this header parameter is OPTIONAL. This header parameter MUST be understood by implementations.

An example use, along with a hypothetical "exp" (expiration-time) field is:

```
{"alg":"ES256",
 "crit":["exp"],
 "exp":1363284000
}
```

4.2. Public Header Parameter Names

Additional Header Parameter Names can be defined by those using JWSs. However, in order to prevent collisions, any new Header Parameter Name SHOULD either be registered in the IANA JSON Web Signature and Encryption Header Parameters registry Section 9.1 or be a Public Name: a value that contains a Collision Resistant Namespace. In each case, the definer of the name or value needs to take reasonable precautions to make sure they are in control of the part of the namespace they use to define the Header Parameter Name.

New header parameters should be introduced sparingly, as they can result in non-interoperable JWSs.

4.3. Private Header Parameter Names

A producer and consumer of a JWS may agree to use Header Parameter Names that are Private Names: names that are not Reserved Names Section 4.1 or Public Names Section 4.2. Unlike Public Names, Private Names are subject to collision and should be used with caution.

5. Producing and Consuming JWSs

5.1. Message Signing or MACing

To create a JWS, one MUST perform these steps. The order of the steps is not significant in cases where there are no dependencies between the inputs and outputs of the steps.

1. Create the content to be used as the JWS Payload.

2. Base64url encode the octets of the JWS Payload. This encoding becomes the Encoded JWS Payload.

3. Create a JWS Header containing the desired set of header parameters. Note that white space is explicitly allowed in the representation and no canonicalization need be performed before encoding.

4. Base64url encode the octets of the UTF-8 representation of the JWS Header to create the Encoded JWS Header.

5. Compute the JWS Signature in the manner defined for the particular algorithm being used over the JWS Signing Input (the concatenation of the Encoded JWS Header, a period ('.') character, and the Encoded JWS Payload). The "alg" (algorithm) header parameter MUST be present in the JWS Header, with the algorithm value accurately representing the algorithm used to construct the JWS Signature.

6. Base64url encode the representation of the JWS Signature to create the Encoded JWS Signature.

7. The three encoded parts are the result values used in both the JWS Compact Serialization and the JWS JSON Serialization representations.

8. If the JWS JSON Serialization is being used, repeat this process for each digital signature or MAC value being applied.

9. Create the desired serialized output. The JWS Compact Serialization of this result is the concatenation of the Encoded JWS Header, the Encoded JWS Payload, and the Encoded JWS Signature in that order, with the three strings being separated by two period ('.') characters. The JWS JSON Serialization is described in Section 7.

5.2. Message Signature or MAC Validation

When validating a JWS, the following steps MUST be taken. The order of the steps is not significant in cases where there are no dependencies between the inputs and outputs of the steps. If any of the listed steps fails, then the JWS MUST be rejected.

1. Parse the serialized input to determine the values of the Encoded JWS Header, the Encoded JWS Payload, and the Encoded JWS Signature. When using the JWS Compact Serialization, these three values are represented as text strings in that order, separated by two period ('.') characters. The JWS JSON Serialization is described in Section 7.

2. The Encoded JWS Header MUST be successfully base64url decoded following the restriction given in this specification that no padding characters have been used.

3. The resulting JWS Header MUST be completely valid JSON syntax conforming to RFC 4627 [RFC4627].

4. The resulting JWS Header MUST be validated to only include parameters and values whose syntax and semantics are both understood and supported or that are specified as being ignored when not understood.

5. The Encoded JWS Payload MUST be successfully base64url decoded following the restriction given in this specification that no padding characters have been used.

6. The Encoded JWS Signature MUST be successfully base64url decoded following the restriction given in this specification that no padding characters have been used.

7. The JWS Signature MUST be successfully validated against the JWS Signing Input (the concatenation of the Encoded JWS Header, a period ('.') character, and the Encoded JWS Payload) in the manner defined for the algorithm being used, which MUST be accurately represented by the value of the "alg" (algorithm) header parameter, which MUST be present.

8. If the JWS JSON Serialization is being used, repeat this process for each digital signature or MAC value contained in the representation.

5.3. String Comparison Rules

Processing a JWS inevitably requires comparing known strings to values in JSON objects. For example, in checking what the algorithm is, the Unicode string encoding "alg" will be checked against the member names in the JWS Header to see if there is a matching Header Parameter Name. A similar process occurs when determining if the value of the "alg" header parameter represents a supported algorithm.

Comparisons between JSON strings and other Unicode strings MUST be performed as specified below:

1. Remove any JSON escaping from the input JSON string and convert the string into a sequence of Unicode code points.

2. Likewise, convert the string to be compared against into a sequence of Unicode code points.

3. Unicode Normalization [USA15] MUST NOT be applied at any point to either the JSON string or to the string it is to be compared against.

4. Comparisons between the two strings MUST be performed as a Unicode code point to code point equality comparison. (Note that values that originally used different Unicode encodings (UTF-8, UTF-16, etc.) may result in the same code point values.)

Also, see the JSON security considerations in Section 10.2 and the Unicode security considerations in Section 10.3.

6. Securing JWSs with Cryptographic Algorithms

JWS uses cryptographic algorithms to digitally sign or MAC the JWS Header and the JWS Payload. The JSON Web Algorithms (JWA) [JWA] specification describes a set of cryptographic algorithms and identifiers to be used with this specification. Specifically, Section 3.1 specifies a set of "alg" (algorithm) header parameter values intended for use this specification. It also describes the semantics and operations that are specific to these algorithms.

Public keys employed for digital signing can be identified using the Header Parameter methods described in Section 4.1 or can be distributed using methods that are outside the scope of this specification.

7. JSON Serialization

The JWS JSON Serialization represents digitally signed or MACed content as a JSON object with a "signatures" member containing an array of per-signature information and a "payload" member containing a shared Encoded JWS Payload value. Each member of the "signatures" array is a JSON object with a "header" member containing an Encoded JWS Header value and a "signature" member containing an Encoded JWS Signature value.

Unlike the JWS Compact Serialization, content using the JWS JSON Serialization MAY be secured with more than one digital signature and/or MAC value. Each is represented as an Encoded JWS Signature value in the "signature" member of an object in the "signatures" array. For each signature, there is an Encoded JWS Encoded Header value in the "header" member of the same object in the "signatures" array. This specifies the digital signature or MAC applied to the Encoded JWS Header value and the shared Encoded JWS Payload value to create the JWS Signature value. Therefore, the syntax is:

```
{"signatures":[
  {"header":"<header 1 contents>",
   "signature":"<signature 1 contents>"},
  ...
  {"header":"<header N contents>",
   "signature":"<signature N contents>"}],
 "payload":"<payload contents>"
}
```

The contents of the Encoded JWS Header, Encoded JWS Payload, and Encoded JWS Signature values are exactly as specified in the rest of this specification. They are interpreted and validated in the same manner, with each corresponding "header" and "signature" value being created and validated together.

Each JWS Signature value is computed on the JWS Signing Input corresponding to the concatenation of the Encoded JWS Header, a period ('.') character, and the Encoded JWS Payload in the same manner as for the JWS Compact Serialization. This has the desirable result that each Encoded JWS Signature value in the "signatures" array is identical to the value that would be used for the same parameter in the JWS Compact Serialization, as is the shared JWS Payload value.

7.1. Example JWS-JS

This section contains an example using the JWS JSON Serialization. This example demonstrates the capability for conveying multiple

digital signatures and/or MACs for the same payload.

The Encoded JWS Payload used in this example is the same as used in the examples in Appendix A (with line breaks for display purposes only):

```
eyJpc3MiOiJqb2UiLA0KICJleHAiOjEzMDA4MTkzODAsDQogImh0dHA6Ly9leGFt
cGxlLmNvbS9pc19yb290Ijp0cnVlfQ
```

Two digital signatures are used in this example: an RSA SHA-256 signature, for which the header and signature values are the same as in Appendix A.2, and an ECDSA P-256 SHA-256 signature, for which the header and signature values are the same as in Appendix A.3. The two Decoded JWS Header Segments used are:

```
{"alg":"RS256"}
```

and:

```
{"alg":"ES256"}
```

Since the computations of the JWS Header and JWS Signature values are the same as in Appendix A.2 and Appendix A.3, they are not repeated here.

The complete JSON Web Signature JSON Serialization (JWS-JS) for these values is as follows (with line breaks for display purposes only):

```
{"signatures":[
  {"header":"eyJhbGciOiJSUzI1NiJ9",
   "signature":
    "cC4hiUPoj9Eetdgtv3hF80EGrhuB__dzERat0XF9g2VtQgr9PJbu3XOiZj5RZ
     mh7AAuHIm4Bh-0Qc_lF5YKt_O8W2Fp5jujGbds9uJdbF9CUAr7t1dnZcAcQjb
     KBYNX4BAynRFdiuB--f_nZLgrnbyTyWzO75vRK5h6xBArLIARNPvkSjtQBMHl
     b1L07Qe7K0GarZRmB_eSN9383LcOLn6_dO--xi12jzDwusC-eOkHWEsqtFZES
     c6BfI7noOPqvhJ1phCnvWh6IeYI2w9QOYEUipUTI8np6LbgGY9Fs98rqVt5AX
     LIhWkWywlVmtVrBp0igcN_IoypGlUPQGe77Rw"},
  {"header":"eyJhbGciOiJFUzI1NiJ9",
   "signature":
    "DtEhU3ljbEg8L38VWAfUAqOyKAM6-Xx-F4GawxaepmXFCgfTjDxw5djxLa8IS
     lSApmWQxfKTUJqPP3-Kg6NU1Q"}],
 "payload":
  "eyJpc3MiOiJqb2UiLA0KICJleHAiOjEzMDA4MTkzODAsDQogImh0dHA6Ly9leGF
   tcGxlLmNvbS9pc19yb290Ijp0cnVlfQ"
}
```

8. Implementation Considerations

The JWS Compact Serialization is mandatory to implement. Implementation of the JWS JSON Serialization is OPTIONAL.

9. IANA Considerations

The following registration procedure is used for all the registries established by this specification.

Values are registered with a Specification Required [RFC5226] after a two-week review period on the [TBD]@ietf.org mailing list, on the advice of one or more Designated Experts. However, to allow for the allocation of values prior to publication, the Designated Expert(s) may approve registration once they are satisfied that such a specification will be published.

Registration requests must be sent to the [TBD]@ietf.org mailing list for review and comment, with an appropriate subject (e.g., "Request for access token type: example"). [[Note to RFC-EDITOR: The name of the mailing list should be determined in consultation with the IESG and IANA. Suggested name: jose-reg-review.]]

Within the review period, the Designated Expert(s) will either approve or deny the registration request, communicating this decision to the review list and IANA. Denials should include an explanation and, if applicable, suggestions as to how to make the request successful.

IANA must only accept registry updates from the Designated Expert(s) and should direct all requests for registration to the review mailing list.

9.1. JSON Web Signature and Encryption Header Parameters Registry

This specification establishes the IANA JSON Web Signature and Encryption Header Parameters registry for reserved JWS and JWE Header Parameter Names. The registry records the reserved Header Parameter Name and a reference to the specification that defines it. The same Header Parameter Name MAY be registered multiple times, provided that the parameter usage is compatible between the specifications. Different registrations of the same Header Parameter Name will typically use different Header Parameter Usage Location(s) values.

9.1.1. Registration Template

Header Parameter Name:
The name requested (e.g., "example"). This name is case sensitive. Names that match other registered names in a case insensitive manner SHOULD NOT be accepted.

Header Parameter Usage Location(s):
The header parameter usage locations, which should be one or more of the values "JWS" or "JWE".

Change Controller:
For Standards Track RFCs, state "IETF". For others, give the name of the responsible party. Other details (e.g., postal address, email address, home page URI) may also be included.

Specification Document(s):
Reference to the document(s) that specify the parameter, preferably including URI(s) that can be used to retrieve copies of the document(s). An indication of the relevant sections may also be included but is not required.

9.1.2. Initial Registry Contents

This specification registers the Header Parameter Names defined in Section 4.1 in this registry.

- Header Parameter Name: "alg"
- Header Parameter Usage Location(s): JWS
- Change Controller: IETF
- Specification Document(s): Section 4.1.1 of [[this document]]

- Header Parameter Name: "jku"
- Header Parameter Usage Location(s): JWS
- Change Controller: IETF
- Specification Document(s): Section 4.1.2 of [[this document]]

- Header Parameter Name: "jwk"
- Header Parameter Usage Location(s): JWS
- Change Controller: IETF
- Specification document(s): Section 4.1.3 of [[this document]]

- Header Parameter Name: "x5u"
- Header Parameter Usage Location(s): JWS
- Change Controller: IETF
- Specification Document(s): Section 4.1.4 of [[this document]]

- Header Parameter Name: "x5t"
- Header Parameter Usage Location(s): JWS
- Change Controller: IETF
- Specification Document(s): Section 4.1.5 of [[this document]]

- Header Parameter Name: "x5c"
- Header Parameter Usage Location(s): JWS
- Change Controller: IETF
- Specification Document(s): Section 4.1.6 of [[this document]]

- Header Parameter Name: "kid"
- Header Parameter Usage Location(s): JWS
- Change Controller: IETF
- Specification Document(s): Section 4.1.7 of [[this document]]

- Header Parameter Name: "typ"
- Header Parameter Usage Location(s): JWS
- Change Controller: IETF
- Specification Document(s): Section 4.1.8 of [[this document]]

- Header Parameter Name: "cty"
- Header Parameter Usage Location(s): JWS
- Change Controller: IETF
- Specification Document(s): Section 4.1.9 of [[this document]]

- Header Parameter Name: "crit"
- Header Parameter Usage Location(s): JWS
- Change Controller: IETF
- Specification Document(s): Section 4.1.10 of [[this document]]

9.2. JSON Web Signature and Encryption Type Values Registry

This specification establishes the IANA JSON Web Signature and Encryption Type Values registry for values of the JWS and JWE "typ" (type) header parameter. It is RECOMMENDED that all registered "typ" values also include a MIME Media Type [RFC2046] value that the registered value is a short name for. The registry records the "typ" value, the MIME type value that it is an abbreviation for (if any), and a reference to the specification that defines it.

MIME Media Type [RFC2046] values MUST NOT be directly registered as new "typ" values; rather, new "typ" values MAY be registered as short names for MIME types.

9.2.1. Registration Template

"typ" Header Parameter Value:
The name requested (e.g., "example"). This name is case sensitive. Names that match other registered names in a case insensitive manner SHOULD NOT be accepted.

Abbreviation for MIME Type:
The MIME type that this name is an abbreviation for (e.g., "application/example").

Change Controller:
For Standards Track RFCs, state "IETF". For others, give the name of the responsible party. Other details (e.g., postal address, email address, home page URI) may also be included.

Specification Document(s):
Reference to the document(s) that specify the parameter, preferably including URI(s) that can be used to retrieve copies of the document(s). An indication of the relevant sections may also be included but is not required.

9.2.2. Initial Registry Contents

This specification registers the "JWS" and "JWS-JS" type values in this registry:

- "typ" Header Parameter Value: "JWS"
- Abbreviation for MIME type: application/jws
- Change Controller: IETF
- Specification Document(s): Section 4.1.8 of [[this document]]

- "typ" Header Parameter Value: "JWS-JS"
- Abbreviation for MIME type: application/jws-js
- Change Controller: IETF
- Specification Document(s): Section 4.1.8 of [[this document]]

9.3. Media Type Registration

9.3.1. Registry Contents

This specification registers the "application/jws" and "application/jws-js" Media Types [RFC2046] in the MIME Media Type registry [RFC4288] to indicate, respectively, that the content is a JWS using the JWS Compact Serialization or a JWS using the JWS JSON Serialization.

- Type name: application

- Subtype name: jws
- Required parameters: n/a
- Optional parameters: n/a
- Encoding considerations: JWS values are encoded as a series of base64url encoded values (some of which may be the empty string) separated by period ('.') characters
- Security considerations: See the Security Considerations section of [[this document]]
- Interoperability considerations: n/a
- Published specification: [[this document]]
- Applications that use this media type: OpenID Connect, Mozilla Persona, Salesforce, Google, numerous others that use signed JWTs
- Additional information: Magic number(s): n/a, File extension(s): n/a, Macintosh file type code(s): n/a
- Person & email address to contact for further information: Michael B. Jones, mbj@microsoft.com
- Intended usage: COMMON
- Restrictions on usage: none
- Author: Michael B. Jones, mbj@microsoft.com
- Change Controller: IETF

- Type name: application
- Subtype name: jws-js
- Required parameters: n/a
- Optional parameters: n/a
- Encoding considerations: JWS-JS values are represented as a JSON Object; UTF-8 encoding SHOULD be employed for the JSON object.
- Security considerations: See the Security Considerations section of [[this document]]
- Interoperability considerations: n/a
- Published specification: [[this document]]
- Applications that use this media type: TBD
- Additional information: Magic number(s): n/a, File extension(s): n/a, Macintosh file type code(s): n/a
- Person & email address to contact for further information: Michael B. Jones, mbj@microsoft.com
- Intended usage: COMMON
- Restrictions on usage: none
- Author: Michael B. Jones, mbj@microsoft.com
- Change Controller: IETF

10. Security Considerations

10.1. Cryptographic Security Considerations

All of the security issues faced by any cryptographic application must be faced by a JWS/JWE/JWK agent. Among these issues are

protecting the user's private and symmetric keys, preventing various attacks, and helping the user avoid mistakes such as inadvertently encrypting a message for the wrong recipient. The entire list of security considerations is beyond the scope of this document, but some significant concerns are listed here.

All the security considerations in XML DSIG 2.0 [W3C.CR-xmldsig-core2-20120124], also apply to this specification, other than those that are XML specific. Likewise, many of the best practices documented in XML Signature Best Practices [W3C.WD-xmldsig-bestpractices-20110809] also apply to this specification, other than those that are XML specific.

Keys are only as strong as the amount of entropy used to generate them. A minimum of 128 bits of entropy should be used for all keys, and depending upon the application context, more may be required. In particular, it may be difficult to generate sufficiently random values in some browsers and application environments.

Creators of JWSs should not allow third parties to insert arbitrary content into the message without adding entropy not controlled by the third party.

When utilizing TLS to retrieve information, the authority providing the resource MUST be authenticated and the information retrieved MUST be free from modification.

When cryptographic algorithms are implemented in such a way that successful operations take a different amount of time than unsuccessful operations, attackers may be able to use the time difference to obtain information about the keys employed. Therefore, such timing differences must be avoided.

A SHA-1 hash is used when computing "x5t" (x.509 certificate thumbprint) values, for compatibility reasons. Should an effective means of producing SHA-1 hash collisions be developed, and should an attacker wish to interfere with the use of a known certificate on a given system, this could be accomplished by creating another certificate whose SHA-1 hash value is the same and adding it to the certificate store used by the intended victim. A prerequisite to this attack succeeding is the attacker having write access to the intended victim's certificate store.

If, in the future, certificate thumbprints need to be computed using hash functions other than SHA-1, it is suggested that additional related header parameters be defined for that purpose. For example, it is suggested that a new "x5t#S256" (X.509 Certificate Thumbprint using SHA-256) header parameter could be defined and used.

10.2. JSON Security Considerations

Strict JSON validation is a security requirement. If malformed JSON is received, then the intent of the sender is impossible to reliably discern. Ambiguous and potentially exploitable situations could arise if the JSON parser used does not reject malformed JSON syntax.

Section 2.2 of the JavaScript Object Notation (JSON) specification [RFC4627] states "The names within an object SHOULD be unique", whereas this specification states that "Header Parameter Names within this object MUST be unique; JWSs with duplicate Header Parameter Names MUST be rejected". Thus, this specification requires that the Section 2.2 "SHOULD" be treated as a "MUST". Ambiguous and potentially exploitable situations could arise if the JSON parser used does not enforce the uniqueness of member names.

Some JSON parsers might not reject input that contains extra significant characters after a valid input. For instance, the input "{"tag":"value"}ABCD" contains a valid JSON object followed by the extra characters "ABCD". Such input MUST be rejected in its entirety.

10.3. Unicode Comparison Security Considerations

Header Parameter Names and algorithm names are Unicode strings. For security reasons, the representations of these names must be compared verbatim after performing any escape processing (as per RFC 4627 [RFC4627], Section 2.5). This means, for instance, that these JSON strings must compare as being equal ("sig", "\u0073ig"), whereas these must all compare as being not equal to the first set or to each other ("SIG", "Sig", "si\u0047").

JSON strings can contain characters outside the Unicode Basic Multilingual Plane. For instance, the G clef character (U+1D11E) may be represented in a JSON string as "\uD834\uDD1E". Ideally, JWS implementations SHOULD ensure that characters outside the Basic Multilingual Plane are preserved and compared correctly; alternatively, if this is not possible due to these characters exercising limitations present in the underlying JSON implementation, then input containing them MUST be rejected.

11. References

11.1. Normative References

[ITU.X690.1994]
International Telecommunications Union, "Information

Technology - ASN.1 encoding rules: Specification of Basic Encoding Rules (BER), Canonical Encoding Rules (CER) and Distinguished Encoding Rules (DER)", ITU-T Recommendation X.690, 1994.

[JWA] Jones, M., "JSON Web Algorithms (JWA)", draft-ietf-jose-json-web-algorithms (work in progress), April 2013.

[JWK] Jones, M., "JSON Web Key (JWK)", draft-ietf-jose-json-web-key (work in progress), April 2013.

[RFC1421] Linn, J., "Privacy Enhancement for Internet Electronic Mail: Part I: Message Encryption and Authentication Procedures", RFC 1421, February 1993.

[RFC2046] Freed, N. and N. Borenstein, "Multipurpose Internet Mail Extensions (MIME) Part Two: Media Types", RFC 2046, November 1996.

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, March 1997.

[RFC2818] Rescorla, E., "HTTP Over TLS", RFC 2818, May 2000.

[RFC3629] Yergeau, F., "UTF-8, a transformation format of ISO 10646", STD 63, RFC 3629, November 2003.

[RFC3986] Berners-Lee, T., Fielding, R., and L. Masinter, "Uniform Resource Identifier (URI): Generic Syntax", STD 66, RFC 3986, January 2005.

[RFC4288] Freed, N. and J. Klensin, "Media Type Specifications and Registration Procedures", RFC 4288, December 2005.

[RFC4627] Crockford, D., "The application/json Media Type for JavaScript Object Notation (JSON)", RFC 4627, July 2006.

[RFC4648] Josefsson, S., "The Base16, Base32, and Base64 Data Encodings", RFC 4648, October 2006.

[RFC5226] Narten, T. and H. Alvestrand, "Guidelines for Writing an IANA Considerations Section in RFCs", BCP 26, RFC 5226, May 2008.

[RFC5246] Dierks, T. and E. Rescorla, "The Transport Layer Security (TLS) Protocol Version 1.2", RFC 5246, August 2008.

[RFC5280] 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.

[USA15] Davis, M., Whistler, K., and M. Duerst, "Unicode Normalization Forms", Unicode Standard Annex 15, 09 2009.

[USASCII] American National Standards Institute, "Coded Character Set -- 7-bit American Standard Code for Information Interchange", ANSI X3.4, 1986.

[W3C.WD-xmldsig-bestpractices-20110809] Datta, P. and F. Hirsch, "XML Signature Best Practices", World Wide Web Consortium WD WD-xmldsig-bestpractices-20110809, August 2011, <http://www.w3.org/TR/2011/WD-xmldsig-bestpractices-20110809>.

11.2. Informative References

[CanvasApp] Facebook, "Canvas Applications", 2010.

[JSS] Bradley, J. and N. Sakimura (editor), "JSON Simple Sign", September 2010.

[JWE] Jones, M., Rescorla, E., and J. Hildebrand, "JSON Web Encryption (JWE)", draft-ietf-jose-json-web-encryption (work in progress), April 2013.

[JWT] Jones, M., Bradley, J., and N. Sakimura, "JSON Web Token (JWT)", draft-ietf-oauth-json-web-token (work in progress), April 2013.

[MagicSignatures] Panzer (editor), J., Laurie, B., and D. Balfanz, "Magic Signatures", January 2011.

[RFC4122] Leach, P., Mealling, M., and R. Salz, "A Universally Unique IDentifier (UUID) URN Namespace", RFC 4122, July 2005.

[W3C.CR-xmldsig-core2-20120124] Eastlake, D., Reagle, J., Yiu, K., Solo, D., Datta, P., Hirsch, F., Cantor, S., and T. Roessler, "XML Signature Syntax and Processing Version 2.0", World Wide Web Consortium CR CR-xmldsig-core2-20120124, January 2012, <http://www.w3.org/TR/2012/CR-xmldsig-core2-20120124>.

Appendix A. JWS Examples

This section provides several examples of JWSs. While these examples all represent JSON Web Tokens (JWTs) [JWT], the payload can be any base64url encoded content.

A.1. Example JWS using HMAC SHA-256

A.1.1. Encoding

The following example JWS Header declares that the data structure is a JSON Web Token (JWT) [JWT] and the JWS Signing Input is secured using the HMAC SHA-256 algorithm.

```
{"typ":"JWT",
 "alg":"HS256"}
```

The following octet sequence contains the UTF-8 representation of the JWS Header:

```
[123, 34, 116, 121, 112, 34, 58, 34, 74, 87, 84, 34, 44, 13, 10, 32,
34, 97, 108, 103, 34, 58, 34, 72, 83, 50, 53, 54, 34, 125]
```

Base64url encoding these octets yields this Encoded JWS Header value:

```
eyJ0eXAiOiJKV1QiLA0KICJhbGciOiJIUzI1NiJ9
```

The JWS Payload used in this example is the octets of the UTF-8 representation of the JSON object below. (Note that the payload can be any base64url encoded octet sequence, and need not be a base64url encoded JSON object.)

```
{"iss":"joe",
 "exp":1300819380,
 "http://example.com/is_root":true}
```

The following octet sequence, which is the UTF-8 representation of the JSON object above, is the JWS Payload:

```
[123, 34, 105, 115, 115, 34, 58, 34, 106, 111, 101, 34, 44, 13, 10,
32, 34, 101, 120, 112, 34, 58, 49, 51, 48, 48, 56, 49, 57, 51, 56,
48, 44, 13, 10, 32, 34, 104, 116, 116, 112, 58, 47, 47, 101, 120, 97,
109, 112, 108, 101, 46, 99, 111, 109, 47, 105, 115, 95, 114, 111,
111, 116, 34, 58, 116, 114, 117, 101, 125]
```

Base64url encoding the above yields the Encoded JWS Payload value (with line breaks for display purposes only):

```
eyJpc3MiOiJqb2UiLA0KICJleHAiOjEzMDA4MTkzODAsDQogImh0dHA6Ly9leGFt
cGxlLmNvbS9pc19yb290Ijp0cnVlfQ
```

Concatenating the Encoded JWS Header, a period ('.') character, and the Encoded JWS Payload yields this JWS Signing Input value (with line breaks for display purposes only):

```
eyJ0eXAiOiJKV1QiLA0KICJhbGciOiJIUzI1NiJ9
.
eyJpc3MiOiJqb2UiLA0KICJleHAiOjEzMDA4MTkzODAsDQogImh0dHA6Ly9leGFt
cGxlLmNvbS9pc19yb290Ijp0cnVlfQ
```

The ASCII representation of the JWS Signing Input is the following octet sequence:

```
[101, 121, 74, 48, 101, 88, 65, 105, 79, 105, 74, 75, 86, 49, 81,
105, 76, 65, 48, 75, 73, 67, 74, 104, 98, 71, 99, 105, 79, 105, 74,
73, 85, 122, 73, 49, 78, 105, 74, 57, 46, 101, 121, 74, 112, 99, 51,
77, 105, 79, 105, 74, 113, 98, 50, 85, 105, 76, 65, 48, 75, 73, 67,
74, 108, 101, 72, 65, 105, 79, 106, 69, 122, 77, 68, 65, 52, 77, 84,
107, 122, 79, 68, 65, 115, 68, 81, 111, 103, 73, 109, 104, 48, 100,
72, 65, 54, 76, 121, 57, 108, 101, 71, 70, 116, 99, 71, 120, 108, 76,
109, 78, 118, 98, 83, 57, 112, 99, 49, 57, 121, 98, 50, 57, 48, 73,
106, 112, 48, 99, 110, 86, 108, 102, 81]
```

HMACs are generated using keys. This example uses the key represented by the following octet sequence:

```
[3, 35, 53, 75, 43, 15, 165, 188, 131, 126, 6, 101, 119, 123, 166,
143, 90, 179, 40, 230, 240, 84, 201, 40, 169, 15, 132, 178, 210, 80,
46, 191, 211, 251, 90, 146, 210, 6, 71, 239, 150, 138, 180, 195, 119,
98, 61, 34, 61, 46, 33, 114, 5, 46, 79, 8, 192, 205, 154, 245, 103,
208, 128, 163]
```

Running the HMAC SHA-256 algorithm on the octets of the ASCII representation of the JWS Signing Input with this key yields the following octet sequence:

```
[116, 24, 223, 180, 151, 153, 224, 37, 79, 250, 96, 125, 216, 173,
187, 186, 22, 212, 37, 77, 105, 214, 191, 240, 91, 88, 5, 88, 83,
132, 141, 121]
```

Base64url encoding the above HMAC output yields the Encoded JWS Signature value:

```
dBjftJeZ4CVP-mB92K27uhbUJU1p1r_wW1gFWFOEjXk
```

Concatenating these values in the order Header.Payload.Signature with

period ('.') characters between the parts yields this complete JWS representation using the JWS Compact Serialization (with line breaks for display purposes only):

```
eyJ0eXAiOiJKV1QiLA0KICJhbGciOiJIUzI1NiJ9
.
eyJpc3MiOiJqb2UiLA0KICJleHAiOjEzMDA4MTkzODAsDQogImh0dHA6Ly9leGFt
cGxlLmNvbS9pc19yb290Ijp0cnVlfQ
.
dBjftJeZ4CVP-mB92K27uhbUJU1p1r_wW1gFWFOEjXk
```

A.1.2. Decoding

Decoding the JWS requires base64url decoding the Encoded JWS Header, Encoded JWS Payload, and Encoded JWS Signature to produce the JWS Header, JWS Payload, and JWS Signature octet sequences. The octet sequence containing the UTF-8 representation of the JWS Header is decoded into the JWS Header string.

A.1.3. Validating

Next we validate the decoded results. Since the "alg" parameter in the header is "HS256", we validate the HMAC SHA-256 value contained in the JWS Signature. If any of the validation steps fail, the JWS MUST be rejected.

First, we validate that the JWS Header string is legal JSON.

To validate the HMAC value, we repeat the previous process of using the correct key and the ASCII representation of the JWS Signing Input as input to the HMAC SHA-256 function and then taking the output and determining if it matches the JWS Signature. If it matches exactly, the HMAC has been validated.

A.2. Example JWS using RSA SHA-256

A.2.1. Encoding

The JWS Header in this example is different from the previous example in two ways: First, because a different algorithm is being used, the "alg" value is different. Second, for illustration purposes only, the optional "typ" parameter is not used. (This difference is not related to the algorithm employed.) The JWS Header used is:

```
{"alg":"RS256"}
```

The following octet sequence contains the UTF-8 representation of the JWS Header:

[123, 34, 97, 108, 103, 34, 58, 34, 82, 83, 50, 53, 54, 34, 125]

Base64url encoding these octets yields this Encoded JWS Header value:

```
eyJhbGciOiJSUzI1NiJ9
```

The JWS Payload used in this example, which follows, is the same as in the previous example. Since the Encoded JWS Payload will therefore be the same, its computation is not repeated here.

```
{"iss":"joe",
 "exp":1300819380,
 "http://example.com/is_root":true}
```

Concatenating the Encoded JWS Header, a period ('.') character, and the Encoded JWS Payload yields this JWS Signing Input value (with line breaks for display purposes only):

```
eyJhbGciOiJSUzI1NiJ9
.
eyJpc3MiOiJqb2UiLA0KICJleHAiOjEzMDA4MTkzODAsDQogImh0dHA6Ly9leGFt
cGxlLmNvbS9pc19yb290Ijp0cnVlfQ
```

The ASCII representation of the JWS Signing Input is the following octet sequence:

[101, 121, 74, 104, 98, 71, 99, 105, 79, 105, 74, 83, 85, 122, 73, 49, 78, 105, 74, 57, 46, 101, 121, 74, 112, 99, 51, 77, 105, 79, 105, 74, 113, 98, 50, 85, 105, 76, 65, 48, 75, 73, 67, 74, 108, 101, 72, 65, 105, 79, 106, 69, 122, 77, 68, 65, 52, 77, 84, 107, 122, 79, 68, 65, 115, 68, 81, 111, 103, 73, 109, 104, 48, 100, 72, 65, 54, 76, 121, 57, 108, 101, 71, 70, 116, 99, 71, 120, 108, 76, 109, 78, 118, 98, 83, 57, 112, 99, 49, 57, 121, 98, 50, 57, 48, 73, 106, 112, 48, 99, 110, 86, 108, 102, 81]

The RSA key consists of a public part (Modulus, Exponent), and a Private Exponent. The values of the RSA key used in this example, presented as the octet sequences representing big endian integers are:

Parameter Name	Value
Modulus	[161, 248, 22, 10, 226, 227, 201, 180, 101, 206, 141, 45, 101, 98, 99, 54, 43, 146, 125, 190, 41, 225, 240, 36, 119, 252, 22, 37, 204, 144, 161, 54, 227, 139, 217, 52, 151, 197, 182, 234, 99, 221, 119, 17, 230, 124, 116, 41, 249, 86, 176, 251, 138, 143, 8, 154, 220, 75, 105, 137, 60, 193, 51, 63, 83, 237, 208, 25, 184, 119, 132, 37, 47, 236, 145, 79, 228, 133, 119, 105, 89, 75, 234, 66, 128, 211, 44, 15, 85, 191, 98, 148, 79, 19, 3, 150, 188, 110, 155, 223, 110, 189, 210, 189, 163, 103, 142, 236, 160, 198, 104, 247, 1, 179, 141, 191, 251, 56, 200, 52, 44, 226, 254, 109, 39, 250, 222, 74, 90, 72, 116, 151, 157, 212, 185, 207, 154, 222, 196, 199, 91, 5, 133, 44, 44, 15, 94, 248, 165, 193, 117, 3, 146, 249, 68, 232, 237, 100, 193, 16, 198, 182, 71, 96, 154, 164, 120, 58, 235, 156, 108, 154, 215, 85, 49, 48, 80, 99, 139, 131, 102, 92, 111, 111, 122, 130, 163, 150, 112, 42, 31, 100, 27, 130, 211, 235, 242, 57, 34, 25, 73, 31, 182, 134, 135, 44, 87, 22, 245, 10, 248, 53, 141, 154, 139, 157, 23, 195, 64, 114, 143, 127, 135, 216, 154, 24, 216, 252, 171, 103, 173, 132, 89, 12, 46, 207, 117, 147, 57, 54, 60, 7, 3, 77, 111, 96, 111, 158, 33, 224, 84, 86, 202, 229, 233, 161]
Exponent	[1, 0, 1]

Private Exponent	[18, 174, 113, 164, 105, 205, 10, 43, 195, 126, 82, 108, 69, 0, 87, 31, 29, 97, 117, 29, 100, 233, 73, 112, 123, 98, 89, 15, 157, 11, 165, 124, 150, 60, 64, 30, 63, 207, 47, 44, 211, 189, 236, 136, 229, 3, 191, 198, 67, 155, 11, 40, 200, 47, 125, 55, 151, 103, 31, 82, 19, 238, 216, 193, 90, 37, 216, 213, 206, 160, 2, 94, 227, 171, 46, 139, 127, 121, 33, 111, 198, 59, 234, 86, 39, 83, 180, 6, 68, 198, 161, 81, 39, 217, 178, 149, 69, 64, 160, 187, 225, 163, 5, 86, 152, 45, 78, 159, 222, 95, 100, 37, 241, 77, 75, 113, 52, 65, 181, 93, 199, 59, 155, 74, 237, 204, 146, 172, 227, 146, 126, 55, 245, 125, 12, 253, 94, 117, 129, 250, 81, 44, 143, 73, 97, 169, 235, 11, 128, 248, 168, 7, 70, 114, 138, 85, 255, 70, 71, 31, 52, 37, 6, 59, 157, 83, 100, 47, 94, 222, 30, 132, 214, 19, 8, 26, 250, 92, 34, 208, 81, 40, 91, 214, 59, 148, 59, 86, 93, 137, 138, 5, 104, 84, 19, 229, 60, 60, 108, 101, 37, 255, 31, 227, 78, 61, 220, 112, 240, 213, 100, 80, 253, 164, 139, 161, 46, 16, 78, 157, 235, 159, 184, 24, 129, 225, 196, 189, 242, 93, 146, 71, 244, 80, 200, 101, 146, 121, 104, 231, 115, 52, 244, 65, 79, 117, 167, 80, 225, 57, 84, 110, 58, 138, 115, 157]

The RSA private key (Modulus, Private Exponent) is then passed to the RSA signing function, which also takes the hash type, SHA-256, and the octets of the ASCII representation of the JWS Signing Input as inputs. The result of the digital signature is an octet sequence, which represents a big endian integer. In this example, it is:

[112, 46, 33, 137, 67, 232, 143, 209, 30, 181, 216, 45, 191, 120, 69, 243, 65, 6, 174, 27, 129, 255, 247, 115, 17, 22, 173, 209, 113, 125, 131, 101, 109, 66, 10, 253, 60, 150, 238, 221, 115, 162, 102, 62, 81, 102, 104, 123, 0, 11, 135, 34, 110, 1, 135, 237, 16, 115, 249, 69, 229, 130, 173, 252, 239, 22, 216, 90, 121, 142, 232, 198, 109, 219, 61, 184, 151, 91, 23, 208, 148, 2, 190, 237, 213, 217, 217, 112, 7, 16, 141, 178, 129, 96, 213, 248, 4, 12, 167, 68, 87, 98, 184, 31, 190, 127, 249, 217, 46, 10, 231, 111, 36, 242, 91, 51, 187, 230, 244, 74, 230, 30, 177, 4, 10, 203, 32, 4, 77, 62, 249, 18, 142, 212, 1, 48, 121, 91, 212, 189, 59, 65, 238, 202, 208, 102, 171, 101, 25, 129, 253, 228, 141, 247, 127, 55, 45, 195, 139, 159, 175, 221, 59, 239, 177, 139, 93, 163, 204, 60, 46, 176, 47, 158, 58, 65, 214, 18, 202, 173, 21, 145, 18, 115, 160, 95, 35, 185, 232, 56, 250, 175, 132, 157, 105, 132, 41, 239, 90, 30, 136, 121, 130, 54, 195, 212, 14, 96, 69, 34, 165, 68, 200, 242, 122, 122, 45, 184, 6, 99, 209, 108, 247, 202, 234, 86, 222, 64, 92, 178, 33, 90, 69, 178, 194, 85, 102, 181, 90, 193, 167, 72, 160, 112, 223, 200, 163, 42, 70, 149, 67, 208, 25, 238,

251, 71]

Base64url encoding the digital signature produces this value for the Encoded JWS Signature (with line breaks for display purposes only):

```
cC4hiUPoj9Eetdgtv3hF80EGrhuB__dzERat0XF9g2VtQgr9PJbu3XOiZj5RZmh7
AAuHIm4Bh-0Qc_lF5YKt_O8W2Fp5jujGbds9uJdbF9CUAr7t1dnZcAcQjbKBYNX4
BAynRFdiuB--f_nZLgrnbyTyWzO75vRK5h6xBArLIARNPvkSjtQBMHlb1L07Qe7K
0GarZRmB_eSN9383LcOLn6_dO--xi12jzDwusC-eOkHWEsqtFZESc6BfI7noOPqv
hJ1phCnvWh6IeYI2w9QOYEUipUTI8np6LbgGY9Fs98rqVt5AXLIhWkWywlVmtVrB
p0igcN_IoypGlUPQGe77Rw
```

Concatenating these values in the order Header.Payload.Signature with period ('.') characters between the parts yields this complete JWS representation using the JWS Compact Serialization (with line breaks for display purposes only):

```
eyJhbGciOiJSUzI1NiJ9
.
eyJpc3MiOiJqb2UiLA0KICJleHAiOjEzMDA4MTkzODAsDQogImh0dHA6Ly9leGFt
cGxlLmNvbS9pc19yb290Ijp0cnVlfQ
.
cC4hiUPoj9Eetdgtv3hF80EGrhuB__dzERat0XF9g2VtQgr9PJbu3XOiZj5RZmh7
AAuHIm4Bh-0Qc_lF5YKt_O8W2Fp5jujGbds9uJdbF9CUAr7t1dnZcAcQjbKBYNX4
BAynRFdiuB--f_nZLgrnbyTyWzO75vRK5h6xBArLIARNPvkSjtQBMHlb1L07Qe7K
0GarZRmB_eSN9383LcOLn6_dO--xi12jzDwusC-eOkHWEsqtFZESc6BfI7noOPqv
hJ1phCnvWh6IeYI2w9QOYEUipUTI8np6LbgGY9Fs98rqVt5AXLIhWkWywlVmtVrB
p0igcN_IoypGlUPQGe77Rw
```

A.2.2. Decoding

Decoding the JWS requires base64url decoding the Encoded JWS Header, Encoded JWS Payload, and Encoded JWS Signature to produce the JWS Header, JWS Payload, and JWS Signature octet sequences. The octet sequence containing the UTF-8 representation of the JWS Header is decoded into the JWS Header string.

A.2.3. Validating

Since the "alg" parameter in the header is "RS256", we validate the RSA SHA-256 digital signature contained in the JWS Signature. If any of the validation steps fail, the JWS MUST be rejected.

First, we validate that the JWS Header string is legal JSON.

Validating the JWS Signature is a little different from the previous example. First, we base64url decode the Encoded JWS Signature to produce a digital signature S to check. We then pass (n, e), S and

the octets of the ASCII representation of the JWS Signing Input to an RSA signature verifier that has been configured to use the SHA-256 hash function.

A.3. Example JWS using ECDSA P-256 SHA-256

A.3.1. Encoding

The JWS Header for this example differs from the previous example because a different algorithm is being used. The JWS Header used is:

```
{"alg":"ES256"}
```

The following octet sequence contains the UTF-8 representation of the JWS Header:

```
[123, 34, 97, 108, 103, 34, 58, 34, 69, 83, 50, 53, 54, 34, 125]
```

Base64url encoding these octets yields this Encoded JWS Header value:

```
eyJhbGciOiJFUzI1NiJ9
```

The JWS Payload used in this example, which follows, is the same as in the previous examples. Since the Encoded JWS Payload will therefore be the same, its computation is not repeated here.

```
{"iss":"joe",
 "exp":1300819380,
 "http://example.com/is_root":true}
```

Concatenating the Encoded JWS Header, a period ('.') character, and the Encoded JWS Payload yields this JWS Signing Input value (with line breaks for display purposes only):

```
eyJhbGciOiJFUzI1NiJ9
.
eyJpc3MiOiJqb2UiLA0KICJleHAiOjEzMDA4MTkzODAsDQogImh0dHA6Ly9leGFt
cGxlLmNvbS9pc19yb290Ijp0cnVlfQ
```

The ASCII representation of the JWS Signing Input is the following octet sequence:

```
[101, 121, 74, 104, 98, 71, 99, 105, 79, 105, 74, 70, 85, 122, 73,
49, 78, 105, 74, 57, 46, 101, 121, 74, 112, 99, 51, 77, 105, 79, 105,
74, 113, 98, 50, 85, 105, 76, 65, 48, 75, 73, 67, 74, 108, 101, 72,
65, 105, 79, 106, 69, 122, 77, 68, 65, 52, 77, 84, 107, 122, 79, 68,
65, 115, 68, 81, 111, 103, 73, 109, 104, 48, 100, 72, 65, 54, 76,
121, 57, 108, 101, 71, 70, 116, 99, 71, 120, 108, 76, 109, 78, 118,
```

98, 83, 57, 112, 99, 49, 57, 121, 98, 50, 57, 48, 73, 106, 112, 48, 99, 110, 86, 108, 102, 81]

The ECDSA key consists of a public part, the EC point (x, y), and a private part d. The values of the ECDSA key used in this example, presented as the octet sequences representing three 256 bit big endian integers are:

Parameter Name	Value
x	[127, 205, 206, 39, 112, 246, 196, 93, 65, 131, 203, 238, 111, 219, 75, 123, 88, 7, 51, 53, 123, 233, 239, 19, 186, 207, 110, 60, 123, 209, 84, 69]
y	[199, 241, 68, 205, 27, 189, 155, 126, 135, 44, 223, 237, 185, 238, 185, 244, 179, 105, 93, 110, 169, 11, 36, 173, 138, 70, 35, 40, 133, 136, 229, 173]
d	[142, 155, 16, 158, 113, 144, 152, 191, 152, 4, 135, 223, 31, 93, 119, 233, 203, 41, 96, 110, 190, 210, 38, 59, 95, 87, 194, 19, 223, 132, 244, 178]

The ECDSA private part d is then passed to an ECDSA signing function, which also takes the curve type, P-256, the hash type, SHA-256, and the octets of the ASCII representation of the JWS Signing Input as inputs. The result of the digital signature is the EC point (R, S), where R and S are unsigned integers. In this example, the R and S values, given as octet sequences representing big endian integers are:

Result Name	Value
R	[14, 209, 33, 83, 121, 99, 108, 72, 60, 47, 127, 21, 88, 7, 212, 2, 163, 178, 40, 3, 58, 249, 124, 126, 23, 129, 154, 195, 22, 158, 166, 101]
S	[197, 10, 7, 211, 140, 60, 112, 229, 216, 241, 45, 175, 8, 74, 84, 128, 166, 101, 144, 197, 242, 147, 80, 154, 143, 63, 127, 138, 131, 163, 84, 213]

Concatenating the S array to the end of the R array and base64url encoding the result produces this value for the Encoded JWS Signature (with line breaks for display purposes only):

DtEhU3ljbEg8L38VWAfUAqOyKAM6-Xx-F4GawxaepmXFCgfTjDxw5djxLa8ISlSA

```
pmWQxfKTUJqPP3-Kg6NU1Q
```

Concatenating these values in the order Header.Payload.Signature with period ('.') characters between the parts yields this complete JWS representation using the JWS Compact Serialization (with line breaks for display purposes only):

```
eyJhbGciOiJFUzI1NiJ9
.
eyJpc3MiOiJqb2UiLA0KICJleHAiOjEzMDA4MTkzODAsDQogImh0dHA6Ly9leGFt
cGxlLmNvbS9pc19yb290Ijp0cnVlfQ
.
DtEhU3ljbEg8L38VWAfUAqOyKAM6-Xx-F4GawxaepmXFCgfTjDxw5djxLa8ISlSA
pmWQxfKTUJqPP3-Kg6NU1Q
```

A.3.2. Decoding

Decoding the JWS requires base64url decoding the Encoded JWS Header, Encoded JWS Payload, and Encoded JWS Signature to produce the JWS Header, JWS Payload, and JWS Signature octet sequences. The octet sequence containing the UTF-8 representation of the JWS Header is decoded into the JWS Header string.

A.3.3. Validating

Since the "alg" parameter in the header is "ES256", we validate the ECDSA P-256 SHA-256 digital signature contained in the JWS Signature. If any of the validation steps fail, the JWS MUST be rejected.

First, we validate that the JWS Header string is legal JSON.

Validating the JWS Signature is a little different from the first example. First, we base64url decode the Encoded JWS Signature as in the previous examples but we then need to split the 64 member octet sequence that must result into two 32 octet sequences, the first R and the second S. We then pass (x, y), (R, S) and the octets of the ASCII representation of the JWS Signing Input to an ECDSA signature verifier that has been configured to use the P-256 curve with the SHA-256 hash function.

As explained in Section 3.4 of the JSON Web Algorithms (JWA) [JWA] specification, the use of the K value in ECDSA means that we cannot validate the correctness of the digital signature in the same way we validated the correctness of the HMAC. Instead, implementations MUST use an ECDSA validator to validate the digital signature.

A.4. Example JWS using ECDSA P-521 SHA-512

A.4.1. Encoding

The JWS Header for this example differs from the previous example because a different ECDSA curve and hash function are used. The JWS Header used is:

```
{"alg":"ES512"}
```

The following octet sequence contains the UTF-8 representation of the JWS Header:

```
[123, 34, 97, 108, 103, 34, 58, 34, 69, 83, 53, 49, 50, 34, 125]
```

Base64url encoding these octets yields this Encoded JWS Header value:

```
eyJhbGciOiJFUzUxMiJ9
```

The JWS Payload used in this example, is the ASCII string "Payload". The representation of this string is the octet sequence:

```
[80, 97, 121, 108, 111, 97, 100]
```

Base64url encoding these octets yields the Encoded JWS Payload value:

```
UGF5bG9hZA
```

Concatenating the Encoded JWS Header, a period ('.') character, and the Encoded JWS Payload yields this JWS Signing Input value:

```
eyJhbGciOiJFUzUxMiJ9.UGF5bG9hZA
```

The ASCII representation of the JWS Signing Input is the following octet sequence:

```
[101, 121, 74, 104, 98, 71, 99, 105, 79, 105, 74, 70, 85, 122, 85,
120, 77, 105, 74, 57, 46, 85, 71, 70, 53, 98, 71, 57, 104, 90, 65]
```

The ECDSA key consists of a public part, the EC point (x, y), and a private part d. The values of the ECDSA key used in this example, presented as the octet sequences representing three 521 bit big endian integers are:

Parameter Name	Value
x	[1, 233, 41, 5, 15, 18, 79, 198, 188, 85, 199, 213, 57, 51, 101, 223, 157, 239, 74, 176, 194, 44, 178, 87, 152, 249, 52, 235, 4, 227, 198, 186, 227, 112, 26, 87, 167, 145, 14, 157, 129, 191, 54, 49, 89, 232, 235, 203, 21, 93, 99, 73, 244, 189, 182, 204, 248, 169, 76, 92, 89, 199, 170, 193, 1, 164]
y	[0, 52, 166, 68, 14, 55, 103, 80, 210, 55, 31, 209, 189, 194, 200, 243, 183, 29, 47, 78, 229, 234, 52, 50, 200, 21, 204, 163, 21, 96, 254, 93, 147, 135, 236, 119, 75, 85, 131, 134, 48, 229, 203, 191, 90, 140, 190, 10, 145, 221, 0, 100, 198, 153, 154, 31, 110, 110, 103, 250, 221, 237, 228, 200, 200, 246]
d	[1, 142, 105, 111, 176, 52, 80, 88, 129, 221, 17, 11, 72, 62, 184, 125, 50, 206, 73, 95, 227, 107, 55, 69, 237, 242, 216, 202, 228, 240, 242, 83, 159, 70, 21, 160, 233, 142, 171, 82, 179, 192, 197, 234, 196, 206, 7, 81, 133, 168, 231, 187, 71, 222, 172, 29, 29, 231, 123, 204, 246, 97, 53, 230, 61, 130]

The ECDSA private part d is then passed to an ECDSA signing function, which also takes the curve type, P-521, the hash type, SHA-512, and the octets of the ASCII representation of the JWS Signing Input as inputs. The result of the digital signature is the EC point (R, S), where R and S are unsigned integers. In this example, the R and S values, given as octet sequences representing big endian integers are:

Result Name	Value
R	[1, 220, 12, 129, 231, 171, 194, 209, 232, 135, 233, 117, 247, 105, 122, 210, 26, 125, 192, 1, 217, 21, 82, 91, 45, 240, 255, 83, 19, 34, 239, 71, 48, 157, 147, 152, 105, 18, 53, 108, 163, 214, 68, 231, 62, 153, 150, 106, 194, 164, 246, 72, 143, 138, 24, 50, 129, 223, 133, 206, 209, 172, 63, 237, 119, 109]

S	[0, 111, 6, 105, 44, 5, 41, 208, 128, 61, 152, 40, 92, 61, 152, 4, 150, 66, 60, 69, 247, 196, 170, 81, 193, 199, 78, 59, 194, 169, 16, 124, 9, 143, 42, 142, 131, 48, 206, 238, 34, 175, 83, 203, 220, 159, 3, 107, 155, 22, 27, 73, 111, 68, 68, 21, 238, 144, 229, 232, 148, 188, 222, 59, 242, 103]

Concatenating the S array to the end of the R array and base64url encoding the result produces this value for the Encoded JWS Signature (with line breaks for display purposes only):

```
AdwMgeerwtHoh-l192l60hp9wAHZFVJbLfD_UxMi70cwnZOYaRI1bKPWROc-mZZq
wqT2SI-KGDKB34XO0aw_7XdtAG8GaSwFKdCAPZgoXD2YBJZCPEX3xKpRwcdOO8Kp
EHwJjyqOgzDO7iKvU8vcnwNrmxYbSW9ERBXukOXolLzeO_Jn
```

Concatenating these values in the order Header.Payload.Signature with period ('.') characters between the parts yields this complete JWS representation using the JWS Compact Serialization (with line breaks for display purposes only):

```
eyJhbGciOiJFUzUxMiJ9
.
eyJpc3MiOiJqb2UiLA0KICJleHAiOjEzMDA4MTkzODAsDQogImh0dHA6Ly9leGFt
cGxlLmNvbS9pc19yb290Ijp0cnVlfQ
.
AdwMgeerwtHoh-l192l60hp9wAHZFVJbLfD_UxMi70cwnZOYaRI1bKPWROc-mZZq
wqT2SI-KGDKB34XO0aw_7XdtAG8GaSwFKdCAPZgoXD2YBJZCPEX3xKpRwcdOO8Kp
EHwJjyqOgzDO7iKvU8vcnwNrmxYbSW9ERBXukOXolLzeO_Jn
```

A.4.2. Decoding

Decoding the JWS requires base64url decoding the Encoded JWS Header, Encoded JWS Payload, and Encoded JWS Signature to produce the JWS Header, JWS Payload, and JWS Signature octet sequences. The octet sequence containing the UTF-8 representation of the JWS Header is decoded into the JWS Header string.

A.4.3. Validating

Since the "alg" parameter in the header is "ES512", we validate the ECDSA P-521 SHA-512 digital signature contained in the JWS Signature. If any of the validation steps fail, the JWS MUST be rejected.

First, we validate that the JWS Header string is legal JSON.

Validating the JWS Signature is similar to the previous example. First, we base64url decode the Encoded JWS Signature as in the

previous examples but we then need to split the 132 member octet sequence that must result into two 66 octet sequences, the first R and the second S. We then pass (x, y), (R, S) and the octets of the ASCII representation of the JWS Signing Input to an ECDSA signature verifier that has been configured to use the P-521 curve with the SHA-512 hash function.

As explained in Section 3.4 of the JSON Web Algorithms (JWA) [JWA] specification, the use of the K value in ECDSA means that we cannot validate the correctness of the digital signature in the same way we validated the correctness of the HMAC. Instead, implementations MUST use an ECDSA validator to validate the digital signature.

A.5. Example Plaintext JWS

The following example JWS Header declares that the encoded object is a Plaintext JWS:

```
{"alg":"none"}
```

Base64url encoding the octets of the UTF-8 representation of the JWS Header yields this Encoded JWS Header:

```
eyJhbGciOiJub25lIn0
```

The JWS Payload used in this example, which follows, is the same as in the previous examples. Since the Encoded JWS Payload will therefore be the same, its computation is not repeated here.

```
{"iss":"joe",
 "exp":1300819380,
 "http://example.com/is_root":true}
```

The Encoded JWS Signature is the empty string.

Concatenating these parts in the order Header.Payload.Signature with period ('.') characters between the parts yields this complete JWS (with line breaks for display purposes only):

```
eyJhbGciOiJub25lIn0
.
eyJpc3MiOiJqb2UiLA0KICJleHAiOjEzMDA4MTkzODAsDQogImh0dHA6Ly9leGFt
cGxlLmNvbS9pc19yb290Ijp0cnVlfQ
.
```

Appendix B. "x5c" (X.509 Certificate Chain) Example

The JSON array below is an example of a certificate chain that could be used as the value of an "x5c" (X.509 Certificate Chain) header parameter, per Section 4.1.6. Note that since these strings contain base64 encoded (not base64url encoded) values, they are allowed to contain white space and line breaks.


```
["MIIE3jCCA8agAwIBAgICAwEwDQYJKoZIhvcNAQEFBQAwYzELMAkGA1UEBhMCVVM
  xITAfBgNVBAoTGFRoZSBHbyBEYWRkeSBHcm91cCwgSW5jLjExMC8GA1UECxMoR2
  8gRGFkZHkgQ2xhc3MgMiBDZXJ0aWZpY2F0aW9uIEF1dGhvcml0eTAeFw0wNjExM
  TYwMTU0MzdaFw0yNjExMTYwMTU0MzdaMIHKMQswCQYDVQQGEwJVUzEQMA4GA1UE
  CBMHQXJpem9uYTETMBEGA1UEBxMKU2NvdHRzZGFsZTEaMBgGA1UEChMRR29EYWR
  keS5jb20sIEluYy4xMzAxBgNVBAsTKmh0dHA6Ly9jZXJ0aWZpY2F0ZXMuZ29kYW
  RkeS5jb20vcmVwb3NpdG9yeTEwMC4GA1UEAxMnR28gRGFkZHkgU2VjdXJlIENlc
  nRpZmljYXRpb24gQXV0aG9yaXR5MREwDwYDVQQFEwgwNzk2OTI4NzCCASIwDQYJ
  KoZIhvcNAQEBBQADggEPADCCAQoCggEBAMQt1RWMnCZM7DI161+4WQFapmGBWTt
  wY6vj3D3HKrjJM9N55DrtPDAjhI6zMBS2sofDPZVUBJ7fmd0LJR4h3mUpfjWoqV
  Tr9vcyOdQmVZWt7/v+WIbXnvQAjYwqDL1CBM6nPwT27oDyqu9SoWlm2r4arV3aL
  GbqGmu75RpRSgAvSMeYddi5Kcju+GZtCpyz8/x4fKL4o/K1w/O5epHBp+YlLpyo
  7RJlbmr2EkRTcDCVw5wrWCs9CHRK8r5RsL+H0EwnWGu1NcWdrxcx+AuP7q2BNgW
  JCJjPOq8lh8BJ6qf9Z/dFjpfMFDniNoW1fho3/Rb2cRGadDAW/hOUoz+EDU8CAw
  EAAaOCATIwggEuMB0GA1UdDgQWBBT9rGEyk2xF1uLuhV+auud2mWjM5zAfBgNVH
  SMEGDAWgBTSxLDSkdRMEXGzYcs9of7dqGrU4zASBgNVHRMBAf8ECDAGAQH/AgEA
  MDMGCCsGAQUFBwEBBCcwJTAjBggrBgEFBQcwAYYXaHR0cDovL29jc3AuZ29kYWR
  keS5jb20wRgYDVR0fBD8wPTA7oDmgN4Y1aHR0cDovL2NlcnRpZmljYXRlcy5nb2
  RhZGR5LmNvbS9yZXBvc2l0b3J5L2dkcm9vdC5jcmwwSwYDVR0gBEQwQjBABgRVH
  SAAMDgwNgYIKwYBBQUHAgEWKmh0dHA6Ly9jZXJ0aWZpY2F0ZXMuZ29kYWRkeS5j
  b20vcmVwb3NpdG9yeTAOBgNVHQ8BAf8EBAMCAQYwDQYJKoZIhvcNAQEFBQADggE
  BANKGwOy9+aG2Z+5mC6IGOgRQjhVyrEp0lVPLN8tESe8HkGsz2ZbwlFalEzAFPI
  UyIXvJxwqoJKSQ3kbTJSMUA2fCENZvD117esyfxVgqwcSeIaha86ykRvOe5GPLL
  5CkKSkB2XIsKd83ASe8T+5o0yGPwLPk9Qnt0hCqU7S+8MxZC9Y7lhyVJEnfzuz9
  p0iRFEUOOjZv2kWzRaJBydTXRE4+uXR21aITVSzGh6O1mawGhId/dQb8vxRMDsx
  uxN89txJx9OjxUUAiKEngHUuHqDTMBqLdElrRhjZkAzVvb3du6/KFUJheqwNTrZ
  EjYx8WnM25sgVjOuH0aBsXBTWVU+4=",
 "MIIE+zCCBGSgAwIBAgICAQ0wDQYJKoZIhvcNAQEFBQAwgbsxJDAiBgNVBAcTG1Z
  hbGlDZXJ0IFZhbGlkYXRpb24gTmV0d29yazEXMBUGA1UEChMOVmFsaUNlcnQsIE
  luYy4xNTAzBgNVBAsTLFZhbGlDZXJ0IENsYXNzIDIgUG9saWN5IFZhbGlkYXRpb
  24gQXV0aG9yaXR5MSEwHwYDVQQDExhodHRwOi8vd3d3LnZhbGljZXJ0LmNvbS8x
  IDAeBgkqhkiG9w0BCQEWEWluZm9AdmFsaWNlcnQuY29tMB4XDTA0MDYyOTE3MDY
  yMFoXDTI0MDYyOTE3MDYyMFowYzELMAkGA1UEBhMCVVMxITAfBgNVBAoTGFRoZS
  BHbyBEYWRkeSBHcm91cCwgSW5jLjExMC8GA1UECxMoR28gRGFkZHkgQ2xhc3MgM
  iBDZXJ0aWZpY2F0aW9uIEF1dGhvcml0eTCCASAwDQYJKoZIhvcNAQEBBQADggEN
  ADCCAQgCggEBAN6d1+pXGEmhW+vXX0iG6r7d/+TvZxz0ZWizV3GgXne77ZtJ6XC
  APVYYYwhv2vLM0D9/AlQiVBDYsoHUwHU9S3/Hd8M+eKsaA7Ugay9qK7HFiH7Eux
  6wwdhFJ2+qN1j3hybX2C32qRe3H3I2TqYXP2WYktsqbl2i/ojgC95/5Y0V4evLO
  tXiEqITLdiOr18SPaAIBQi2XKVlOARFmR6jYGB0xUGlcmIbYsUfb18aQr4CUWWo
  riMYavx4A6lNf4DD+qta/KFApMoZFv6yyO9ecw3ud72a9nmYvLEHZ6IVDd2gWMZ
```

Eewo+YihfukEHU1jPEX44dMX4/7VpkI+EdOqXG68CAQOjggHhMIIB3TAdBgNVHQ
4EFgQU0sSw0pHUTBFxs2HLPaH+3ahq1OMwgdIGA1UdIwSByjCBx6GBwaSBvjCBu
zEkMCIGA1UEBxMbVmFsaUNlcnQgVmFsaWRhdGlvbiBOZXR3b3JrMRcwFQYDVQQK
Ew5WYWxpQ2VydCwgSW5jLjE1MDMGA1UECxMsVmFsaUNlcnQgQ2xhc3MgMiBQb2x
pY3kgVmFsaWRhdGlvbiBBdXRob3JpdHkxITAfBgNVBAMTGGh0dHA6Ly93d3cudm
FsaWNlcnQuY29tLzEgMB4GCSqGSIb3DQEJARYRaW5mb0B2YWxpY2VydC5jb22CA
QEwDwYDVR0TAQH/BAUwAwEB/zAzBggrBgEFBQcBAQQnMCUwIwYIKwYBBQUHMAGG
F2h0dHA6Ly9vY3NwLmdvZGFkZHkuY29tMEQGA1UdHwQ9MDswOaA3oDWGM2h0dHA
6Ly9jZXJ0aWZpY2F0ZXMuZ29kYWRkeS5jb20vcmVwb3NpdG9yeS9yb290LmNybD
BLBgNVHSAERDBCMEAGBFUdIAAwODA2BggrBgEFBQcCARYqaHR0cDovL2NlcnRpZ
mljYXRlcy5nb2RhZGR5LmNvbS9yZXBvc2l0b3J5MA4GA1UdDwEB/wQEAwIBBjAN
BgkqhkiG9w0BAQUFAAOBgQC1QPmnHfbq/qQaQlpE9xXUhUaJwL6e4+PrxeNYiY+
Sn1eocSxI0YGyeR+sBjUZsE4OWBsUs5iB0QQeyAfJg594RAoYC5jcdnplDQ1tgM
QLARzLrUc+cb53S8wGd9D0VmsfSxOaFIqII6hR8INMqzW/Rn453HWkrugp++85j
09VZw==",
"MIIC5zCCAlACAQEwDQYJKoZIhvcNAQEFBQAwgbsxJDAiBgNVBAcTG1ZhbGlDZXJ
0IFZhbGlkYXRpb24gTmV0d29yazEXMBUGA1UEChMOVmFsaUNlcnQsIEluYy4xNT
AzBgNVBAsTLFZhbGlDZXJ0IENsYXNzIDIgUG9saWN5IFZhbGlkYXRpb24gQXV0a
G9yaXR5MSEwHwYDVQQDExhodHRwOi8vd3d3LnZhbGljZXJ0LmNvbS8xIDAeBgkq
hkiG9w0BCQEWEWluZm9AdmFsaWNlcnQuY29tMB4XDTk5MDYyNjAwMTk1NFoXDTE
5MDYyNjAwMTk1NFowgbsxJDAiBgNVBAcTG1ZhbGlDZXJ0IFZhbGlkYXRpb24gTm
V0d29yazEXMBUGA1UEChMOVmFsaUNlcnQsIEluYy4xNTAzBgNVBAsTLFZhbGlDZ
XJ0IENsYXNzIDIgUG9saWN5IFZhbGlkYXRpb24gQXV0aG9yaXR5MSEwHwYDVQQD
ExhodHRwOi8vd3d3LnZhbGljZXJ0LmNvbS8xIDAeBgkqhkiG9w0BCQEWEWluZm9
AdmFsaWNlcnQuY29tMIGfMA0GCSqGSIb3DQEBAQUAA4GNADCBiQKBgQDOOnHK5a
vIWZJV16vYdA757tn2VUdZZUcOBVXc65g2PFxTXdMwzzjsvUGJ7SVCCSRrCl6zf
N1SLUzm1NZ9WlmpZdRJEy0kTRxQb7XBhVQ7/nHk01xC+YDgkRoKWzk2Z/M/VXwb
P7RfZHM047QSv4dk+NoS/zcnwbNDu+97bi5p9wIDAQABMA0GCSqGSIb3DQEBBQU
AA4GBADt/UG9vUJSZSWI4OB9L+KXIPqeCgfYrx+jFzug6EILLGACOTb2oWH+heQ
C1u+mNr0HZDzTuIYEZoDJJKPTEjlbVUjP9UNV+mWwD5MlM/Mtsq2azSiGM5bUMM
j4QssxsodyamEwCW/POuZ6lcg5Ktz885hZo+L7tdEy8W9ViH0Pd"]

Appendix C. Notes on implementing base64url encoding without padding

This appendix describes how to implement base64url encoding and decoding functions without padding based upon standard base64 encoding and decoding functions that do use padding.

To be concrete, example C# code implementing these functions is shown below. Similar code could be used in other languages.

```
static string base64urlencode(byte [] arg)
{
  string s = Convert.ToBase64String(arg); // Regular base64 encoder
  s = s.Split('=')[0]; // Remove any trailing '='s
  s = s.Replace('+', '-'); // 62nd char of encoding
  s = s.Replace('/', '_'); // 63rd char of encoding
  return s;
}

static byte [] base64urldecode(string arg)
{
  string s = arg;
  s = s.Replace('-', '+'); // 62nd char of encoding
  s = s.Replace('_', '/'); // 63rd char of encoding
  switch (s.Length % 4) // Pad with trailing '='s
  {
    case 0: break; // No pad chars in this case
    case 2: s += "=="; break; // Two pad chars
    case 3: s += "="; break; // One pad char
    default: throw new System.Exception(
      "Illegal base64url string!");
  }
  return Convert.FromBase64String(s); // Standard base64 decoder
}
```

As per the example code above, the number of '=' padding characters that needs to be added to the end of a base64url encoded string without padding to turn it into one with padding is a deterministic function of the length of the encoded string. Specifically, if the length mod 4 is 0, no padding is added; if the length mod 4 is 2, two '=' padding characters are added; if the length mod 4 is 3, one '=' padding character is added; if the length mod 4 is 1, the input is malformed.

An example correspondence between unencoded and encoded values follows. The octet sequence below encodes into the string below, which when decoded, reproduces the octet sequence.
3 236 255 224 193
A-z_4ME

Appendix D. Possible Compact Serialization for Multiple Signatures

Appendix C of [JWE] suggests a possible compact serialization for JWEs with multiple recipients. This suggests a corresponding compact serialization for JWSs with multiple digital signatures and/or MACs. This possible compact serialization concatenates instances of the per-signature/MAC fields, separating them with tilde ('~')

characters, which are URL-safe.

The concatenation of the Encoded JWS Header values goes before the first period ('.') character in the compact serialization. The concatenation of the corresponding Encoded JWS Signature values goes after the second period ('.') character in the compact serialization.

A complete compact serialization of the multi-signature/MAC JWS in Section 7.1 (with line breaks for display purposes only) would be:

```
eyJhbGciOiJSUzI1NiJ9
~
eyJhbGciOiJFUzI1NiJ9
.
eyJpc3MiOiJqb2UiLA0KICJleHAiOjEzMDA4MTkzODAsDQogImh0dHA6Ly9leGF
tcGxlLmNvbS9pc19yb290Ijp0cnVlfQ
.
cC4hiUPoj9Eetdgtv3hF80EGrhuB__dzERat0XF9g2VtQgr9PJbu3XOiZj5RZ
mh7AAuHIm4Bh-0Qc_lF5YKt_O8W2Fp5jujGbds9uJdbF9CUAr7t1dnZcAcQjb
KBYNX4BAynRFdiuB--f_nZLgrnbyTyWzO75vRK5h6xBArLIARNPvkSjtQBMHl
b1L07Qe7K0GarZRmB_eSN9383LcOLn6_dO--xi12jzDwusC-eOkHWEsqtFZES
c6BfI7noOPqvhJ1phCnvWh6IeYI2w9QOYEUipUTI8np6LbgGY9Fs98rqVt5AX
LIhWkWywlVmtVrBp0igcN_IoypGlUPQGe77Rw
~
DtEhU3ljbEg8L38VWAfUAqOyKAM6-Xx-F4GawxaepmXFCgfTjDxw5djxLa8IS
lSApmWQxfKTUJqPP3-Kg6NU1Q
```

This representation is suggested for those who may desire or require a compact, URL-safe serialization of JWSs with multiple digital signatures and/or MACs. It is a suggestion to implementers for whom this functionality would be valuable, and not a normative part of this specification.

Appendix E. Acknowledgements

Solutions for signing JSON content were previously explored by Magic Signatures [MagicSignatures], JSON Simple Sign [JSS], and Canvas Applications [CanvasApp], all of which influenced this draft.

Thanks to Axel Nennker for his early implementation and feedback on the JWS and JWE specifications.

This specification is the work of the JOSE Working Group, which includes dozens of active and dedicated participants. In particular, the following individuals contributed ideas, feedback, and wording that influenced this specification:

Dirk Balfanz, Richard Barnes, Brian Campbell, Breno de Medeiros, Dick Hardt, Joe Hildebrand, Jeff Hodges, Edmund Jay, Yaron Y. Goland, Ben Laurie, James Manger, Tony Nadalin, Axel Nennker, John Panzer, Emmanuel Raviart, Eric Rescorla, Jim Schaad, Paul Tarjan, Hannes Tschofenig, and Sean Turner.

Jim Schaad and Karen O'Donoghue chaired the JOSE working group and Sean Turner and Stephen Farrell served as Security area directors during the creation of this specification.

Appendix F. Document History

[[to be removed by the RFC editor before publication as an RFC]]

-10

- Added an appendix suggesting a possible compact serialization for JWSs with multiple digital signatures and/or MACs.

-09

- Added JWS JSON Serialization, as specified by draft-jones-jose-jws-json-serialization-04.
- Registered "application/jws-js" MIME type and "JWS-JS" typ header parameter value.
- Defined that the default action for header parameters that are not understood is to ignore them unless specifically designated as "MUST be understood" or included in the new "crit" (critical) header parameter list. This addressed issue #6.
- Changed term "JWS Secured Input" to "JWS Signing Input".
- Changed from using the term "byte" to "octet" when referring to 8 bit values.
- Changed member name from "recipients" to "signatures" in the JWS JSON Serialization.
- Added complete values using the JWS Compact Serialization for all examples.

-08

- Applied editorial improvements suggested by Jeff Hodges and Hannes Tschofenig. Many of these simplified the terminology used.

- Clarified statements of the form "This header parameter is OPTIONAL" to "Use of this header parameter is OPTIONAL".

- Added a Header Parameter Usage Location(s) field to the IANA JSON Web Signature and Encryption Header Parameters registry.

- Added seriesInfo information to Internet Draft references.

-07

- Updated references.

-06

- Changed "x5c" (X.509 Certificate Chain) representation from being a single string to being an array of strings, each containing a single base64 encoded DER certificate value, representing elements of the certificate chain.

- Applied changes made by the RFC Editor to RFC 6749's registry language to this specification.

-05

- Added statement that "StringOrURI values are compared as case-sensitive strings with no transformations or canonicalizations applied".

- Indented artwork elements to better distinguish them from the body text.

-04

- Completed JSON Security Considerations section, including considerations about rejecting input with duplicate member names.

- Completed security considerations on the use of a SHA-1 hash when computing "x5t" (x.509 certificate thumbprint) values.

- Refer to the registries as the primary sources of defined values and then secondarily reference the sections defining the initial contents of the registries.

- Normatively reference XML DSIG 2.0 [W3C.CR-xmldsig-core2-20120124] for its security considerations.

- Added this language to Registration Templates: "This name is case sensitive. Names that match other registered names in a case

insensitive manner SHOULD NOT be accepted."

- Reference draft-jones-jose-jws-json-serialization instead of draft-jones-json-web-signature-json-serialization.

- Described additional open issues.

- Applied editorial suggestions.

-03

- Added the "cty" (content type) header parameter for declaring type information about the secured content, as opposed to the "typ" (type) header parameter, which declares type information about this object.

- Added "Collision Resistant Namespace" to the terminology section.

- Reference ITU.X690.1994 for DER encoding.

- Added an example JWS using ECDSA P-521 SHA-512. This has particular illustrative value because of the use of the 521 bit integers in the key and signature values. This is also an example in which the payload is not a base64url encoded JSON object.

- Added an example "x5c" value.

- No longer say "the UTF-8 representation of the JWS Secured Input (which is the same as the ASCII representation)". Just call it "the ASCII representation of the JWS Secured Input".

- Added Registration Template sections for defined registries.

- Added Registry Contents sections to populate registry values.

- Changed name of the JSON Web Signature and Encryption "typ" Values registry to be the JSON Web Signature and Encryption Type Values registry, since it is used for more than just values of the "typ" parameter.

- Moved registries JSON Web Signature and Encryption Header Parameters and JSON Web Signature and Encryption Type Values to the JWS specification.

- Numerous editorial improvements.

-02

- Clarified that it is an error when a "kid" value is included and no matching key is found.

- Removed assumption that "kid" (key ID) can only refer to an asymmetric key.

- Clarified that JWSs with duplicate Header Parameter Names MUST be rejected.

- Clarified the relationship between "typ" header parameter values and MIME types.

- Registered application/jws MIME type and "JWS" typ header parameter value.

- Simplified JWK terminology to get replace the "JWK Key Object" and "JWK Container Object" terms with simply "JSON Web Key (JWK)" and "JSON Web Key Set (JWK Set)" and to eliminate potential confusion between single keys and sets of keys. As part of this change, the Header Parameter Name for a public key value was changed from "jpk" (JSON Public Key) to "jwk" (JSON Web Key).

- Added suggestion on defining additional header parameters such as "x5t#S256" in the future for certificate thumbprints using hash algorithms other than SHA-1.

- Specify RFC 2818 server identity validation, rather than RFC 6125 (paralleling the same decision in the OAuth specs).

- Generalized language to refer to Message Authentication Codes (MACs) rather than Hash-based Message Authentication Codes (HMACs) unless in a context specific to HMAC algorithms.

- Reformatted to give each header parameter its own section heading.

-01

- Moved definition of Plaintext JWSs (using "alg":"none") here from the JWT specification since this functionality is likely to be useful in more contexts that just for JWTs.

- Added "jpk" and "x5c" header parameters for including JWK public keys and X.509 certificate chains directly in the header.

- Clarified that this specification is defining the JWS Compact Serialization. Referenced the new JWS-JS spec, which defines the JWS JSON Serialization.

- Added text "New header parameters should be introduced sparingly since an implementation that does not understand a parameter MUST reject the JWS".

- Clarified that the order of the creation and validation steps is not significant in cases where there are no dependencies between the inputs and outputs of the steps.

- Changed "no canonicalization is performed" to "no canonicalization need be performed".

- Corrected the Magic Signatures reference.

- Made other editorial improvements suggested by JOSE working group participants.

-00

- Created the initial IETF draft based upon draft-jones-json-web-signature-04 with no normative changes.

- Changed terminology to no longer call both digital signatures and HMACs "signatures".

Authors' Addresses

Michael B. Jones
Microsoft

Email: mbj@microsoft.com
URI: http://self-issued.info/

John Bradley
Ping Identity

Email: ve7jtb@ve7jtb.com

Nat Sakimura
Nomura Research Institute

Email: n-sakimura@nri.co.jp