OCRA: OATH Challenge-Response Algorithms
draft-mraihi-mutual-oath-hotp-variants-08.txt

Abstract

This document describes the OATH algorithm for challenge-response authentication and signatures. This algorithm is based on the HOTP algorithm [RFC4226] that was introduced by OATH (initiative for Open AuTHentication) [OATH] and submitted as an individual draft to the IETF in 2006.
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1. Introduction

OATH has identified several use cases and scenarios that require an asynchronous variant to accommodate users who do not want to maintain a synchronized authentication system. A commonly accepted method for this is to use a challenge-response scheme.

Such challenge response mode of authentication is widely adopted in the industry. Several vendors already offer software applications and hardware devices implementing challenge-response - but each of those uses vendor-specific proprietary algorithms. For the benefits of users there is a need for a standardized challenge-response algorithm which allows multi-sourcing of token purchases and validation systems to facilitate the democratization of strong authentication.

Additionally, this specification describes the means to create symmetric key based digital signatures. Such signatures are variants of challenge-response mode where the data to be signed becomes the challenge.

2. Requirements Terminology

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].

3. Algorithm Requirements

This section presents the main requirements that drove this algorithm design. A lot of emphasis was placed on flexibility and usability, under the constraints and specificity of the HOTP algorithm and hardware token capabilities.

R1 - The algorithm MUST support asynchronous challenge-response based authentication.

R2 - The algorithm MUST be capable of supporting symmetric key based digital signatures. Essentially this is a variation of challenge-response where the challenge is derived from the data that need to be signed.

R3 - The algorithm MUST be capable of supporting server-authentication, whereby the user can verify that he/she is talking to a trusted server.
R4 - The algorithm SHOULD use HOTP [RFC4226] as a key building block.

R5 - The length and format of the input challenge SHOULD be configurable.

R6 - The output length and format of the generated response SHOULD be configurable.

R7 - The challenge MAY be generated with integrity checking (e.g., parity bits). This will allow tokens with pin pads to perform simple error checking when the user enters the challenge value into a token.

R8 - There MUST be a unique secret (key) for each token/soft token that is shared between the token and the authentication server. The keys MUST be randomly generated or derived using a key derivation algorithm.

R9 - The algorithm MAY enable additional data attributes such as a timestamp or session information to be included in the computation. These data inputs MAY be used individually or all together.

4. OCRA Background

OATH introduced the HOTP algorithm as a first open, freely available building block towards strengthening authentication for end-users in a variety of applications. One-time passwords are very efficient at solving specific security issues thanks to the dynamic nature of OTP computations.

After carefully analyzing different use cases, OATH came to the conclusion that providing for extensions to the HOTP algorithms was important. A very natural extension is to introduce a challenge mode for computing HOTP values based on random questions. Equally beneficial is being able to perform mutual authentication between two parties, or short-signature computation for authenticating transaction to improve the security of e-commerce applications.

4.1 HOTP Algorithm

The HOTP algorithm, as defined in [RFC4226] is based on an increasing counter value and a static symmetric key known only to the prover and verifier parties.

As a reminder:

$$\text{HOTP}(K, C) = \text{Truncate}(\text{HMAC-SHA1}(K, C))$$
Where Truncate represents the function that converts an HMAC-SHA-1 value into an HOTP value.

We refer the reader to [RFC4226] for the full description and further details on the rationale and security analysis of HOTP.

The present draft describes the different variants based on similar constructions as HOTP.

5. Definition of OCRA

OCRA is a generalization of HOTP with variable data inputs not solely based on an incremented counter and secret key values.

The definition of OCRA requires a cryptographic function, a key K and a set of DataInput parameters. This section first formally introduces the OCRA algorithm and then introduces the definitions and default values recommended for all parameters.

In a nutshell, 

\[
\text{OCRA} = \text{CryptoFunction}(K, \text{DataInput})
\]

Where:

- K: a shared secret key known to both parties;
- DataInput: a structure that contains the concatenation of the various input data values defined in details in section 5.1;
- CryptoFunction: this is the function performing the OCRA computation from the secret key K and the DataInput material; CryptoFunction is described in details in section 5.2.

5.1 DataInput Parameters

This structure is the concatenation over byte array of the OCRASuite value as defined in section 6 with the different parameters used in the computation, save for the secret key K.

\[
\text{DataInput} = \{\text{OCRASuite} | \text{00} | C | Q | P | S | T\}
\]

where:

- OCRASuite is a value representing the suite of operations to compute an OCRA response;
- 00 is a byte value used as a separator;
- C is an unsigned 8-byte counter value processed high-order bit first, and MUST be synchronized between all parties; It loops around from "(Hex)0" to "(Hex)FFFFFFFFFFFF" and then starts over at "(Hex)0";
Q, mandatory, is a 128-byte list of (concatenated) challenge question(s) generated by the parties; if Q is less than 128 bytes, then it should be padded with zeroes to the right;
P is a 20-byte SHA1-hash of PIN/password that is known to all parties during the execution of the algorithm;
S is a 64-byte UTF-8 encoded string that contains information about the current session;
T is an 8-byte unsigned integer in big endian (i.e. network byte order) representing the number of minutes since midnight UTC of January 1, 1970. More specifically, if the OCRA computation includes a timestamp T, you SHOULD first convert your current local time to UTC time (text form). You can then derive the UTC time in milliseconds and T (minutes from Epoch time).

When computing a response, the concatenation order is always the following:

\[
\text{C} \mid \text{OTHER-PARTY-GENERATED-CHALLENGE-QUESTION} \mid \text{YOUR-GENERATED-CHALLENGE-QUESTION} \mid \text{P} \mid \text{S} \mid \text{T}
\]

If a value is empty (i.e. a certain input is not used in the computation) then the value is simply not represented in the string.

The counter on the token or client MUST be incremented every time a new computation is requested by the user. The server’s counter value MUST only be incremented after a successful OCRA authentication.

5.2 CryptoFunction

The default CryptoFunction is HOTP-SHA1-6, i.e. the default mode of computation for OCRA is HOTP with the default 6-digit dynamic truncation and a combination of DataInput values as the message to compute the HMAC-SHA1 digest.

As indicated in section 5.1, we denote t as the length in digits of the truncation output. For instance, if \( t = 6 \), then the output of the truncation is a 6-digit value.

We define the HOTP family of functions as an extension to HOTP:
- HOTP-H-t: these are the different possible truncated versions of HOTP, using the dynamic truncation method for extracting an HOTP value from the HMAC output;
- We will denote HOTP-H-t as the realization of an HOTP function that uses an HMAC function with the hash function H, and the
dynamic truncation as described in [RFC 4226] to extract a t-digit value;
- t=0 means that no truncation is performed and the full HMAC value is used for authentication purpose.

We list the following preferred modes of computation, where * denotes the default CryptoFunction:
- HOTP-SHA1-4: HOTP with SHA-1 as the hash function for HMAC and a dynamic truncation to a 4-digit value; this mode is not recommended in the general case but can be useful when a very short authentication code is needed by an application;
- *HOTP-SHA1-6: HOTP with SHA-1 as the hash function for HMAC and a dynamic truncation to a 6-digit value;
- HOTP-SHA1-8: HOTP with SHA-1 as the hash function for HMAC and a dynamic truncation to an 8-digit value;
- HOTP-SHA256-6: HOTP with SHA-256 as the hash function for HMAC and a dynamic truncation to a 6-digit value;
- HOTP-SHA512-6: HOTP with SHA-512 as the hash function for HMAC and a dynamic truncation to a 6-digit value;

This table summarizes all possible values for the CryptoFunction:

<table>
<thead>
<tr>
<th>Name</th>
<th>HMAC Function Used</th>
<th>Size of Truncation (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOTP-SHA1-t</td>
<td>HMAC-SHA1</td>
<td>0 (no truncation), 4-10</td>
</tr>
<tr>
<td>HOTP-SHA256-t</td>
<td>HMAC-SHA256</td>
<td>0 (no truncation), 4-10</td>
</tr>
<tr>
<td>HOTP-SHA512-t</td>
<td>HMAC-SHA512</td>
<td>0 (no truncation), 4-10</td>
</tr>
</tbody>
</table>

6. The OCRASuite

An OCRASuite value is a text string that captures one mode of operation for the OCRA algorithm, completely specifying the various options for that computation. An OCRASuite value is represented as follows:

Algorithm: CryptoFunction: DataInput

The client and server need to agree on one or two values of OCRASuite. These values may be agreed at time of token provisioning or for more sophisticated client-server interactions these values may be negotiated for every transaction.

Note that for Mutual Challenge-Response or Signature with Server Authentication modes, the client and server will need to agree on two values of OCRASuite - one for server computation and another for client computation.

Algorithm
Description: Indicates the version of OCRA algorithm.
Values: OCRA-v where v represents the version number (e.g. 1, 2 etc.). This document specifies version 1 of the OCRA algorithm.

CryptoFunction
-------------
Description: Indicates the function used to compute OCRA values
Values: Permitted values are described in section 5.2

DataInput
--------
Description: This component of the OCRASuite string captures the list of valid inputs for that computation; [] indicates a value is optional:
[C] | QFxx | [P | S | T]: Challenge-Response computation
[C] | QFxx | [P | T]: Plain Signature computation

Each input that is used for the computation is represented by a single letter (except Q) and they are separated by a hyphen.

The input for challenge is further qualified by the formats supported by the client for challenge question(s).
Supported values can be:

<table>
<thead>
<tr>
<th>Format (F)</th>
<th>Up To Length (xx)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (alphanumeric)</td>
<td>04-64</td>
</tr>
<tr>
<td>N (numeric)</td>
<td>04-64</td>
</tr>
<tr>
<td>H (hexadecimal)</td>
<td>04-64</td>
</tr>
</tbody>
</table>

The default format for challenge question is N08, numeric and upto 8 digits.

For example OCRA-1:HOTP-SHA512-8:C-QN08-P means version 1 of the OCRA algorithm with HMAC-SHA512 function, truncated to an 8-digit value, using the counter, a random challenge and a hash of the PIN/Password as parameters. It also indicates that the client supports only numeric challenge upto 8 digits in length.

7. Algorithm Modes for Authentication

This section describes the typical modes in which the above defined computation can be used for authentication.
7.1 One way Challenge-Response

A challenge/response is a security mechanism in which the verifier presents a question (challenge) to the prover who must provide a valid answer (response) to be authenticated.

To use this algorithm for a one-way challenge-response, the verifier will communicate a challenge value (typically randomly generated) to the prover. The prover will use the challenge in the computation as described above. The prover then communicates the response to the verifier to authenticate.

Therefore in this mode, the typical data inputs will be:

C - Counter, optional.
Q - Challenge question, mandatory, supplied by the verifier.
P - Hashed version of PIN/password, optional.
S - Session information, optional
T - Timestamp, optional.

The diagram below shows the message exchange between the client (prover) and the server (verifier) to complete a one-way challenge-response authentication.

It is assumed that the client and server have a pre-shared key K that is used for the computation.
7.2 Mutual Challenge-Response

Mutual challenge-response is a variation of one-way challenge-response where both the client and server mutually authenticate each other.

To use this algorithm, the client will first send a random client-challenge to the server. The server computes the server-response and sends it to the client along with a server-challenge.

The client will first verify the server-response to be assured that it is talking to a valid server. It will then compute the client-response and send it to the server to authenticate. The server verifies the client-response to complete the two-way authentication process.

In this mode there are two computations: client-response and server-response. There are two separate challenge questions, generated by both parties. We denote these challenge questions Q1 and Q2.

Typical data inputs for server-response computation will be:
C - Counter, optional.
QC - Challenge question, mandatory, supplied by the client.
QS - Challenge question, mandatory, supplied by the server.
S - Session information, optional.
T - Timestamp, optional.

Typical data inputs for client-response computation will be:
C - Counter, optional.
QS - Challenge question, mandatory, supplied by the server.
QC - Challenge question, mandatory, supplied by the client.
P - Hashed version of PIN/password, optional.
S - Session information, optional.
T - Timestamp, optional.

The following picture shows the messages that are exchanged between the client and the server to complete a two-way mutual challenge-response authentication.

It is assumed that the client and server have a pre-shared key K (or pair of keys if using dual-key mode of computation) that is used for the computation.
1. Client sends client-challenge
   QC = Client-challenge

2. Server computes server-response
   and sends server-challenge
   RS = OCRA(K, [C] | QC | QS | [S | T])
   QS = Server-challenge
   Response = RS, QS

3. Client verifies server-response
   and computes client-response
   OCRA(K, [C] | QC | QS | [S | T]) != RS -> STOP
   RC = OCRA(K, [C] | QS | QC | [P | S | T])
   Response = RC

4. Server verifies client-response
   OCRA(K, [C] | QS | QC | [P|S|T]) != RC -> STOP
   Response = OK

8. Algorithm Modes for Signature

In this section we describe the typical modes in which the above defined computation can be used for digital signatures.

8.1 Plain Signature

To use this algorithm in plain signature mode, the server will communicate a signature-challenge value to the client (signer). The signature-challenge is either the data to be signed or derived from the data to be signed using a hash function, for example.

The client will use the signature-challenge in the computation as described above. The client then communicates the signature value (response) to the server to authenticate.

Therefore in this mode, the data inputs will be:

C - Counter, optional.
QS - Signature-challenge, mandatory, supplied by the server.
P - Hashed version of PIN/password, optional.
T - Timestamp, optional.
The picture below shows the messages that are exchanged between the client (prover) and the server (verifier) to complete a plain signature operation.

It is assumed that the client and server have a pre-shared key K that is used for the computation.

8.2 Signature with Server Authentication

This mode is a variation of the plain signature mode where the client can first authenticates the server before generating a digital signature.

To use this algorithm, the client will first send a random client-challenge to the server. The server computes the server-response and sends it to the client along with a signature-challenge. The client will first verify the server-response to authenticate that it is talking to a valid server. It will then compute the signature and send it to the server.

In this mode there are two computations: client-signature and server-response.

Typical data inputs for server-response computation will be:
C - Counter, optional.
QC - Challenge question, mandatory, supplied by the client.
QS - Signature-challenge, mandatory, supplied by the server.
T - Timestamp, optional.
Typical data inputs for client-signature computation will be:
C - Counter, optional.
QC - Challenge question, mandatory, supplied by the client.
QS - Signature-challenge, mandatory, supplied by the server.
P - Hashed version of PIN/password, optional.
T - Timestamp, optional.

The diagram below shows the messages that are exchanged between the client and the server to complete a signature with server authentication transaction.

It is assumed that the client and server have a pre-shared key K (or pair of keys if using dual-key mode of computation) that is used for the computation.

```
CLIENT                     SERVER
1. Client sends client-challenge
   QC = Client-challenge               -->
2. Server computes server-response
   and sends signature-challenge
   RS = OCRA(K, [C] | QC | QS | [T])
   QS = signature-challenge
   Response = RS, QS
<---------------------------------->
3. Client verifies server-response
   and computes signature
   OCRA(K, [C] | QC | QS | [T]) != RS -> STOP
   SIGN = OCRA(K, [C] | QS | QC | [P | T])
   Response = SIGN
<---------------------------------->
4. Server verifies Signature
   OCRA(K, [C] | QS | QC | [P | T]) != SIGN -> STOP
   Response = OK
<---------------------------------->
```

9. Security Considerations

Any algorithm is only as secure as the application and the authentication protocols that implement it. Therefore, this section discusses the critical security requirements that our choice of algorithm imposes on the authentication protocol and validation software.
9.1 Security Analysis of the OCRA algorithm

The security and strength of this algorithm depends on the properties of the underlying building block HOTP, which is a construction based on HMAC [RFC2104] using SHA-1 as the hash function.

The conclusion of the security analysis detailed in [RFC4226] is that, for all practical purposes, the outputs of the dynamic truncation on distinct counter inputs are uniformly and independently distributed strings.

The analysis demonstrates that the best possible attack against the HOTP function is the brute force attack.

9.2 Implementation Considerations

IC1 - In the authentication mode, the client MUST support two-factor authentication, i.e., the communication and verification of something you know (secret code such as a Password, Pass phrase, PIN code, etc.) and something you have (token). The secret code is known only to the user and usually entered with the Response value for authentication purpose (two-factor authentication). Alternatively, instead of sending something you know to the server, the client may use a hash of the Password or PIN code in the computation itself, thus implicitly enabling two-factor authentication.

IC2 - Keys should be of the length of the CryptoFunction output to facilitate interoperability.

IC3 - Keys SHOULD be chosen at random or using a cryptographically strong pseudo-random generator properly seeded with a random value. We RECOMMEND following the recommendations in [RFC1750] for all pseudo-random and random generations. The pseudo-random numbers used for generating the keys SHOULD successfully pass the randomness test specified in [CN].

IC4 - Challenge questions SHOULD be 20-byte values and MUST be at least t-byte values where t stands for the digit-length of the OCRA truncation output.

IC5 - On the client side, the keys SHOULD be embedded in a tamper resistant device or securely implemented in a software application. Additionally, by embedding the keys in a hardware device, you also have the advantage of improving the flexibility (mobility) of the authentication system.
IC6 - We RECOMMEND following the recommendations in [RFC1750] for all pseudo-random and random challenge generations.

IC7 - All the communications SHOULD take place over a secure channel e.g. SSL/TLS, IPsec connections.

IC8 - The OCRA algorithm when used in mutual authentication mode or in signature with server authentication mode MAY use dual key mode - i.e. there are two keys that are shared between the client and the server. One shared key is used to generate the server response on the server side and to verify it on the client side. The other key is used to create the response or signature on the client side and to verify it on the server side.

IC9 - We recommend that implementations MAY use the session information, S as an additional input in the computation. For example, S could be the session identifier from the TLS session. This will enable you to counter certain types of man-in-the-middle attacks. However, this will introduce the additional dependency that first of all the prover needs to have access to the session identifier to compute the response and the verifier will need access to the session identifier to verify the response.

IC10 - In the signature mode, whenever the counter or time (defined as optional elements) are not used in the computation, there might be a risk of replay attack and the implementers should carefully consider this issue in the light of their specific application requirements and security guidelines. The server SHOULD also provide whenever possible a mean for the client (if able) to verify the validity of the signature challenge.

IC11 - We also RECOMMEND storing the keys securely in the validation system, and more specifically encrypting them using tamper-resistant hardware encryption and exposing them only when required: for example, the key is decrypted when needed to verify an OCRA response, and re-encrypted immediately to limit exposure in the RAM for a short period of time. The key store MUST be in a secure area, to avoid as much as possible direct attack on the validation system and secrets database. Particularly, access to the key material should be limited to programs and processes required by the validation system only.

10. IANA Considerations

This document has no actions for IANA.
11. Conclusion

This draft introduced several variants of HOTP for challenge-response based authentication and short signature-like computations.

The OCRASuite provides for an easy integration and support of different flavors within an authentication and validation system.

Finally, OCRA should enable mutual authentication both in connected and off-line modes, with the support of different response sizes and mode of operations.

12. Acknowledgements

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13. References

13.1 Normative


13.2 Informative

[BCK] M. Bellare, R. Canetti and H. Krawczyk, "Keyed Hash Functions and Message Authentication", Proceedings of
import java.lang.reflect.UndeclaredThrowableException;
import java.security.GeneralSecurityException;
import javax.crypto.Mac;
import javax.crypto.spec.SecretKeySpec;
import java.math.BigInteger;

/**
 * This an example implementation of the OATH OCRA algorithm.
 * Visit www.openauthentication.org for more information.
 * @author Johan Rydell, PortWise
 */

public class OCRA {

    private OCRA() {} 

    /**
     * This method uses the JCE to provide the crypto algorithm.
     * HMAC computes a Hashed Message Authentication Code with the crypto hash algorithm as a parameter.
     * @param crypto the crypto algorithm (HmacSHA1, HmacSHA256, HmacSHA512)
     * @param keyBytes the bytes to use for the HMAC key
     * @param text the message or text to be authenticated.
     */
    public static byte[] hmac_sha1(String crypto, byte[] keyBytes, byte[] text) {
        try {
            Mac hmac = Mac.getInstance(crypto);
            SecretKeySpec macKey = new SecretKeySpec(keyBytes, "RAW");
            hmac.init(macKey);
            return hmac.doFinal(text);
        } catch (GeneralSecurityException | UndeclaredThrowableException e) {
            // Handle exception
        }
    }
}
} catch (GeneralSecurityException gse) {
    throw new UndeclaredThrowableException(gse);
}

private static final int[] DIGITS_POWER
// 0 1 2 3 4 5 6 7 8
= {1,10,100,1000,10000,100000,1000000,10000000,100000000 };

/**
 * This method generates an OCRA HOTP value for the given
 * set of parameters.
 *
 * @param ocraSuite    the OCRA Suite
 * @param key          the shared secret, HEX encoded
 * @param counter      the counter that changes on a
 *                     per use basis, HEX encoded
 * @param question     the challenge question
 * @param password     a password that can be used
 * @param sessionInformation      Static information
 *                                that identifies the
 *                                current session
 * @param timeStamp    a value that reflects a time
 *
 * @return A numeric String in base 10 that includes
 *        (@link truncationDigits) digits
 */
static public String generateOCRA(String ocraSuite,
String key,
String counter,
String question,
String password,
String sessionInformation,
String timeStamp)
{
    int codeDigits = 0;
    String crypto = "";
    String result = null;
    int ocraSuiteLength = ocraSuite.length();
    int counterLength = 0;
    int questionLength = 0;
    int passwordLength = 0;
    int sessionInformationLength = 0;
    int timeStampLength = 0;

    if(ocraSuite.toLowerCase().indexOf("sha1") > 1)
        crypto = "HmacSHA1";
    if(ocraSuite.toLowerCase().indexOf("sha256") > 1)
        crypto = "HmacSHA256";
    if(ocraSuite.toLowerCase().indexOf("sha512") > 1)
        crypto = "HmacSHA512";
// How many digits should we return
StringoS = ocraSuite.substring(ocraSuite.indexOf(":") + 1).
  ocraSuite.indexOf(":") + 1));

codeDigits = Integer.decode(oS.substring
  (oS.lastIndexOf("-")+1,
   oS.length()));

// The size of the byte array message to be encrypted
// Counter
if(ocraSuite.toLowerCase().indexOf(":c") > 1) {
  counterLength=8;
}

// Question
if((ocraSuite.toLowerCase().indexOf(":q") > 1) ||
  (ocraSuite.toLowerCase().indexOf("-q") > 1)) {
  questionLength=128;
}

// Password
if((ocraSuite.toLowerCase().indexOf(":p") > 1) ||
  (ocraSuite.toLowerCase().indexOf("-p") > 1)){
  passwordLength=20;
}

// sessionInformation
if((ocraSuite.toLowerCase().indexOf(":s") > 1) ||
  (ocraSuite.toLowerCase().indexOf("-s",
     ocraSuite.indexOf(":") + 1)) > 1)){
  sessionInformationLength=64;
}

// TimeStamp
if((ocraSuite.toLowerCase().indexOf(":t") > 1) ||
  (ocraSuite.toLowerCase().indexOf("-t") > 1)){
  timeStampLength=8;
}

// Remember to add "1" for the "00" byte delimiter
byte[] msg = new byte[ocraSuiteLength +
  counterLength +
  questionLength +
  passwordLength +
  sessionInformationLength +
  timeStampLength +
  1];

// Put the bytes of "ocraSuite" parameters
// into the message
byte[] bArray = ocraSuite.getBytes();
for(int i = 0; i < bArray.length; i++){
  msg[i] = bArray[i];
}
// Put the bytes of "Counter" to the message
// Input is HEX encoded
if(counter.length() > 0 ){
    bArray = new BigInteger(counter,16).toByteArray();
    if(bArray.length == 9){
        // First byte is the "sign" byte
        for (int i = 0; i < 8 && i < bArray.length ; i++)
        {
            msg[i + 8 - bArray.length + ocraSuiteLength + 1] =
            bArray[i+1];
        }
    }
    else {
        for (int i = 0; i < 8 && i < bArray.length ; i++)
        {
            msg[i + 8 - bArray.length + ocraSuiteLength + 1] = bArray[i];
        }
    }
}

// Put the bytes of "question" to the message
// Input is text encoded
if(question.length() > 0 ){
    bArray = question.getBytes();
    for (int i = 0; i < 128 && i < bArray.length ; i++)
    {
        msg[i + ocraSuiteLength + 1 + counterLength] = bArray[i];
    }
}

// Put the bytes of "password" to the message
// Input is HEX encoded
if(password.length() > 0){
    bArray = new BigInteger(password,16).toByteArray();
    if(bArray.length == 21){
        // First byte is the "sign" byte
        for (int i = 0; i < 20 && i < bArray.length ; i++)
        {
            msg[i + ocraSuiteLength + 1 + counterLength + questionLength] = bArray[i+1];
        }
    }
    else {
        for (int i = 0; i < 20 && i < bArray.length ; i++)
        {
            msg[i + ocraSuiteLength + 1 + counterLength + questionLength] = bArray[i];
        }
    }
}
// Put the bytes of "sessionInformation" to the message
// Input is text encoded
if(sessionInformation.length() > 0){
    bArray = sessionInformation.getBytes();
    for (int i = 0; i < 128 && i < bArray.length ; i++) {
        msg[i + ocraSuiteLength + 1 + counterLength + questionLength + passwordLength] = bArray[i];
    }
}

// Put the bytes of "time" to the message
// Input is text value of minutes
if(timeStamp.length() > 0){
    bArray = new BigInteger(timeStamp,16).toByteArray();
    if(bArray.length == 9){
        // First byte is the "sign" byte
        for (int i = 0; i < 8 && i < bArray.length ; i++) {
            msg[i + 8 - bArray.length + ocraSuiteLength + 1 + counterLength + questionLength + passwordLength + sessionInformationLength] = bArray[i+1];
        }
    }
    else {
        for (int i = 0; i < 8 && i < bArray.length ; i++) {
            msg[i + 8 - bArray.length + ocraSuiteLength + 1 + counterLength + questionLength + passwordLength + sessionInformationLength] = bArray[i];
        }
    }
}

byte[] hash;
bArray = new BigInteger(key,16).toByteArray();
if(bArray[0] == 0){
    byte[] b = new byte[bArray.length - 1];
    for(int i = 0 ; i < b.length; i++)
        b[i]=bArray[i+1];
    hash = hmac_sha1(crypto, b, msg);
}
else{
    // compute hmac hash
    hash = hmac_sha1(crypto, bArray, msg);
}

// put selected bytes into result int
int offset = hash[hash.length - 1] & 0xf;
int binary =
    ((hash[offset] & 0x7f) << 24)
    | ((hash[offset + 1] & 0xff) << 16)
```java
| ((hash[offset + 2] & 0xff) << 8) |
| (hash[offset + 3] & 0xff); |

int otp = binary % DIGITS_POWER[codeDigits];

result = Integer.toString(otp);
while (result.length() < codeDigits) {
    result = "0" + result;
}
return result;
```

---

**Appendix B: Test Vectors**

OCRA Test Vectors  (OCRA Test Vectors generated on March 29, 2008)

For all computations, Key (K) = 12345678901234567890

***** OCRA-V1 Plain Challenge Response *****

===> Q only, Digit (D) = 6, Algorithm (A) = HMACSHA1

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===> Q and P = 1234, Digit (D) = 8, Algorithm (A) = HMACSHA256

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===> C & Q, Digit (D) = 8, Algorithm (A) = HMACSHA512

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===> Q & T, Digit (D) = 8, Algorithm (A) = HMACSHA512, Time (T) Mar 25 2008, 12:06:30 PM ie. OCRATime = 20107866 *****

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***** OCRA-V1 Mutual Challenge/Response, Digit (D) = 8, Algorithm (A) = HMACSHA256 *****

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***** OCRA-V1 Mutual Challenge/Response with Client PIN = 1234 *****

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OATH-HOTP-VARIANTS Expires - July 2009 [Page 23]
OCRA: OATH Challenge Response Algorithms  

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T6.9  OCRA-1:HOTP-SHA512-8:QA08  CLI22224SRV11114  03327937  
T6.10 OCRA-1:HOTP-SHA512-8:QA08-P  SRV11114CLI22224  89550664  

***** OCRA-V1 Plain Signature (a) no time stamp, Digit (D) = 8,  
Algorithm (A) = HMACSHA256 *****  

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***** OCRA-V1 Plain Signature (b) with timestamp  
Time (T), Mar 25 2008, 12:06:30 PM, OCRATime = 20107866 *****  

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Notes:  
1. Computations are done on March 21, 2008 based on the OCRA specification draft-mraihi-mutual-oath-hotp-variants-07.txt  
2. OCRA Time calculations:  
   Local Time "Mar 25 2008, 12:06:30 PM" at "America/Los_Angeles" time zone (local OCRATime=20107446) is converted (with time zone plus daylight time savings) to UTC Time "Mar 25 2008, 19:06:30 PM" at "GMT" time zone (UTC OCRATime=20107866)  
3. OCRA Time is treated the same as Counter of 8-byte long value with big-endian order and no base64 encoding.
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