HTTPAUTH Working Group
Internet-Draft
Intended status: Experimental
Expires: January 7, 2016

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July 6, 2015

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).

Status of this Memo

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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}, and 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].

```
C: S_{c1} = random
C: K_{c1} = g^(S_{c1})
                 ----- ID, K_{c1} ----->
C: t_{1} = H1(K_{c1})                S: t_{1} = H1(K_{c1})
                                      S: fetch J = g^pi by ID
                                      S: S_{s1} = random
                                      S: K_{s1} = (J * K_{c1}^(t_{1}))^(S_{s1})
                 <----- K_{s1} -----
C: t_{2} = H2(K_{c1}, K_{s1})        S: t_{2} = H2(K_{c1}, K_{s1})
C: z = K_{s1}^((S_{c1} + t_{2}) / (S_{c1} * t_{1} + pi))
                                      S: z' = (K_{c1} * g^(t_{2}))^(S_{s1})
(assumption at this point: z = z' if authentication succeeded)

C: VK_{c} = H4(K_{c1}, K_{s1}, z)     S: VK_{c}' = H4(K_{c1}, K_{s1}, z')
                 ----- VK_{c} ------->
                                      S: assert(VK_{c} = VK_{c}')

C: VK_{s}' = H3(K_{c1}, K_{s1}, z)    S: VK_{s} = H3(K_{c1}, K_{s1}, z')
                 <----- VK_{s} ------
C: assert(VK_{s} = VK_{s}')
```

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

- iso-kam3-dl-2048-sha256: for the 2048-bit discrete-logarithm setting with the SHA-256 hash function.
- iso-kam3-dl-4096-sha512: for the 4096-bit discrete-logarithm setting with the SHA-512 hash function.
- iso-kam3-ec-p256-sha256: for the 256-bit prime-field elliptic-curve setting with the SHA-256 hash function.
- iso-kam3-ec-p521-sha512: for the 521-bit prime-field elliptic-curve setting with the SHA-512 hash function.

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

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

K_{s1} = (J(pi) * K_{c1}^(t_1))^(S_{s1}) 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 = INT(H(octet(2) | OCTETS(K_{c1}) | OCTETS(K_{s1}))),

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

z = K_{s1}^((S_{c1} + t_2) / (S_{c1} * t_1 + pi) mod r) mod q.

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

z = (K_{c1} * g^(t_2))^(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 VK_c and 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 * 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] * p denotes an integer-multiplication of point p: it calculates p + p + ... (x times) ... + 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 * y) mod z = x mod z.

The function J is defined as

J(pi) = [pi] * G.

The value of K_{c1} is derived as

K_{c1} = P(K_{c1}'), where K_{c1}' = [S_{c1}] * 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] * 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}] * (J(pi) + [t_1] * 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] * 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:

$z = P([(S_{c1} + t_2) / (S_{c1} * t_1 + pi) \bmod r] * P'(K_{s1}))$.

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

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

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:

Token	Description	Specification
iso-kam3-dl-2048-sha256	ISO-11770-4 KAM3, 2048-bit DL	This document
iso-kam3-dl-4096-sha512	ISO-11770-4 KAM3, 4096-bit DL	This document
iso-kam3-ec-p256-sha256	ISO-11770-4 KAM3, 256-bit EC	This document
iso-kam3-ec-p521-sha512	ISO-11770-4 KAM3, 521-bit EC	This document

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

[FIPS.180-2.2002] National Institute of Standards and Technology, “Secure Hash Standard,” FIPS PUB 180-2, August 2002.

[FIPS.186-4.2013] National Institute of Standards and Technology, “Digital Signature Standard (DSS),” FIPS PUB 186-4, July 2013.

[I-D.ietf-httpauth-mutual] Oiwa, Y., Watanabe, H., Takagi, H., Maeda, K., Hayashi, T., and Y. Ioku, “Mutual Authentication Protocol for HTTP,” draft-ietf-httpauth-mutual-05 (work in progress), July 2015.

[RFC2119] Bradner, S., “Key words for use in RFCs to Indicate Requirement Levels,” BCP 14, RFC 2119, March 1997 (TXT, HTML, XML).

[RFC3526] Kivinen, T. and M. Kojo, “More Modular Exponential (MODP) Diffie-Hellman groups for Internet Key Exchange (IKE),” RFC 3526, May 2003 (TXT).

7.2. Informative References

[ISO.11770-4.2006] International Organization for Standardization, “Information technology – Security techniques – Key management – Part 4: Mechanisms based on weak secrets,” ISO Standard 11770-4, May 2006.

[RFC6090] McGrew, D., Igoe, K., and M. Salter, “Fundamental Elliptic Curve Cryptography Algorithms,” RFC 6090, February 2011 (TXT).

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 = 0xFFFFFFFF FFFFFFFF C90FDAA2 2168C234 C4C6628B 80DC1CD1
      29024E08 8A67CC74 020BBEA6 3B139B22 514A0879 8E3404DD
      EF9519B3 CD3A431B 302B0A6D F25F1437 4FE1356D 6D51C245
      E485B576 625E7EC6 F44C42E9 A637ED6B 0BFF5CB6 F406B7ED
      EE386BFB 5A899FA5 AE9F2411 7C4B1FE6 49286651 ECE45B3D
      C2007CB8 A163BF05 98DA4836 1C55D39A 69163FA8 FD24CF5F
      83655D23 DCA3AD96 1C62F356 208552BB 9ED52907 7096966D
      670C354E 4ABC9804 F1746C08 CA18217C 32905E46 2E36CE3B
      E39E772C 180E8603 9B2783A2 EC07A28F B5C55DF0 6F4C52C9
      DE2BCBF6 95581718 3995497C EA956AE5 15D22618 98FA0510
      15728E5A 8AACAA68 FFFFFFFF FFFFFFFF.
```

The generator is:

```
g = 2.
```

The size of the subgroup generated by g is:

```
r = (q - 1) / 2 =
    0x7FFFFFFF FFFFFFFF E487ED51 10B4611A 62633145 C06E0E68
      94812704 4533E63A 0105DF53 1D89CD91 28A5043C C71A026E
      F7CA8CD9 E69D218D 98158536 F92F8A1B A7F09AB6 B6A8E122
      F242DABB 312F3F63 7A262174 D31BF6B5 85FFAE5B 7A035BF6
      F71C35FD AD44CFD2 D74F9208 BE258FF3 24943328 F6722D9E
      E1003E5C 50B1DF82 CC6D241B 0E2AE9CD 348B1FD4 7E9267AF
      C1B2AE91 EE51D6CB 0E3179AB 1042A95D CF6A9483 B84B4B36
      B3861AA7 255E4C02 78BA3604 650C10BE 19482F23 171B671D
      F1CF3B96 0C074301 CD93C1D1 7603D147 DAE2AEF8 37A62964
      EF15E5FB 4AAC0B8C 1CCAA4BE 754AB572 8AE9130C 4C7D0288
      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 = 0xFFFFFFFF FFFFFFFF C90FDAA2 2168C234 C4C6628B 80DC1CD1
      29024E08 8A67CC74 020BBEA6 3B139B22 514A0879 8E3404DD
      EF9519B3 CD3A431B 302B0A6D F25F1437 4FE1356D 6D51C245
      E485B576 625E7EC6 F44C42E9 A637ED6B 0BFF5CB6 F406B7ED
      EE386BFB 5A899FA5 AE9F2411 7C4B1FE6 49286651 ECE45B3D
      C2007CB8 A163BF05 98DA4836 1C55D39A 69163FA8 FD24CF5F
      83655D23 DCA3AD96 1C62F356 208552BB 9ED52907 7096966D
      670C354E 4ABC9804 F1746C08 CA18217C 32905E46 2E36CE3B
      E39E772C 180E8603 9B2783A2 EC07A28F B5C55DF0 6F4C52C9
      DE2BCBF6 95581718 3995497C EA956AE5 15D22618 98FA0510
      15728E5A 8AAAC42D AD33170D 04507A33 A85521AB DF1CBA64
      ECFB8504 58DBEF0A 8AEA7157 5D060C7D B3970F85 A6E1E4C7
      ABF5AE8C DB0933D7 1E8C94E0 4A25619D CEE3D226 1AD2EE6B
      F12FFA06 D98A0864 D8760273 3EC86A64 521F2B18 177B200C
```

```
BBE11757 7A615D6C 770988C0 BAD946E2 08E24FA0 74E5AB31
43DB5BFC E0FD108E 4B82D120 A9210801 1A723C12 A787E6D7
88719A10 BDBA5B26 99C32718 6AF4E23C 1A946834 B6150BDA
2583E9CA 2AD44CE8 DBBBC2DB 04DE8EF9 2E8EFC14 1FBECAA6
287C5947 4E6BC05D 99B2964F A090C3A2 233BA186 515BE7ED
1F612970 CEE2D7AF B81BDD76 2170481C D0069127 D5B05AA9
93B4EA98 8D8FDDC1 86FFB7DC 90A6C08F 4DF435C9 34063199
FFFFFFFF FFFFFFFF.
```

The generator is:

```
g = 2.
```

The size of the subgroup generated by g is:

```
r = (q - 1) / 2 =
    0x7FFFFFFF FFFFFFFF E487ED51 10B4611A 62633145 C06E0E68
      94812704 4533E63A 0105DF53 1D89CD91 28A5043C C71A026E
      F7CA8CD9 E69D218D 98158536 F92F8A1B A7F09AB6 B6A8E122
      F242DABB 312F3F63 7A262174 D31BF6B5 85FFAE5B 7A035BF6
      F71C35FD AD44CFD2 D74F9208 BE258FF3 24943328 F6722D9E
      E1003E5C 50B1DF82 CC6D241B 0E2AE9CD 348B1FD4 7E9267AF
      C1B2AE91 EE51D6CB 0E3179AB 1042A95D CF6A9483 B84B4B36
      B3861AA7 255E4C02 78BA3604 650C10BE 19482F23 171B671D
      F1CF3B96 0C074301 CD93C1D1 7603D147 DAE2AEF8 37A62964
      EF15E5FB 4AAC0B8C 1CCAA4BE 754AB572 8AE9130C 4C7D0288
      0AB9472D 45556216 D6998B86 82283D19 D42A90D5 EF8E5D32
      767DC282 2C6DF785 457538AB AE83063E D9CB87C2 D370F263
      D5FAD746 6D8499EB 8F464A70 2512B0CE E771E913 0D697735
      F897FD03 6CC50432 6C3B0139 9F643532 290F958C 0BBD9006
      5DF08BAB BD30AEB6 3B84C460 5D6CA371 047127D0 3A72D598
      A1EDADFE 707E8847 25C16890 54908400 8D391E09 53C3F36B
      C438CD08 5EDD2D93 4CE1938C 357A711E 0D4A341A 5B0A85ED
      12C1F4E5 156A2674 6DDDE16D 826F477C 97477E0A 0FDF6553
      143E2CA3 A735E02E CCD94B27 D04861D1 119DD0C3 28ADF3F6
      8FB094B8 67716BD7 DC0DEEBB 10B8240E 68034893 EAD82D54
      C9DA754C 46C7EEE0 C37FDBEE 48536047 A6FA1AE4 9A0318CC
      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.

	dl-2048	**dl-4096**	**ec-p256**	**ec-p521**	
Size of K_{c1} etc.	2048	4096	257	522	(bits)
hSize, Size of H(...)	256	512	256	512	(bits)
length of OCTETS(K_{c1}) etc.	256	512	33	66	(octets)
length of kc1, ks1 param. values.	344 *	684 *	66	132	(octets)
length of vkc, vks param. values.	44 *	88 *	64	128	(octets)
minimum allowed S_{c1}	2048	4096	1	1	

(The numbers marked with an * do not include any enclosing quotation marks.)

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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