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Public Key Pinning Extension for HTTP
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Abstract

This memo describes an extension to the HTTP protocol allowing web host operators to instruct user agents (UAs) to remember ("pin") the hosts' cryptographic identities for a given period of time. During that time, UAs will require that the host present a certificate chain including at least one Subject Public Key Info structure whose fingerprint matches one of the pinned fingerprints for that host. By effectively reducing the number of authorities who can authenticate the domain during the lifetime of the pin, pinning may reduce the incidence of man-in-the-middle attacks due to compromised Certification Authorities.

Status of this Memo

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

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This Internet-Draft will expire on June 10, 2013.

Table of Contents

1. Introduction

We propose a new HTTP header to enable a web host to express to user agents (UAs) which Subject Public Key Info (SPKI) structure(s) UAs SHOULD expect to be present in the host's certificate chain in future connections using TLS (see [RFC5246]). We call this "public key pinning". At least one UA (Google Chrome) has experimented with shipping with a user-extensible embedded set of pins. Although effective, this does not scale. This proposal addresses the scale problem.

Deploying public key pinning safely will require operational and organizational maturity due to the risk that hosts may make themselves unavailable by pinning to a SPKI that becomes invalid. (See Section 4.) We believe that, with care, host operators can greatly reduce the risk of MITM attacks and other false-authentication problems for their users without incurring undue risk.

We intend for hosts to use public key pinning together with HSTS ([RFC6797]), but is possible to pin keys without requiring HSTS.

This draft is being discussed on the WebSec Working Group mailing list, websec@ietf.org.

1.1. Requirements Language

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 RFC 2119 [RFC2119].

2. Server and Client Behavior

2.1. Response Header Field Syntax

The Public-Key-Pins HTTP response header field (PKP header field) indicates to a UA that it SHOULD perform Pin Validation (Section 2.6) in regards to the host emitting the response message containing this header field, and provides the necessary information for the UA to do so.

Figure 1 describes the ABNF (Augmented Backus-Naur Form) syntax of the header field. It is based on the Generic Grammar defined in Section 2 of [RFC2616] (which includes a notion of "implied linear whitespace", also known as "implied *LWS").

```
Public-Key-Pins =
    "Public-Key-Pins" ":" [ directive ] *( ";" [ directive ] )
Public-Key-Pins-Report-Only =
    "Public-Key-Pins-Report-Only" ":" [ directive ] *( ";" [ directive ] )

directive        = simple-directive
                 / pin-directive

simple-directive = directive-name [ "=" directive-value ]
directive-name   = token
directive-value  = token
                 / quoted-string

pin-directive    = "pin-" token "=" quoted-string
```

Figure 1: HPKP Header Syntax

token and quoted-string are used as defined in [RFC2616], Section 2.2.

The directives defined in this specification are described below. The overall requirements for directives are:

1. The order of appearance of directives is not significant.

2. All simple-directives MUST appear only once in a PKP header field. Directives are either optional or required, as stipulated in their definitions.

3. Directive names are case-insensitive.

4. UAs MUST ignore any PKP header fields containing directives, or other header field value data, that do not conform to the syntax defined in this specification.

5. If a PKP header field contains any directive(s) the UA does not recognize, the UA MUST ignore the those directives.

6. If the PKP header field otherwise satisfies the above requirements (1 through 5), the UA MUST process the directives it recognizes.

Additional directives extending the semantic functionality of the PKP header field can be defined in other specifications, with a registry (having an IANA policy definition of IETF Review [RFC2616]) defined for them at such time. Such future directives will be ignored by UAs implementing only this specification, as well as by generally non-conforming UAs.

In the pin-directive, the token is the name of a cryptographic hash algorithm, and MUST be either "sha1" or "sha256". The quoted-string is a sequence of base 64 digits: the base 64-encoded SPKI Fingerprint. See Section 2.4.

2.1.1. The max-age Directive

The REQUIRED "max-age" directive specifies the number of seconds, after the reception of the PKP header field, during which the UA SHOULD regard the host (from whom the message was received) as a Known Pinned Host. The delta-seconds production is specified in [RFC2616].

The syntax of the max-age directive's REQUIRED value (after quoted-string unescaping, if necessary) is defined as:

```
max-age-value = delta-seconds
delta-seconds = 1*DIGIT
```

Figure 2: max-age Value Syntax

delta-seconds is used as defined in [RFC2616], Section 3.3.2.

NOTE: A max-age value of zero (i.e., "max-age=0") signals the UA to cease regarding the host as a Known Pinned Host, including the includeSubDomains directive (if asserted for that Known Pinned Host). See Section 2.3.1.

2.1.2. The includeSubDomains Directive

The OPTIONAL "includeSubDomains" directive is a valueless directive which, if present (i.e., it is "asserted"), signals to the UA that the Pinning Policy applies to this Pinned Host as well as any subdomains of the host's domain name.

2.1.3. The report-uri Directive

The OPTIONAL "report-uri" directive indicates the URI to which the UA SHOULD report Pin Validation failures (Section 2.6). The UA POSTs the reports to the given URI as described in Section 3.

TODO: Describe the meaning of Public-Key-Pins-Report-Only and the interaction between it and report-uri. In particular, describe how it is possible to be in enforcement mode (i.e. not -Report-Only) and still POST reports to the report-uri.

2.1.4. The strict Directive

The OPTIONAL "strict" directive is a valueless directive which, if present (i.e., it is "asserted"), signals to the UA that the Pinning Policy contained should be applied to the Pinned Host exactly as specified, ignoring local client policy.

2.1.5. Examples

Figure 3 shows some example response header fields using the pins extension (folded for clarity).

```
Public-Key-Pins: max-age=500;
    pin-sha1="4n972HfV354KP560yw4uqe/baXc=";
    pin-sha1="IvGeLsbqzPxdI0b0wuj2xVTdXgc="

Public-Key-Pins: max-age=31536000;
    pin-sha1="4n972HfV354KP560yw4uqe/baXc=";
    pin-sha256="LPJNul+wow4m6DsqxbninhsWHlwfp0JecwQzYpOLmCQ="

Public-Key-Pins: pin-sha1="4n972HfV354KP560yw4uqe/baXc=";
    pin-sha1="qvTGHdzF6KLavt4PO0gs2a6pQ00=";
    pin-sha256="LPJNul+wow4m6DsqxbninhsWHlwfp0JecwQzYpOLmCQ=";
    max-age=2592000

Public-Key-Pins: pin-sha1="4n972HfV354KP560yw4uqe/baXc=";
    pin-sha1="qvTGHdzF6KLavt4PO0gs2a6pQ00=";
    pin-sha256="LPJNul+wow4m6DsqxbninhsWHlwfp0JecwQzYpOLmCQ=";
    max-age=2592000; includeSubDomains
```

Figure 3: HPKP Header Examples

2.2. Server Processing Model

This section describes the processing model that Pinned Hosts implement. The model comprises two facets: the processing rules for HTTP request messages received over a secure transport (e.g. TLS [RFC5246]); and the processing rules for HTTP request messages received over non-secure transports, such as TCP.

2.2.1. HTTP-over-Secure-Transport Request Type

When replying to an HTTP request that was conveyed over a secure transport, a Pinned Host SHOULD include in its response exactly one PKP header field that MUST satisfy the grammar specified above in Section 2.1. If the Pinned Host does not include the PKP header field, and if the connection passed Pin Validation, UAs MUST treat the host as if it had set its max-age to 0 (see Section 2.3.1).

Establishing a given host as a Known Pinned Host, in the context of a given UA, MAY be accomplished over the HTTP protocol, which is in turn running over secure transport, by correctly returning (per this specification) at least one valid PKP header field to the UA. Other mechanisms, such as a client-side pre-loaded Known Pinned Host list MAY also be used.

2.2.2. HTTP Request Type

Pinned Hosts SHOULD NOT include the PKP header field in HTTP responses conveyed over non-secure transport. UAs MUST ignore any PKP header received in an HTTP response conveyed over non-secure transport.

2.3. User Agent Processing Model

This section describes the HTTP Public Key Pinning processing model for UAs.

TODO: Add a note referring to the HSTS RFC's discussion of IDNs.

2.3.1. Public-Key-Pins Response Header Field Processing

If the UA receives, over a secure transport, an HTTP response that includes a PKP header field conforming to the grammar specified in Section 2.1, and there are no underlying secure transport errors or warnings (see Section 2.5), the UA MUST either:

- Note the host as a Known HSTS Host if it is not already so noted (see Section 2.3.2),

or,

- Update the UA's cached information for the Known Pinned Host if any of of the max-age, includeSubDomains, strict, or report-uri header field value directives convey information different than that already maintained by the UA.

- The max-age value is essentially a "time to live" value relative to the time of the most recent observation of the PKP header field.

- If the max-age header field value token has a value of 0, the UA MUST remove its cached Pinning Policy information (including the includeSubDomains and strict directives, if asserted) if the Pinned Host is Known, or, MUST NOT note this Pinned Host if it is not yet Known.

- If a UA receives more than one PKP header field in an HTTP response message over secure transport, then the UA MUST process only the first such header field.

Otherwise:

- If the UA receives the HTTP response over insecure transport, or if the PKP header is not a Valid Pinning Header (see Section 2.5), the UA MUST ignore any present PKP header field(s).

- The UA MUST ignore any PKP header fields not conforming to the grammar specified in Section 2.1.

2.3.2. Noting a Pinned Host - Storage Model

If the substring matching the host production from the Request-URI (of the message to which the host responded) syntactically matches the IP-literal or IPv4address productions from Section 3.2.2 of [RFC3986], then the UA MUST NOT note this host as a Known Pinned Host.

Otherwise, if the substring does not congruently match a Known Pinned Host's domain name, per the matching procedure specified in Section 8.2 of [RFC6797], then the UA MUST note this host as a Known Pinned Host, caching the Pinned Host's domain name and noting along with it the expiry time of this information, as effectively stipulated per the given max-age value, as well as whether or not the includeSubDomains or strict directives are asserted, the value of the report-uri directive (if present), and any other metadata from optional or future PKP header directives.

The UA MUST NOT modify the expiry time nor the includeSubDomains directive of any superdomain matched Known Pinned Host.

A Known Pinned Host is "expired" if its cache entry has an expiry date in the past. The UA MUST evict all expired Known Pinned Hosts from its cache, if at any time, an expired Known Pinned Host exists in the cache.

2.3.3. HTTP-Equiv <Meta> Element Attribute

UAs MUST NOT heed http-equiv="Public-Key-Pins" attribute settings on <meta> elements [W3C.REC-html401-19991224] in received content.

2.3.4. UA Processing Examples

TODO.

2.4. Semantics of Pins

An SPKI Fingerprint is defined as the output of a known cryptographic hash algorithm whose input is the DER-encoded ASN.1 representation of the SubjectPublicKeyInfo (SPKI) field of an X.509 certificate. A Pin is defined as the combination of the known algorithm identifier and the SPKI Fingerprint computed using that algorithm.

The SPKI Fingerprint is encoded in base 64 for use in an HTTP header. (See [RFC4648].)

In this version of the specification, the known cryptographic hash algorithms are SHA-1, identified as "sha1", and SHA-256, identified as "sha256". (Future versions of this specification may add new algorithms and deprecate old ones.) UAs MUST ignore Pins for which they do not recognize the algorithm identifier. UAs MUST continue to process the rest of a PKP response header field and note Pins for algorithms they do recognize; UAs MUST recognize "sha1" and "sha256".

Figure 4 reproduces the definition of the SubjectPublicKeyInfo structure in [RFC5280].

```
SubjectPublicKeyInfo  ::=  SEQUENCE  {
    algorithm            AlgorithmIdentifier,
    subjectPublicKey     BIT STRING  }

AlgorithmIdentifier  ::=  SEQUENCE  {
    algorithm            OBJECT IDENTIFIER,
    parameters           ANY DEFINED BY algorithm OPTIONAL  }
```

Figure 4: SPKI Definition

If the SubjectPublicKeyInfo of a certificate is incomplete when taken in isolation, such as when holding a DSA key without domain parameters, a public key pin cannot be formed.

We pin public keys, rather than entire certificates, to enable operators to generate new certificates containing old public keys (see [why-pin-key]).

See Appendix A for an example non-normative program that generates SPKI Fingerprints from SubjectPublicKeyInfo fields in certificates.

2.5. Noting Pins

Upon receipt of the Public-Key-Pins response header field, the UA notes the host as a Pinned Host, storing the Pins and their associated directives in non-volatile storage (for example, along

with the HSTS metadata). The Pins and their associated directives collectively known as Pinning Metadata.

The UA MUST observe these conditions when noting a Host:

- The UA MUST note the Pins if and only if it received the Public-Key-Pins response header field over an error-free TLS connection. If the host is a Pinned Host, this includes the validation added in Section 2.6.

- The UA MUST note the Pins if and only if the TLS connection was authenticated with a certificate chain containing at least one of the SPKI structures indicated by at least one of the given SPKI Fingerprints. (See Section 2.6.)

- The UA MUST note the Pins if and only if the given set of Pins contains at least one Pin that does NOT refer to an SPKI in the certificate chain. (That is, the host must set a Backup Pin; see Section 4.1.)

If the Public-Key-Pins response header field does not meet all three of these criteria, the UA MUST NOT note the host as a Pinned Host. A Public-Key-Pins response header field that meets all these critera is known as a Valid Pinning Header.

The UA MUST ignore Public-Key-Pins response header fields received on connections that do not meet the first criterion.

TODO: Consider whether or not this requirement makes sense: If the UA receives a Public-Key-Pins header from a Pinned Host that meets the first criterion, but not the following two, the UA MUST discard any previously set Pinning Metadata for that host in its non-volatile store. Whether or not the Known Pinned Host is in strict mode, should the UA note new pins when Pin Validation is disabled per local policy?

Whenever a UA receives a Valid Pinning Header, it MUST set its Pinning Metadata to the exact Pins, max-age, and (if any) report-uri and strict mode given in the most recently received Valid Pinning Header.

For forward compatibility, the UA MUST ignore any unrecognized Public-Key-Pins header directives, while still processing those directives it does recognize. Section 2.1 specifies the directives max-age, pins, includeSubDomains, report-uri, and strict, but future specifications and implementations might use additional directives.

2.6. Validating Pinned Connections

When a UA connects to a Pinned Host, if the TLS connection has errors, the UA MUST terminate the connection without allowing the user to proceed anyway. (This behavior is the same as that required by [RFC6797].)

If the connection has no errors, then the UA will determine whether to apply a new, additional correctness check: Pin Validation. A UA SHOULD perform Pin Validation whenever connecting to a Known Pinned Host, but MAY allow Pin Validation to be disabled for Hosts according to local policy. For example, a UA may disable Pin Validation for Pinned Hosts whose validated certificate chain terminates at a user-defined trust anchor, rather than a trust anchor built-in to the UA. However, if the Pinned Host Metadata indicates that the Pinned Host is operating in "strict mode" (see Section 2.1.4), then the UA MUST perform Pin Validation.

To perform Pin Validation, the UA will compute the SPKI Fingerprints for each certificate in the Pinned Host's validated certificate chain, using each supported hash algorithm for each certificate. (For the purposes of Pin Validation, the UA MUST ignore certificates whose SPKI cannot be taken in isolation and superfluous certificates in the chain that do not form part of the validating chain.) The UA will then check that the set of these SPKI Fingerprints intersects the set of SPKI Fingerprints in that Pinned Host's Pinning Metadata. If there is set intersection, the UA continues with the connection as normal. Otherwise, the UA MUST treat this Pin Failure as a non-recoverable error. Any procedure that matches the results of this Pin Validation procedure is considered equivalent.

Note that, although the UA has previously received Pins at the HTTP layer, it can and MUST perform Pin Validation at the TLS layer, before beginning an HTTP conversation over the TLS channel. The TLS layer thus evaluates TLS connections with pinning information the UA received previously, regardless of mechanism: statically preloaded, via HTTP header, or some other means (possibly in the TLS layer itself).

2.7. Interactions With Preloaded Pin Lists

UAs MAY choose to implement built-in public key pins, alongside any built-in HSTS opt-in list. UAs MUST allow users to override a built-in pin list, including turning it off.

UAs MUST use the newest information -- built-in or set via Valid Pinning Header -- when performing Pin Validation for the host. If the result of noting a Valid Pinning Header is to disable pinning for

the host (such as because the host set a max-age directive with a value of 0), UAs MUST allow this new information to override any built-in pins. That is, a host must be able to un-pin itself even from built-in pins.

2.8. Pinning Self-Signed End Entities

If UAs accept hosts that authenticate themselves with self-signed end entity certificates, they MAY also allow hosts to pin the public keys in such certificates. The usability and security implications of this practice are outside the scope of this specification.

3. Reporting Pin Validation Failure

When a Known Pinned Host has set the report-uri directive, the UA SHOULD report Pin Validation failures to the indicated URI. The UA does this by POSTing a JSON message to the URI; the JSON message takes this form:

```
{
  "date-time": date-time,
  "hostname": hostname,
  "port": port,
  "certificate-chain": [
    pem1, ... pemN
  ],
  "known-pins": [
    known-pin1, ... known-pinN
  ]
}
```

Figure 5: JSON Report Format

Whitespace outside of quoted strings is not significant. The key/value pairs may appear in any order, but each SHOULD appear only once.

The date-time indicates the time the UA observed the Pin Validation failure. It is provided as a string formatted according to Section 5.6, "Internet Date/Time Format", of [RFC3339].

The hostname is the hostname to which the UA made the original request that failed Pin Validation. It is provided as a string.

The port is the port to which the UA made the original request that failed Pin Validation. It is provided either as a string or as an integer.

The certificate-chain is the certificate chain, as constructed by the UA during certificate chain verification. (This may differ from the certificate chain as served by the Known Pinned Host, of course.) It is provided as an array of strings; each string pem1, ... pemN is the PEM representation of each X.509 certificate as described in [I-D.josefsson-pkix-textual].

The known-pins are the Pins that the UA has noted for the Known Pinned Host. They are provided as an array of strings with the syntax:

```
known-pin = token "=" quoted-string
```

Figure 6: Known Pin Syntax

As in Section 2.4, the token refers to the algorithm name, and the quoted-string refers to the base 64 encoding of the SPKI Fingerprint.

4. Security Considerations

Pinning public keys helps hosts strongly assert their cryptographic identity even in the face of issuer error, malfeasance or compromise. But there is some risk that a host operator could lose or lose control of their host's private key (such as by operator error or host compromise). If the operator had pinned only the key of the host's end entity certificate, the operator would not be able to serve their web site or application in a way that UAs would trust for the duration of their pin's max-age. (Recall that UAs MUST close the connection to a host upon Pin Failure.)

Therefore, there is a necessary trade-off between two competing goods: pin specificity and maximal reduction of the scope of issuers on the one hand; and flexibility and resilience of the host's cryptographic identity on the other hand. One way to resolve this trade-off is to compromise by pinning to the key(s) of the issuer(s) of the host's end entity certificate(s). Often, a valid certificate chain will have at least two certificates above the end entity certificate: the intermediate issuer, and the trust anchor. Operators can pin any one or more of the public keys in this chain, and indeed could pin to issuers not in the chain (as, for example, a Backup Pin). Pinning to an intermediate issuer, or even to a trust anchor or root, still significantly reduces the number of issuers who can issue end entity certificates for the Known Pinned Host, while still giving that host flexibility to change keys without a disruption of service.

4.1. Backup Pins

The primary way to cope with the risk of inadvertant Pin Failure is to keep a Backup Pin. A Backup Pin is a fingerprint for the public key of a secondary, not-yet-deployed key pair. The operator keeps the backup key pair offline, and sets a pin for it in the Public-Key-Pins header. Then, in case the operator loses control of their primary private key, they can deploy the backup key pair. UAs, who have had the backup key pair pinned (when it was set in previous Valid Pinning Headers), can connect to the host without error.

Because having a backup key pair is so important to recovery, UAs MUST require that hosts set a Backup Pin. (See Section 2.5.)

5. IANA Considerations

This document has no actions for IANA.

6. Usability Considerations

When pinning works to detect impostor Pinned Hosts, users will experience denial of service. UAs MUST explain the reason why, i.e. that it was impossible to verify the confirmed cryptographic identity of the host.

UAs MUST have a way for users to clear current pins for Pinned Hosts. UAs SHOULD have a way for users to query the current state of Pinned Hosts.

7. Acknowledgements

Thanks to Tobias Gondrom, Jeff Hodges, Adam Langley, Nicolas Lidzborski, SM, James Manger, and Yoav Nir for suggestions and edits that clarified the text. Thanks to Trevor Perrin for suggesting a mechanism to affirmatively break pins ([pin-break-codes]). Adam Langley provided the SPKI fingerprint generation code.

8. What's Changed

Removed the section "Pin Validity Times", which was intended to be in harmony with [I-D.perrin-tls-tack]. Now using max-age purely as specified in [RFC6797].

Added new directives: includeSubDomains, report-uri and strict.

Added, but have not yet described, a new variant of the PKP Header: Public-Key-Pins-Report-Only.

Removed the section on pin break codes and verifiers, in favor the of most-recently-received policy (Section 2.5).

Now using a new header field, Public-Key-Pins, separate from HSTS. This allows hosts to use pinning separately from Strict Transport Security.

Explicitly requiring that UAs perform Pin Validation before the HTTP conversation begins.

Backup Pins are now required.

Separated normative from non-normative material. Removed tangential and out-of-scope non-normative discussion.

9. References

9.1. Normative References

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9.2. Informative References

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[why-pin-key] Langley, A., "Public Key Pinning", May 2011, <http://www.imperialviolet.org/2011/05/04/pinning.html>.

Appendix A. Fingerprint Generation

This Go program generates SPKI Fingerprints, suitable for use in pinning, from PEM-encoded certificates. It is non-normative.

```
package main

import (
        "io/ioutil"
        "os"
        "crypto/sha1"
        "crypto/x509"
        "encoding/base64"
        "encoding/pem"
        "fmt"
)

func main() {
        if len(os.Args) < 2 {
                fmt.Printf("Usage: %s PEM-filename\n", os.Args[0])
                os.Exit(1)
        }
        pemBytes, err := ioutil.ReadFile(os.Args[1])
        if err != nil {
                panic(err.String())
        }
        block, _ := pem.Decode(pemBytes)
        if block == nil {
                panic("No PEM structure found")
        }
        derBytes := block.Bytes
        certs, err := x509.ParseCertificates(derBytes)
        if err != nil {
                panic(err.String())
        }
        cert := certs[0]
        h := sha1.New()
        h.Write(cert.RawSubjectPublicKeyInfo)
        digest := h.Sum()

        fmt.Printf("Hex: %x\nBase64: %s\n", digest,
                base64.StdEncoding.EncodeToString(digest))
}
```

Figure 7: Example SPKI Fingerprint Generation Code

Appendix B. Deployment Guidance

This section is non-normative guidance which may smooth the adoption of public key pinning.

- Operators SHOULD get the backup public key signed by a different (root and/or intermediary) CA than their primary certificate, and store the backup key pair safely offline. The semantics of an SPKI Fingerprint do not require the issuance of a certificate to construct a valid Pin. However, in many deployment scenarios, in order to make a Backup Pin operational the server operator will need to have a certificate to deploy TLS on the host. Failure to obtain a certificate through prior arrangement will leave clients that recognize the site as a Known Pinned Host unable to successfully perform Pin Validation until such a time as the operator can obtain a new certificate from their desired certificate issuer.

- It is most economical to have the backup certificate signed by a completely different signature chain than the live certificate, to maximize recoverability in the event of either root or intermediary signer compromise.

- Operators SHOULD periodically exercise their Backup Pin plan -- an untested backup is no backup at all.

- Operators SHOULD start small. Operators SHOULD first deploy public key pinning by using the report-only mode together with a report-uri directive that points to a reliable report collection endpoint. When moving out of report-only mode, operators should start by setting a max-age of minutes or a few hours, and gradually increase max-age as they gain confidence in their operational capability.

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