Mutual Authentication Protocol for HTTP: KAM3-based Cryptographic Algorithms
draft-ietf-httpauth-mutual-algo-03

Abstract

This document specifies some cryptographic algorithms which will be used for the Mutual user authentication method for the Hyper-text Transport Protocol (HTTP).

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1. Introduction

This document specifies some algorithms for Mutual authentication protocol for Hyper-Text Transport Protocol (HTTP) [I-D.ietf-httpauth-mutual]. The algorithms are based on so-called "Augmented Password-based Authenticated Key Exchange" (Augmented PAKE) techniques. In particular, it uses one of three key exchange algorithm defined in the ISO 11770-4: "Key management - Mechanisms based on weak secrets" [ISO.11770-4.2006] as a basis.

In very brief summary, the Mutual authentication protocol exchanges four values, \(K_{c1}, K_{s1}, VK_c\) and \(VK_s\), to perform authenticated key exchanges, using the password-derived secret \(pi\) and its "augmented version" \(J(pi)\). This document defines the set of functions \(K_{c1}, K_{s1}, J\) for a specific algorithm family.

Please note that, from the view of cryptographic literature, the original functionality of Augmented PAKE is separated into the functions \(K_{c1}\) and \(K_{s1}\) defined in this draft, and the functions \(VK_c\) and \(VK_s\) defined in Section 11 of [I-D.ietf-httpauth-mutual] as "default functions". For the purpose of security analysis, please also refer to these functions.
1.1. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

The term "natural numbers" refers to the non-negative integers (including zero) throughout this document.

This document treats target (codomain) of hash functions to be octet strings. The notation INT(H(s)) gives a natural-number output of hash function H applied to string s.

2. Cryptographic Overview (Non-normative)

The cryptographic primitive used in this algorithm specification is based on a variant of augmented PAKE proposed by T. Kwon, called APKAS-AMP, originally submitted to IEEE P1363.2. The general flow of the successful exchange is shown below, for informative purposes only. The DL-based notations are used, and all group operations (mod q and mod r) are omitted.

Note that the only messages corresponding to the earlier two exchanges are defined in this specification. Those for latter two exchanges are defined in the main specification [I-D.ietf-httpauth-mutual].

3. Authentication Algorithms

This document specifies only one family of the authentication algorithm. The family consists of four authentication algorithms, which only differ in their underlying mathematical groups and security parameters. The algorithms do not add any additional parameters. The tokens for these algorithms are
For discrete-logarithm settings, the underlying groups are the 2048-bit and 4096-bit MODP groups defined in [RFC3526], respectively. See Appendix A for the exact specifications of the groups and associated parameters. The hash functions H are SHA-256 for the 2048-bit group and SHA-512 for the 4096-bit group, respectively, defined in FIPS PUB 180-2 [FIPS.180-2.2002]. The hash iteration count nIterPi is 16384. The representation of the parameters kc1, ks1, vkc, and vks is base64-fixed-number.

For the elliptic-curve settings, the underlying groups are the elliptic curves over the prime fields P-256 and P-521, respectively, specified in the appendix D.1.2 of FIPS PUB 186-4 [FIPS.186-4.2013] specification. The hash functions H, which are referenced by the core document, are SHA-256 for the P-256 curve and SHA-512 for the P-521 curve, respectively. Cofactors of these curves are 1. The hash iteration count nIterPi is 16384. The representation of the parameters kc1, ks1, vkc, and vks is hex-fixed-number.

[[Editorial Note: remove before submission] We should take a care on recent hot discussion topic on the choice of elliptic curves for cryptography.]]

Note: This algorithm is based on the Key Agreement Mechanism 3 (KAM3) defined in Section 6.3 of ISO/IEC 11770-4 [ISO.11770-4.2006] with a few modifications/improvements. However, implementers should use this document as the normative reference, because the algorithm has been changed in several minor details as well as major improvements.

### 3.1. Support Functions and Notations

The algorithm definitions use several support functions and notations defined below:

The integers in the specification are in decimal, or in hexadecimal when prefixed with "0x".

The functions named octet(), OCTETS(), and INT() are those defined in the core specification [I-D.ietf-httpauth-mutual].

Note: The definition of OCTETS() is different from the function GE2OS_x in the original ISO specification, which takes the shortest representation without preceding zeros.

All of the algorithms defined in this specification use the default functions defined in the core specification (defined in Section 11 of [I-D.ietf-httpauth-mutual]) for computing the values pi, VK_c, and VK_s.

### 3.2. Functions for Discrete-Logarithm Settings

In this section, an equation \((x / y \mod z)\) denotes a natural number \(w\) less than \(z\) that satisfies \((w * y) \mod z = x \mod z\).
For the discrete-logarithm, we refer to some of the domain parameters by using the following symbols:

- q: for "the prime" defining the MODP group.
- g: for "the generator" associated with the group.
- r: for the order of the subgroup generated by g.

The function J is defined as

\[ J(|pi|) = g^{(|pi|)} \mod q. \]

The value of \( K_{c1} \) is derived as

\[ K_{c1} = g^{(|S_{c1}|)} \mod q, \]

where \( S_{c1} \) is a random integer within range \([1, r-1]\) and \( r \) is the size of the subgroup generated by \( g \). In addition, \( S_{c1} \) MUST be larger than \( \log(q)/\log(g) \) (so that \( g^{S_{c1}} > q \)).

The value of \( K_{c1} \) SHALL satisfy \( 1 < K_{c1} < q-1 \). The server MUST check this condition upon reception.

Let an intermediate value \( t_1 \) be

\[ t_1 = \text{INT}(H(\text{octet}(1) \mid \text{OCTETS}(K_{c1}))), \]

the value of \( K_{s1} \) is derived from \( J(|pi|) \) and \( K_{c1} \) as:

\[ K_{s1} = (J(|pi|) \ast K_{c1} \ast (t_1)) \mod q, \]

where \( S_{s1} \) is a random number within range \([1, r-1]\). The value of \( K_{s1} \) MUST satisfy \( 1 < K_{s1} < q-1 \). If this condition is not held, the server MUST reject the exchange. The client MUST check this condition upon reception.

Let an intermediate value \( t_2 \) be

\[ t_2 = \text{INT}(H(\text{octet}(2) \mid \text{OCTETS}(K_{c1}) \mid \text{OCTETS}(K_{s1}))), \]

the value \( z \) on the client side is derived by the following equation:

\[ z = K_{s1} \ast (S_{c1} + t_2) / (S_{c1} \ast t_1 + |pi|) \mod r \mod q. \]

The value \( z \) on the server side is derived by the following equation:

\[ z = (K_{c1} \ast g^{t_2}) \ast (S_{s1}) \mod q. \]

(Note: the original ISO specification contained a message pair containing verification of value \( z \) along with the "transcript" of the protocol exchange. The functionality of this kind is contained in the functions \( \text{VK}_{c} \) and \( \text{VK}_{s} \).)
3.3. Functions for Elliptic-Curve Settings

For the elliptic-curve setting, we refer to some of the domain parameters by the following symbols:

- $q$: for the prime used to define the group.
- $G$: for the defined point called the generator.
- $h$: for the cofactor of the group.
- $r$: for the order of the subgroup generated by $G$.

The function $P(p)$ converts a curve point $p$ into an integer representing point $p$, by computing $x \times 2 + (y \mod 2)$, where $(x, y)$ are the coordinates of point $p$. $P'(z)$ is the inverse of function $P$, that is, it converts an integer $z$ to a point $p$ that satisfies $P(p) = z$. If such $p$ exists, it is uniquely defined. Otherwise, $z$ does not represent a valid curve point. The operator $+$ indicates the elliptic-curve group operation, and the operation $[x] \times p$ denotes an integer-multiplication of point $p$: it calculates $p + p + \ldots \ (x \text{ times}) \ldots + p$. See the literature on elliptic-curve cryptography for the exact algorithms used for those functions (e.g. Section 3 of [RFC6090], which uses different notations, though.) $0_E$ represents the infinity point. The equation $(x / y \mod z)$ denotes a natural number $w$ less than $z$ that satisfies $(w \times y) \mod z = x \mod z$.

The function $J$ is defined as

$$J(pi) = [pi] \times G.$$ 

The value of $K_{c1}$ is derived as

$$K_{c1} = P(K_{c1}'),$$

where $K_{c1}' = [S_{c1}] \times G$,

where $S_{c1}$ is a random number within range $[1, r-1]$. The value of $K_{c1}$ MUST represent a valid curve point, and $[h] \times K_{c1}'$ SHALL NOT be $0_E$. The server MUST check this condition upon reception.

Let an intermediate integer $t_1$ be

$$t_1 = INT(H(octet(1) | OCTETS(K_{c1}))),$$

the value of $K_{s1}$ is derived from $J(pi)$ and $K_{c1}' = P'(K_{c1})$ as:

$$K_{s1} = P([S_{s1}] \times (J(pi) + [t_1] \times K_{c1}')),$$

where $S_{s1}$ is a random number within range $[1, r-1]$. The value of $K_{s1}$ MUST represent a valid curve point and satisfy $[h] \times P'(K_{s1}) <> 0_E$. If this condition is not satisfied, the server MUST reject the exchange. The client MUST check this condition upon reception.

Let an intermediate integer $t_2$ be

$$t_2 = INT(H(octet(2) | OCTETS(K_{c1}) | OCTETS(K_{s1}))),$$

the value $z$ on the client side is derived by the following equation:
\[ z = P\left(\left(\frac{S_{c1} + t_2}{S_{c1} * t_1 + \pi}\right) \bmod r\right) * P'(K_{s1}). \]

The value \( z \) on the server side is derived by the following equation:

\[ z = P\left([S_{s1}] * (P'(K_{c1}) + [t_2] * G)\right). \]

4. IANA Considerations

This document defines four new tokens to be added for "HTTP Mutual authentication algorithms" registry; iso-kam3-dl-2048-sha256, iso-kam3-dl-4096-sha512, iso-kam3-ec-p256-sha256 and iso-kam3-ec-p521-sha512, as follows:

<table>
<thead>
<tr>
<th>Token</th>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>iso-kam3-dl-2048-sha256</td>
<td>ISO-11770-4 KAM3, 2048-bit DL</td>
<td>This document</td>
</tr>
<tr>
<td>iso-kam3-dl-4096-sha512</td>
<td>ISO-11770-4 KAM3, 4096-bit DL</td>
<td>This document</td>
</tr>
<tr>
<td>iso-kam3-ec-p256-sha256</td>
<td>ISO-11770-4 KAM3, 256-bit EC</td>
<td>This document</td>
</tr>
<tr>
<td>iso-kam3-ec-p521-sha512</td>
<td>ISO-11770-4 KAM3, 521-bit EC</td>
<td>This document</td>
</tr>
</tbody>
</table>

5. Security Considerations

Refer the corresponding section of the core specification for algorithm-independent, generic considerations, too.

5.1. General Implementation Considerations

- During the exchange, the value VK\(_s\), defined in [I-D.ietf-httpauth-mutual], MUST only be sent when the server has received a correct (expected) value of VK\(_c\). This is a requirement from underlying cryptography stated in [ISO.11770-4.2006].
- All random numbers used in these algorithms MUST be at least cryptographically computationally secure against forward and backward guessing attacks.
- Computation times of all numerical operations on discrete-logarithm group elements and elliptic-curve points MUST be normalized and made independent of the exact values, to prevent timing-based side-channel attacks.

5.2. Cryptographic Assumptions and Considerations

The notices on this subsection is mostly for those who analyze the security of this algorithm, and those who might want to make a derived work of this algorithm specification.

- Handling of invalid K\(_{s1}\) value in the exchange (now: to reject the exchange) has been changed from original ISO specification (original: to retry with another random S\(_{s1}\) value). This is due to an observation that this condition is less likely from the random error caused by unlucky choice of S\(_{s1}\), but more likely from the systematic failure from invalid J(pi) value, even implying possible denial-of-service attacks.
- The usual construction of authenticated key exchange algorithms are build from a key-exchange period and a key verification period, and the latter usually involving some kind of exchange transaction to be verified, to avoid security risks or vulnerabilities caused from mixing of values.
from two or more key exchanges. In the design of the algorithms in this document, such a functionality is defined in generalized manner in the core specification [I-D.ietf-httpauth-mutual] (see definitions of $VK_c$ and $VK_s$). If any attempts to reuse the algorithm defined above with any other protocols exist, care MUST be taken on that aspect.

- The domain parameters chosen and specified in this draft has a few assumptions. In the DL setting, $q$ has to be safe prime ($[(q - 1) / 2]$ must also be prime), and $r$ should be the largest possible value $[(q - 1) / 2]$. In the EC setting, $r$ has to be prime. Defining a variation of this algorithm using a different domain parameter SHOULD care about these conditions.

6. Notice on intellectual properties

The National Institute of Advanced Industrial Science and Technology (AIST) and Yahoo! Japan, Inc. has jointly submitted a patent application on the protocol proposed in this documentation to the Patent Office of Japan. The patent is intended to be open to any implementers of this protocol and its variants under non-exclusive royalty-free manner. For the details of the patent application and its status, please contact the author of this document.

The elliptic-curve based authentication algorithms might involve several existing third-party patents. The authors of the document take no position regarding the validity or scope of such patents, and other patents as well.

7. References

7.1. Normative References


7.2. Informative References


Appendix A. (Informative) Group Parameters for Discrete-Logarithm Based Algorithms

The MODP group used for the iso-kam3-dl-2048-sha256 algorithm is defined by the following parameters.

The prime is:

\[
q = 0x7FFFFFFFFFFFFFFFF FFFFFFFFF C90FDAA2 2168C234 C46628B 80DC1C1D 29024E08 8A67CC74 020BBE9A 3B139B22 514A0879 8E3404DD EF9519B3 CD3A431B 302B0A6D F25F1437 4FE1356D 65F1C245 E485B576 625E7EC6 F44C42E9 A637ED6B 0BF5CB6 F406B7ED EE386BF5 5A899FA5 AE9F2411 7C4B1F66 49286651 ECE45B3D C2007CB8 A163BF05 9DA84836 1C55D39A 69163FA8 FD24C5F5 83655D23 DCA3AD96 1C62F356 208552BB 9ED52907 709696ED 670C354E 4ABC9804 F1746C08 CA18217C 32905E46 2E36C3E3 E39E772C 180E8603 9B2783A2 EC07A28F B5C55DF0 6F4C52C9 DE28CBF6 95581718 3995497C EA956AE5 15D2261B 98FA0510 15728E5A 8AACAA68 FFFFFFFF FFFFFFFF.
\]

The generator is:

\[
g = 2.
\]

The size of the subgroup generated by g is:

\[
r = (q - 1) / 2 = 0x7FFFFFFFFFFFFFFFF E487ED51 10B4611A 62633145 C06E0E68 94812704 4533E63A 0105DF53 1D89CD91 28A5043C C71A02E6 F7CA8CD9 E69D12B8 9B155396 F92F8A1B A7F09AB6 B6A8E122 F242DABB 312F3F63 7A2E2174 D318F65B 85FFAE5B 7A035BF6 F71C35FD AD44C6D2 D74F9208 BE258FF3 24943328 F672DD9E E1003E5C 5B1DF82 CC6D2418 0E2A95CD 348B1FD4 7E6276AF C1B2AE91 EE5D6CB3 0E3179AB 1D89CD91 28A5043C C71A02E6 F7CA8CD9 E69D12B8 9B155396 F92F8A1B A7F09AB6 B6A8E122 F242DABB 312F3F63 7A2E2174 D318F65B 85FFAE5B 7A035BF6 B3861A27 255E4C02 78BA3604 650C10BE 19482F23 171B671D F1CF38B6 0C074301 CD93C1D1 7603D147 DA02AE0B 37A62964 EF1E5FB8 4AC0B08C 1C63AABE 754AB572 8AE9130C 4C7DD028 0AB9472D 45565534 7FFFFFFF FFFFFFFF.
\]

The MODP group used for the iso-kam3-dl-4096-sha512 algorithm is defined by the following parameters.

The prime is:

\[
q = 0x7FFFFFFFFFFFFFFFF FFFFFFFFF C90FDAA2 2168C234 C46628B 80DC1C1D 29024E08 8A67CC74 020BBE9A 3B139B22 514A0879 8E3404DD EF9519B3 CD3A431B 302B0A6D F25F1437 4FE1356D 65F1C245 E485B576 625E7EC6 F44C42E9 A637ED6B 0BF5CB6 F406B7ED EE386BF5 5A899FA5 AE9F2411 7C4B1F66 49286651 ECE45B3D C2007CB8 A163BF05 9DA84836 1C55D39A 69163FA8 FD24C5F5 83655D23 DCA3AD96 1C62F356 208552BB 9ED52907 709696ED 670C354E 4ABC9804 F1746C08 CA18217C 32905E46 2E36C3E3 E39E772C 180E8603 9B2783A2 EC07A28F B5C55DF0 6F4C52C9 DE28CBF6 95581718 3995497C EA956AE5 15D2261B 98FA0510 15728E5A 8AACAA68 FFFFFFFF FFFFFFFF.
\]
Appendix B. (Informative) Derived Numerical Values

This section provides several numerical values for implementing this protocol, derived from the above specifications. The values shown in this section are for informative purposes only.

<table>
<thead>
<tr>
<th></th>
<th>dl-2048</th>
<th>dl-4096</th>
<th>ec-p256</th>
<th>ec-p521</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of $K_{c1}$ etc.</td>
<td>2048</td>
<td>4096</td>
<td>257</td>
<td>522</td>
</tr>
<tr>
<td>hSize, Size of $H(\cdot)$</td>
<td>256</td>
<td>512</td>
<td>256</td>
<td>512</td>
</tr>
<tr>
<td>length of OCTETS($K_{c1}$) etc.</td>
<td>256</td>
<td>512</td>
<td>33</td>
<td>66</td>
</tr>
<tr>
<td>length of $k_{c1}$, $k_{s1}$ param. values.</td>
<td>344 *</td>
<td>684 *</td>
<td>66</td>
<td>132</td>
</tr>
<tr>
<td>length of $v_{k_{c1}}$, $v_{k_{s1}}$ param. values.</td>
<td>44 *</td>
<td>88 *</td>
<td>64</td>
<td>128</td>
</tr>
<tr>
<td>minimum allowed $S_{c1}$</td>
<td>2048</td>
<td>4096</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Appendix C. (Informative) Draft Change Log

C.1. Changes in HTTPAUTH-WG revision 03
   - IANA registration information added.

C.2. Changes in HTTPAUTH-WG revision 02
   - No technical changes: references updated.

C.3. Changes in HTTPAUTH-WG revision 01
   - Changed behavior on failed generation of $K_{s1}$.
   - Security considerations updated.

C.4. Changes in HTTPAUTH-WG revision 00
   - Added a note on the choice of elliptic curves.

C.5. Changes in HTTPAUTH revision 02
   - Added nIterPi parameter to adjust to the changes to the core draft.
   - Added a note on the verification of exchange transaction.

C.6. Changes in HTTPAUTH revision 01
   - Notation change: integer output of hash function will be notated as INT(H(*)), changed from H(*).

C.7. Changes in revision 02
   - Implementation hints in appendix changed (number of characters for base64-fixed-number does not contain double-quotes).

C.8. Changes in revision 01
   - Parameter names renamed.
   - Some expressions clarified without changing the value.

C.9. Changes in revision 00
   - The document is separated from the revision 08 of the core documentation.
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