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Internet-Draft	Microsoft
Intended status: Standards Track	J. Bradley
Expires: January 31, 2013	Ping Identity
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	July 30, 2012

JSON Web Signature (JWS)

draft-ietf-jose-json-web-signature-05

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.

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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 bytes.

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 cryptographically securing a JWS Header and a JWS Payload with a JWS Signature value.

JWS Header

A string representing a JSON object that describes the digital signature or MAC operation applied to create the JWS Signature value.

JWS Payload

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

JWS Signature

A byte array containing the cryptographic material that secures the JWS Header and the JWS Payload.

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 bytes of the UTF-8 **[RFC3629]** representation of the JWS Header.

Encoded JWS Payload

Base64url encoding of the JWS Payload.

Encoded JWS Signature

Base64url encoding of the JWS Signature.

JWS Secured 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 JSON object representing a JWS Header.

Header Parameter Value

The value of a member of the JSON object representing a 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 period ('.') characters.

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. The representation consists of three parts: the JWS Header, the JWS Payload, and the JWS Signature. In the Compact Serialization, the three parts are base64url-encoded for transmission, and represented as the concatenation of the encoded strings in that order, with the three strings being separated by period ('.') characters. (A JSON Serialization for this information is defined in the separate JSON Web Signature JSON Serialization (JWS-JS) [\[JWS-JS\]](#) specification.)

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

```
eyJpc3MiOiJqb2UiLA0KICJleHAiOiJleZMDA4MTkzODAsDQogImh0dHA6Ly9leGFt  
cGx1LmNvbS9pc19yb290Ijp0cnVlfQ
```

Computing the HMAC of the bytes of the ASCII [\[USASCII\]](#) representation of the JWS Secured 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_ww1gFWF0EjXk
```

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

```
eyJ0eXAiOiJKV1QiLA0KICJhbGciOiJIUzI1NiJ9  
.  
eyJpc3MiOiJqb2UiLA0KICJleHAiOiJleZMDA4MTkzODAsDQogImh0dHA6Ly9leGFt  
cGx1LmNvbS9pc19yb290Ijp0cnVlfQ  
.  
dBjftJeZ4CVP-mB92K27uhbUJU1p1r_ww1gFWF0EjXk
```

```
eyJpc3MiOiJqb2UiLA0KICJleHAiOjEzMDA4MTkzODAsDQogImh0dHA6Ly9leGFTcGx1LmNvbS9pc19yb290Ijp0cnV1fQ
```

```
.dBjftJeZ4CVP-mB92K27uhbUJU1p1r_wW1gFwF0EjXk
```

This computation is illustrated in more detail in [Appendix A.1](#).

4. JWS Header TOC

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 MUST understand the entire contents of the header; otherwise, the JWS MUST be rejected.

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 TOC

The following header parameter names are reserved with meanings as defined below. All the names are short because a core goal of JWSs is for the representations to be compact.

Additional reserved header parameter names MAY be defined via the IANA JSON Web Signature and Encryption Header Parameters registry [Section 7.1](#). 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 TOC

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 URI that contains a Collision Resistant Namespace. The `alg` value is a case sensitive string containing a StringOrURI value. This header parameter is REQUIRED.

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 is the values defined in Section 3.1 of the JSON Web Algorithms (JWA) [\[JWA\]](#) specification.

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

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 [\[RFC2818\]](#). This header parameter is OPTIONAL.

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

TOC

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

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

TOC

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 of the entity that digitally signed 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]**. This header parameter is OPTIONAL.

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

TOC

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. 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 7.1**.

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

TOC

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 values. Each value is a base64 encoded (**[RFC4648]** Section 4 - not base64url encoded) DER **[ITU.X690.1994]** PKIX certificate value. The certificate containing the public key of the entity that digitally signed 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. This header parameter is OPTIONAL.

See **Appendix B** for an example `x5c` value.

4.1.7. "kid" (Key ID) Header Parameter

TOC

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. This header parameter is OPTIONAL.

When used with a JWK, the `kid` value MAY be used to match a JWK `kid` parameter value.

4.1.8. "typ" (Type) Header Parameter

TOC

The `typ` (type) header parameter is used to declare the type of this object. The type value `JWS` MAY be used to indicate that this object is a JWS. The `typ` value is a case sensitive string. 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 7.2](#) or be a URI that contains a Collision Resistant Namespace.

4.1.9. "cty" (Content Type) Header Parameter

TOC

The `cty` (content type) header parameter is used to declare the type of the secured content (the Payload). The `cty` value is a case sensitive string. 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.

4.2. Public Header Parameter Names

TOC

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 7.1](#) or be a URI 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

TOC

A producer and consumer of a JWS may agree to any header parameter name that is not a Reserved Name [Section 4.1](#) or a Public Name [Section 4.2](#). Unlike Public Names, these private names are subject to collision and should be used with caution.

5. Rules for Creating and Validating a JWS

TOC

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 bytes 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 bytes 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. The JWS Secured Input is always 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 JSON 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, taken together, are the result. The 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 period ('.') characters.

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 three parts of the input (which are separated by period characters when using the JWS Compact Serialization) into the Encoded JWS Header, the Encoded JWS Payload, and the Encoded JWS Signature.
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.
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 Secured 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.

Processing a JWS inevitably requires comparing known strings to values in the header. 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 applied escaping to produce an array of Unicode code points.
2. **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.
3. Comparisons between the two strings **MUST** be performed as a Unicode code point to code point equality comparison.

6. Securing JWSs with Cryptographic Algorithms

TOC

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 and algorithm families.

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. IANA Considerations

TOC

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.

7.1. JSON Web Signature and Encryption Header Parameters Registry

TOC

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.

7.1.1. Registration Template

TOC

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.

Change Controller:

For standards-track RFCs, state "IETF". For others, give the name of the responsible party. Other details (e.g., postal address, e-mail address, home page URI) may also be included.

Specification Document(s):

Reference to the document that specifies the parameter, preferably including a URI that can be used to retrieve a copy of the document. An indication of the relevant sections may also be included, but is not required.

7.1.2. Initial Registry Contents

TOC

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

- Header Parameter Name: [alg](#)
- Change Controller: IETF
- Specification Document(s): **Section 4.1.1** of [[this document]]

- Header Parameter Name: [jku](#)
- Change Controller: IETF
- Specification Document(s): **Section 4.1.2** of [[this document]]

- Header Parameter Name: [jwk](#)
- Change Controller: IETF
- Specification document(s): **Section 4.1.3** of [[this document]]

- Header Parameter Name: `x5u`
- Change Controller: IETF
- Specification Document(s): **Section 4.1.4** of [[this document]]
- Header Parameter Name: `x5t`
- Change Controller: IETF
- Specification Document(s): **Section 4.1.5** of [[this document]]
- Header Parameter Name: `x5c`
- Change Controller: IETF
- Specification Document(s): **Section 4.1.6** of [[this document]]
- Header Parameter Name: `kid`
- Change Controller: IETF
- Specification Document(s): **Section 4.1.7** of [[this document]]
- Header Parameter Name: `typ`
- Change Controller: IETF
- Specification Document(s): **Section 4.1.8** of [[this document]]
- Header Parameter Name: `cty`
- Change Controller: IETF
- Specification Document(s): **Section 4.1.9** of [[this document]]

7.2. JSON Web Signature and Encryption Type Values Registry TOC

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.

7.2.1. Registration Template TOC

"`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, e-mail address, home page URI) may also be included.

Specification Document(s):

Reference to the document that specifies the parameter, preferably including a URI that can be used to retrieve a copy of the document. An indication of the relevant sections may also be included, but is not required.

7.2.2. Initial Registry Contents TOC

This specification registers the JWS type value 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]]

7.3. Media Type Registration

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7.3.1. Registry Contents

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This specification registers the `application/jws` Media Type [\[RFC2046\]](#) in the MIME Media Type registry [\[RFC4288\]](#) to indicate that the content is a JWS using the Compact 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 Browser ID, 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

8. Security Considerations

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8.1. Cryptographic Security Considerations

TOC

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 key, 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-xmlsig-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-xmlsig-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.

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.

8.2. JSON Security Considerations

TOC

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.

8.3. Unicode Comparison Security Considerations

TOC

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 MAY 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.

9. Open Issues

TOC

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

The following items remain to be considered or done in this draft:

- Should we define an optional nonce and/or timestamp header parameter? (Use of a nonce is an effective countermeasure to some kinds of attacks.)
- Some have objected to the language "Implementations MUST understand the entire contents of the header; otherwise, the JWS MUST be rejected" in this spec and the related language in the JWE, JWK, and JWT specs. Others believe that this is essential in a security specification.
- Finish the Security Considerations section.

TOC

10.1. Normative References

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10.2. Informative References

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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.1.1. Encoding

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

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

The following byte array 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 bytes yields this Encoded JWS Header value:

```
eyJ0eXAiOiJKV1QiLA0KICJhbGciOiJIUzI1NiJ9
```

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

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

The following byte array, 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  
cGx1LmNvbS9pc19yb290Ijp0cnV1fQ
```

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

```
eyJ0eXAiOiJKV1QiLA0KICJhbGciOiJIUzI1NiJ9  
.  
eyJpc3MiOiJqb2UiLA0KICJleHAiOjEzMDA4MTkzODAsDQogImh0dHA6Ly9leGFt  
cGx1LmNvbS9pc19yb290Ijp0cnV1fQ
```

The ASCII representation of the JWS Secured Input is the following byte array:

```
[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 byte array:

```
[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 bytes of the ASCII representation of the JWS Secured Input with this key yields the following byte array:

```
[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_wW1gFwF0EjXk
```

A.1.2. Decoding

TOC

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 byte arrays. The byte array containing the UTF-8 representation of the JWS Header is decoded into the JWS Header string.

A.1.3. Validating

TOC

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 Secured 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. JWS using RSA SHA-256

TOC

A.2.1. Encoding

TOC

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 byte array 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 bytes 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 Secured Input value (with line breaks for display purposes only):

```
eyJhbGciOiJSUzI1NiJ9  
.  
eyJpc3MiOiJqb2UiLA0KICJleHAiOjEzMDA4MTkzODAsDQogImh0dHA6Ly9leGFT  
cGx1LmNvbS9pc19yb290Ijp0cnV1fQ
```

The ASCII representation of the JWS Secured Input is the following byte array:

[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 byte arrays 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 bytes of the ASCII representation of the JWS Secured Input as inputs. The result of the digital signature is a byte array, 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__dzERat0XF9g2VtQgr9PJbu3X0iZj5RZmh7
AAuHIm4Bh-0Qc_lF5Ykt_08W2Fp5jujGbds9uJdbF9CUAr7t1dnZcAcQjbKBYNX4
BAynRFdiuB--f_nZLgrnbyTyWz075vRK5h6xBARLIARNPvkSjtQBMH1b1L07Qe7K
0GarZrMb_eSN9383Lc0Ln6_d0--xi12jzDwusC-e0kHWesqtFZEsc6BfI7no0Pqv
hJ1phCnvWh6IeYI2w9Q0YEUIpUTI8np6LbgGY9Fs98rqVt5AXLIhWkWyw1VmtVrB
p0igcN_IoypGlUPQGe77Rw
```

A.2.2. Decoding

TOC

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 byte arrays. The byte array containing the UTF-8 representation of the JWS Header is decoded into the JWS Header string.

A.2.3. Validating

TOC

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

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

TOC

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 byte array 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 bytes yields this Encoded JWS Header value:

```
eyJhbGciOiJIJFuzI1NiJ9
```

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 Secured Input value (with line breaks for display purposes only):

```
eyJhbGciOiJIJFuzI1NiJ9
.
eyJpc3MiOiJqb2UiLA0KICJleHAiOjEzMDA4MTkzODAsDQogImh0dHA6Ly9leGFT
cGx1LmNvbS9pc19yb290Ijpb0cnV1fQ
```

The ASCII representation of the JWS Secured Input is the following byte array:

```
[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 byte arrays 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 bytes of the ASCII representation of the JWS Secured 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 byte arrays 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):

```
DtEhU31jbEg8L38VwAfUAq0yKAM6-Xx-F4GawxaepmXFCgfTjDxw5djxLa8ISlSA  
pmWQxfKTUJqPP3-Kg6NU1Q
```

A.3.2. Decoding

TOC

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 byte arrays. The byte array containing the UTF-8 representation of the JWS Header is decoded into the JWS Header string.

A.3.3. Validating

TOC

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 byte array that must result into two 32 byte arrays, the first R and the second S. We then pass (x, y), (R, S) and the bytes of the ASCII representation of the JWS Secured 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. JWS using ECDSA P-521 SHA-512

TOC

A.4.1. Encoding

TOC

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 byte array 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 bytes yields this Encoded JWS Header value:

eyJhbGciOiJIJFuzUxMiJ9

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

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

Base64url encoding these bytes yields the Encoded JWS Payload value:

UGF5bG9hZA

Concatenating the Encoded JWS Header, a period character, and the Encoded JWS Payload yields this JWS Secured Input value:

eyJhbGciOiJIJFuzUxMiJ9.UGF5bG9hZA

The ASCII representation of the JWS Secured Input is the following byte array:

[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 byte arrays 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 bytes of the ASCII representation of the JWS Secured 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 byte arrays 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] [0, 111, 6, 105, 44, 5, 41, 208, 128, 61, 152, 40, 92, 61, 152, 4, 150, 66, 60, 69, 247, 196,


```
S 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_UxMi70cwnZ0YaRI1bKPWR0c-mZZq
wqT2SI-KGDkKB34X00aw_7XdtAG8GaSwFKdCAPZgoXD2YBJZCPEX3xKpRwcd008Kp
EHwJjyq0gzD07iKvU8vcnwNrmxYbSW9ERBXuk0Xo1Lze0_Jn
```

A.4.2. Decoding

TOC

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 byte arrays. The byte array containing the UTF-8 representation of the JWS Header is decoded into the JWS Header string.

A.4.3. Validating

TOC

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 byte array that must result into two 66 byte arrays, the first R and the second S. We then pass (x, y), (R, S) and the bytes of the ASCII representation of the JWS Secured 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

TOC

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

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

Base64url encoding the bytes 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):

```
eyJhbGciOiJIub251In0
.
eyJpc3MiOiJqb2UiLA0KICJleHAiOjEzMDA4MTkzODAsDQogImh0dHA6Ly9leGFt
cGx1LmNvbS9pc19yb290Ijpb0cnVlFQ
.
```

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

TOC

The string 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](#).

```
-----BEGIN CERTIFICATE-----
MIIE3jCCA8agAwIBAgICAwEwDQYJKoZIhvcNAQEFBQAwwYzELMAkGA1UEBhMCVVM
xITAFBgNVBAoTGFROZSBHbyBEYWRkeSBHcm91cCwgSW5jLjExMC8GA1UECXMOR2
8gRGFkZHZkgQ2xhc3MgMiBDZXJ0awZpY2F0aw9uIEF1dGhvcm10eTAeFw0wNjExM
TYwMTU0MzdaFw0yNjExMTYwMTU0MzdaMIHkMQswCQYDVQQGEwJVUzEQMA4GA1UE
CBMHQXJpem9uYTETMBEGA1UEBxMKU2NvdHRzZGFsZTEaMBGGA1UEChMRR29EYWR
keS5jb20sIEluYy4xMzAxMzAxMzAxMzAxMzAxMzAxMzAxMzAxMzAxMzAxMzAxMz
RkeS5jb20vcmluZW50aG9yaXR5MREwDwYDVQQFEwgnZk20TI4NzCCASIDQYJKo
ZIhvcNAQEBBQADgGEPADCCAQoCggEBAMQt1RWMnCMZ7DI161+4WQFapmGBWtt
wY6vj3D3HKRjJM9N55DrtpDAjhI6zMBs2sofDPZVUBJ7fmd0LJR4h3mUpfjwoqV
Tr9vcy0dQmVZwt7/v+WIBxnvQAjYwqDL1CBM6nPWT27oDyqu9SoWlm2r4arV3aL
GbgGmu75RpRSgAvSMeYddi5Kcju+GztCpyz8/x4fKL4o/K1w/05epHBp+Y1Lpyo
7RjLbmr2EkRTcDCVw5wrWCs9CHRK8r5RsL+H0EwnWGu1Ncwdrxcx+AuP7q2BNgW
JCjJp0q81h8BJ6qf9Z/dFjpfMFDniNow1fho3/Rb2cRGadDAW/h0Uoz+EDU8CAw
EAAa0CATIwggEuMBOGA1UdDgQWBbT9rGEyk2xF1uLuhV+auud2mWjM5zAfBgNVH
SMEGDAWgBTSxLDSkdRMEXGzYcs9of7dqGrU4zASBgNVHRMBAf8ECDAGAQH/AgEA
MDMGCCsGAQUFBwEBBCCwJTAjBggrBgEFBQcwAYYXaHR0cDovL29jc3AuZ29kYWR
keS5jb20wRgYDVROfBD8wPTA7oDmgN4Y1aHR0cDovL2N1cnRpm1jYXRlcy5nb2
RhZGR5LmNvbS9yZXBvc2l0b3J5L2dkcm9vdC5jcmwwSwYDVROgBEQWQjBAGBVRH
SAAMDgWNgYIKYWBQQUHAgEwKmh0dHA6Ly9jZXJ0awZpY2F0ZXMuZ29kYWRkeS5j
b20vcmluZW50aG9yaXR5TAOBGNVHQB8BAf8EBAMCAQYwDQYJKoZIhvcNAQEFBQAD
ggEBANKGw0y9+aG2Z+5mC6IG0gRQjhVyrEp0lVPLN8tESe8HkGsz2Zbw1Fa1EzAFPI
UyIXvJxwqoJKSQ3kbtJSMUA2fCENZvD117esyfxVgqwcSeIaha86ykRv0e5GPLL
5CkKSkB2XI5kD83ASe8T+5o0yGPwLPk9Qnt0hCqU7S+8MxZC9Y7lhyVJEnfzuz9
p0iRFEU00jZv2kWzRaJBydTXRE4+uXR21aITVSzGh601mawGhId/dQb8vxRMDsx
uxN89txJx90jxUUAiKEngHUuHqDTMBqLdElrRhjZkAzVvb3du6/KFUJheqWNTTrZ
EjYx8WnM25sgVjOuH0aBsXBTWVU+4=
-----END CERTIFICATE-----
-----BEGIN CERTIFICATE-----
MIIE+zCCBGsGawIBAgICAwEwDQYJKoZIhvcNAQEFBQAwwYzELMAkGA1UEBhMCVVM
xITAFBgNVBAoTGFROZSBHbyBEYWRkeSBHcm91cCwgSW5jLjExMC8GA1UECXMOR2
8gRGFkZHZkgQ2xhc3MgMiBDZXJ0awZpY2F0aw9uIEF1dGhvcm10eTAeFw0wNjExM
TYwMTU0MzdaFw0yNjExMTYwMTU0MzdaMIHkMQswCQYDVQQGEwJVUzEQMA4GA1UE
CBMHQXJpem9uYTETMBEGA1UEBxMKU2NvdHRzZGFsZTEaMBGGA1UEChMRR29EYWR
keS5jb20sIEluYy4xMzAxMzAxMzAxMzAxMzAxMzAxMzAxMzAxMzAxMzAxMzAxMz
RkeS5jb20vcmluZW50aG9yaXR5MREwDwYDVQQFEwgnZk20TI4NzCCASIDQYJKo
ZIhvcNAQEBBQADgGEPADCCAQoCggEBAMQt1RWMnCMZ7DI161+4WQFapmGBWtt
wY6vj3D3HKRjJM9N55DrtpDAjhI6zMBs2sofDPZVUBJ7fmd0LJR4h3mUpfjwoqV
Tr9vcy0dQmVZwt7/v+WIBxnvQAjYwqDL1CBM6nPWT27oDyqu9SoWlm2r4arV3aL
GbgGmu75RpRSgAvSMeYddi5Kcju+GztCpyz8/x4fKL4o/K1w/05epHBp+Y1Lpyo
7RjLbmr2EkRTcDCVw5wrWCs9CHRK8r5RsL+H0EwnWGu1Ncwdrxcx+AuP7q2BNgW
JCjJp0q81h8BJ6qf9Z/dFjpfMFDniNow1fho3/Rb2cRGadDAW/h0Uoz+EDU8CAw
EAAa0CATIwggEuMBOGA1UdDgQWBbT9rGEyk2xF1uLuhV+auud2mWjM5zAfBgNVH
SMEGDAWgBTSxLDSkdRMEXGzYcs9of7dqGrU4zASBgNVHRMBAf8ECDAGAQH/AgEA
MDMGCCsGAQUFBwEBBCCwJTAjBggrBgEFBQcwAYYXaHR0cDovL29jc3AuZ29kYWR
keS5jb20wRgYDVROfBD8wPTA7oDmgN4Y1aHR0cDovL2N1cnRpm1jYXRlcy5nb2
RhZGR5LmNvbS9yZXBvc2l0b3J5L2dkcm9vdC5jcmwwSwYDVROgBEQWQjBAGBVRH
SAAMDgWNgYIKYWBQQUHAgEwKmh0dHA6Ly9jZXJ0awZpY2F0ZXMuZ29kYWRkeS5j
b20vcmluZW50aG9yaXR5TAOBGNVHQB8BAf8EBAMCAQYwDQYJKoZIhvcNAQEFBQAD
ggEBANKGw0y9+aG2Z+5mC6IG0gRQjhVyrEp0lVPLN8tESe8HkGsz2Zbw1Fa1EzAFPI
UyIXvJxwqoJKSQ3kbtJSMUA2fCENZvD117esyfxVgqwcSeIaha86ykRv0e5GPLL
5CkKSkB2XI5kD83ASe8T+5o0yGPwLPk9Qnt0hCqU7S+8MxZC9Y7lhyVJEnfzuz9
p0iRFEU00jZv2kWzRaJBydTXRE4+uXR21aITVSzGh601mawGhId/dQb8vxRMDsx
uxN89txJx90jxUUAiKEngHUuHqDTMBqLdElrRhjZkAzVvb3du6/KFUJheqWNTTrZ
EjYx8WnM25sgVjOuH0aBsXBTWVU+4=
-----END CERTIFICATE-----
```

```
tXiEqITLdiOr18SPaAIBQI2XKVL0ARFmR6jYGB0xUGlcmIbYsUfb18aQr4CUWwo
riMYavx4A6lNf4DD+qta/KFApMoZfV6yy09ecw3ud72a9nmYvLEHZ6IVDd2gWMZ
Eewo+YihfukEHU1jPEX44dMX4/7Vpki+Ed0qXG68CAQ0jggHhMIIB3TAdBgNVHQ
4EFgQU0sSw0pHUTBFxs2HLPaH+3ahq10MwgdIGA1UdIwSByjCBx6GBwaSBvjCBu
zEkMCIGA1UEBxMbmVmFsaUNlcnQgVmFsaWRhdGlvbiB0ZXR3b3JrMRcwFQYDVQK
Ew5WYwXpQ2VydCwgSW5jLjE1MDMGA1UECXMsVmFsaUNlcnQgQ2xhc3MgMiBQb2x
pY3kgVmFsaWRhdGlvbiBBdXRob3JpdHkxITAFBgNVBAMTGh0dHA6Ly93d3cudm
FsaWNlcnQuY29tLzEgMB4GCSqGSIB3DQEJARYRaW5mb0B2YwXpY2VydC5jb22CA
QEWdWYDVR0TAQH/BAUwAwEB/zAzBggrBgEFBQcBAQQnMCUwIwYIKwYBBQUHMAGG
F2h0dHA6Ly9vY3NwLmdvZGFkZHKuY29tMEQGA1UdHwQ9MDsw0aA3oDWGM2h0dHA
6Ly9jZXJ0aWZpY2F0ZXMuZ29kYWRkeS5jb20vcmlvbn3NpdG9yeS9yb290LmNybD
BLBgNVHSAERDBCMEAGBFudIAAwODA2BggrBgEFBQcCARYqaHR0cDovL2NlcnRpZ
mljYXRlcY5nb2RhZGR5LmNvbS9yZXBvc210b3J5MA4GA1UdDwEB/wQEAWIBBJAN
BgkqhkiG9w0BAQUFAA0BgQC1QPMnHfbq/qQaQ1pE9xXUuUaJwL6e4+PrxeNYiY+
Sn1eocSxIOYGYeR+sBjUZsE40WBSUs5iB0QQeyAfJg594RAoYC5jcdnp1DQ1tgM
QLARzLrUc+cb53S8wGd9D0VmsfSx0aFIqII6hR8INMqzW/Rn453HWkrugp++85j
09VZw==
```

-----END CERTIFICATE-----

-----BEGIN CERTIFICATE-----

```
MIIC5zCCALACAQEwDQYJKoZIhvcNAQEFBQAwwgsxJDAiBgNVBACGTG1ZhbG1DZXJ
0IFZhbG1kYXRpb24gTmV0d29yazEXMBUGA1UEChMOVmFsaUNlcnQsIEluYy4xNT
AzBgNVBAsTLFZhbG1DZXJ0IENsYXNzIDIGUG9saWN5IFZhbG1kYXRpb24gQXV0a
G9yaXR5MSEwHwYDVQDEExodHRwOi8vd3d3LnZhbG1jZXJ0LmNvbS8xIDAeBgkq
hkiG9w0BCQEWELuZm9AdmFsaWNlcnQuY29tMB4XDTk5MDYyNjAwMTk1NFoXDTE
5MDYyNjAwMTk1NFowgsxJDAiBgNVBACGTG1ZhbG1DZXJ0IFZhbG1kYXRpb24gTm
V0d29yazEXMBUGA1UEChMOVmFsaUNlcnQsIEluYy4xNTAzBgNVBAsTLFZhbG1DZ
XJ0IENsYXNzIDIGUG9saWN5IFZhbG1kYXRpb24gQXV0aG9yaXR5MSEwHwYDVQDE
ExodHRwOi8vd3d3LnZhbG1jZXJ0LmNvbS8xIDAeBgkqhkiG9w0BCQEWELuZm9
AdmFsaWNlcnQuY29tMIGfMA0GCSqGSIB3DQEBAQUAA4GNADCBiQKBgQD00nHK5a
vIWZJV16vYdA757tn2VUdZZUc0BVXc65g2PFxTXdMwzzjSVUGJ7SVCCSRrCl6zf
N1SLUzm1NZ9WlmpZdRJEy0kTRxQb7XBhVQ7/nHk01xC+YDgkRoKwzk2Z/M/VXwb
P7RfZHM047Qsv4dk+NoS/zcnwbNDu+97bi5p9wIDAQABMA0GCSqGSIB3DQEBBQU
AA4GBADt/UG9vUJSZSWI40B9L+KXIPqeCgfYrx+jFzug6EILLGACOTb2oWH+heQ
C1u+mNr0HZDzTuIYEZoDJJKPTEjlbVUjP9UNV+mWwD5M1M/Mtsq2azSiGM5bUMM
j4QssxsodyamEwCW/P0uZ6lcg5Ktz885hZo+L7tdEy8W9ViH0Pd
```

-----END CERTIFICATE-----

Appendix C. Notes on implementing base64url encoding without padding

TOC

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); // Standard 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 byte sequence below encodes into the string below, which when decoded, reproduces the byte sequence.

3 236 255 224 193

A-z_4ME

Appendix D. Acknowledgements

TOC

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. Dirk Balfanz, Yaron Y. Goland, John Panzer, and Paul Tarjan all made significant contributions to the design of this specification.

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

Appendix E. Document History

TOC

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

-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-xmlsig-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".

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