Salted Challenge Response Authentication Mechanism (SCRAM)
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Abstract

The secure authentication mechanism most widely deployed and used by Internet application protocols is the transmission of clear-text passwords over a channel protected by Transport Layer Security (TLS). There are some significant security concerns with that mechanism, which could be addressed by the use of a challenge
response authentication mechanism protected by TLS. Unfortunately, the challenge response mechanisms presently on the standards track all fail to meet requirements necessary for widespread deployment, and have had success only in limited use.

This specification describes the Salted Challenge Response Authentication Mechanism (SCRAM), which addresses the security concerns and meets the deployability requirements. When used in combination with TLS or an equivalent security layer, this mechanism could improve the status-quo for application protocol authentication and provide a suitable choice for a mandatory-to-implement mechanism for future application protocol standards.

1. Conventions Used in This Document

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 [RFC2119].

Formal syntax is defined by [RFC4234] including the core rules defined in Appendix B of [RFC4234].

Example lines prefaced by "C:" are sent by the client and ones prefaced by "S:" by the server. If a single "C:" or "S:" label applies to multiple lines, then the line breaks between those lines are for editorial clarity only, and are not part of the actual protocol exchange.

1.1. Terminology

This document uses several terms defined in [RFC4949] ("Internet Security Glossary") including the following: authentication, authentication exchange, authentication information, brute force, challenge-response, cryptographic hash function, dictionary attack, eavesdropping, hash result, keyed hash, man-in-the-middle, nonce, one-way encryption function, password, replay attack and salt. Readers not familiar with these terms should use that glossary as a reference.

Some clarifications and additional definitions follow:

- Authentication information: Information used to verify an identity claimed by a SCRAM client. The authentication information for a SCRAM identity consists of salt and the "StoredKey" and "ServerKey" (as defined in the algorithm overview) for each supported cryptographic hash function.
- Authentication database: The database used to look up the authentication information associated with a particular identity. For application protocols, LDAPv3 (see [RFC4510]) is frequently used as the authentication database. For network-level protocols such as PPP or 802.11x, the use of RADIUS is more common.

- Base64: An encoding mechanism defined in [RFC4648] which converts an octet string input to a textual output string which can be easily displayed to a human. The use of base64 in SCRAM is restricted to the canonical form with no whitespace.

- Octet: An 8-bit byte.

- Octet string: A sequence of 8-bit bytes.

- Salt: A random octet string that is combined with a password before applying a one-way encryption function. This value is used to protect passwords that are stored in an authentication database.

1.2. Notation

The pseudocode description of the algorithm uses the following notations:

- "=:" The variable on the left hand side represents the octet string resulting from the expression on the right hand side.

- "+": Octet string concatenation.

- "[ ]": A portion of an expression enclosed in "[" and "]" may not be included in the result under some circumstances. See the associated text for a description of those circumstances.

- HMAC(key, str): Apply the HMAC keyed hash algorithm (defined in [RFC2104]) using the octet string represented by "key" as the key and the octet string "str" as the input string. The size of the result is the hash result size for the hash function in use. For example, it is 20 octets for SHA-1 (see [RFC3174]).

- H(str): Apply the cryptographic hash function to the octet string "str", producing an octet string as a result. The size of the result depends on the hash result size for the hash function in use.

- H[i](str): Apply the cryptographic hash function to the octet string "str", then repeat the application on the output string for a
number of iterations equal to the integer i minus 1.

- XOR: Apply the exclusive-or operation to combine the octet string on the left of this operator with the octet string on the right of this operator. The length of the output and each of the two inputs will be the same for this use.

2. Introduction

This specification describes the Salted Challenge Response Authentication Mechanism (SCRAM) which addresses the requirements necessary to deploy a challenge-response mechanism more widely than past attempts. When used in combination with Transport Layer Security (TLS, see [RFC4346]) or an equivalent security layer, this mechanism could improve the status-quo for application protocol authentication and provide a suitable choice for a mandatory-to-implement mechanism for future application protocol standards.

For simplicity, this mechanism does not presently include negotiation of a security layer. It is intended to be used with an external security layer such as that provided by TLS or SSH.

SCRAM provides the following protocol features:

- The authentication information stored in the authentication database is not sufficient by itself to impersonate the client. The information is salted to prevent a pre-stored dictionary attack if the database is stolen.

- The server does not gain the ability to impersonate the client to other servers (with an exception for server-authorized proxies).

- The mechanism permits the use of a server-authorized proxy without requiring that proxy to have super-user rights with the back-end server.

- A standard attribute is defined to enable storage of the authentication information in LDAPv3 (see [RFC4510]).

- Bindings to several authentication frameworks are provided so the mechanism is not limited to a small subset of protocols.

- Both the client and server can be authenticated by the protocol.

- The cryptographic hash function used to authenticate can be upgraded gracefully without breaking backwards compatibility or risking downgrade attacks.
For an in-depth discussion of why other challenge response mechanisms are not considered sufficient, see appendix A. For more information about the motivations behind the design of this mechanism, see appendix B.

Comments regarding this draft may be sent either to the ietf-sasl@imc.org mailing list or to the authors.

3. SCRAM Algorithm Overview

To begin with, the client is in possession of a username and password. It sends the username to the server, which retrieves the corresponding authentication information, i.e. a salt, StoredKey, and ServerKey. The server sends the salt and an iteration count to the client, which then computes the following values and sends a ClientProof to the server:

\[
\begin{align*}
\text{SaltedPassword} & := \text{Hi}(\text{HMAC(password, salt)}) \\
\text{ClientKey} & := \text{H}(\text{SaltedPassword}) \\
\text{StoredKey} & := \text{H}(\text{ClientKey}) \\
\text{AuthMessage} & := \text{client-first-message} + "," + \\
& \quad \text{server-first-message} + "," + \\
& \quad \text{final-client-message-without-proof} \\
\text{ClientSignature} & := \text{HMAC}(\text{StoredKey}, \text{AuthMessage}) \\
\text{ClientProof} & := \text{ClientKey} \oplus \text{ClientSignature} \\
\text{ServerKey} & := \text{HMAC}(\text{SaltedPassword}, \text{salt}) \\
\text{ServerSignature} & := \text{HMAC}(\text{ServerKey}, \text{AuthMessage})
\end{align*}
\]

The server authenticates the client by computing the ClientSignature, exclusive-ORing that with the ClientProof to recover the ClientKey and verifying the correctness of the ClientKey by applying the hash function and comparing the result to the StoredKey. If the ClientKey is correct, this proves that the client has access to the user’s password.

Similarly, the client authenticates the server by computing the ServerSignature and comparing it to the value sent by the server. If the two are equal, it proves that the server had access to the user’s SaltedPassword.

The AuthMessage is computed by concatenating messages from the authentication exchange. The format of these messages is defined in the Formal Syntax section.
4. SCRAM Authentication Exchange

SCRAM is a text protocol where the client and server exchange messages containing one or more attribute-value pairs separated by commas. Each attribute has a one-letter name. The messages and their attributes are described in section 4.1, and defined in the Formal Syntax section.

This is a simple example of a SCRAM authentication exchange:

\[
\begin{align*}
C: & \text{n=Chris Newman,h=md5,r=ClientNonce} \\
S: & \text{r=ClientNonceServerNonce,h=md5,s=PxR/wv+epq,i=128} \\
C: & \text{r=ClientNonceServerNonce,p=WxPv/siO5l+qxN4} \\
S: & \text{v=WxPv/siO5l+qxN4}
\end{align*}
\]

First, the client sends a message containing the username, a list of the hash functions it supports, and a random, unique nonce. In response, the server sends its list of supported hash functions, an iteration count i, the user’s salt, and appends its own nonce to the client-specified one. The client then responds with the same nonce and a ClientProof computed as explained earlier. The server verifies the proof and responds with a ServerSignature, concluding the authentication exchange.

4.1 SCRAM attributes

This section describes the permissible attributes, their use, and the format of their values.

- a: This optional attribute specifies an authorization identity. A client may include it in its first message to the server if it wants to authenticate as one user, but subsequently act as a different user. This is typically used by an administrator to perform some management task on behalf of another user, or by a proxy in some situations (see appendix A for more details).

If this attribute is omitted (as it normally would be), or specified with an empty value, the authorization identity is assumed to be the same as the username specified with the (required) "n" attribute.

The server always authenticates the user specified by the "n" attribute. If the "a" attribute specifies a different user, the server associates that identity with the connection after successful authentication and authorization checks.

The syntax of this field is the same as that of the "n" field with...
respect to quoting of ‘=’ and ‘,’.

- n: This attribute specifies the name of the user whose password is used for authentication. A client must include it in its first message to the server. If the "a" attribute is not specified (which would normally be the case), this username is also the identity which will be associated with the connection subsequent to authentication and authorization.

The characters ‘,’ or ‘=’ in usernames are sent as ‘=2C’ and ‘=3D’ respectively. If the server receives a username which contains ‘=’ not followed by either ‘2C’ or ‘3D’, then the server MUST fail the authentication.

- h: This attribute is a colon-separated list of supported hash function names, as defined in the IANA "Hash Function Textual Names" registry.

- r: This attribute specifies a sequence of random printable characters excluding ‘,’ which forms the nonce used as input to the hash function. No quoting is applied to this string (unless the binding of SCRAM to a particular protocol states otherwise). As described earlier, the client supplies an initial value in its first message, and the server augments that value with its own nonce in its first response. It is important that this be value different for each authentication. The client must verify that the initial part of the nonce used in subsequent messages is the same as the nonce it initially specified.

- c: This optional attribute specifies base64-encoded channel-binding data. It may be sent by either the client or the server. If specified, the authentication MUST fail unless the value is successfully verified. Whether this attribute is included, and the meaning and contents of the channel-binding data depends on the external security layer in use. This is necessary to detect a man-in-the-middle attack on the security layer.

- s: This attribute specifies the base64-encoded salt used by the server for this user. It is sent by the server in its first message to the client.

- i: This attribute specifies an iteration count for the selected hash function, and must be sent by the server along with the user’s salt.

- p: This attribute specifies a base64-encoded ClientProof. The client computes this value as described in the overview and sends it to the server.
- v: This attribute specifies a base64-encoded ServerSignature. It is sent by the server in its final message, and may be used by the client to verify that the server has access to the user’s authentication information. This value is computed as explained in the overview.

5. Hash functions

SCRAM can use hash functions defined by the IANA "Hash Function Textual Names" registry.

For interoperability, all SCRAM clients and servers MUST implement the MD5 hash function as defined in [RFC1321].

Servers SHOULD announce a hash iteration-count of at least 128.

6. Formal Syntax

The following syntax specification uses the Augmented Backus-Naur Form (ABNF) notation as specified in [RFC4234].

generic-message = attr-val *("," attr-val)
attr-val = ALPHA "=" value
value = *(value-char)
value-safe-char = %20-2B / %2D-3C / %3E-7E / UTF8-2 / UTF8-2 / UTF-3 / UTF8-4 ;; UTF8-char except CTL, ";", and ",,.
value-char = value-safe-char / ";"
base64-char = ALPHA / DIGIT / "/" / "+"
base64-4 = 4*4(base64-char)
base64-3 = 3*3(base64-char) ";"
base64-2 = 2*2(base64-char) "=="
base64 = *(base64-4) [base64-3 / base64-2]
saslname = 1*(value-safe-char / ";=" / ";" / ";") ;; Conforms to <value>
          ;; Usernames are prepared using SASLPrep.
authzid = "a=" saslname
username = "n=" saslname
channel-binding = "c=" base64
proof = "p=" base64
nonce = "r=" value [value]
   ;; Second part provided by server.
salt = "s=" base64
verifier = "v=" base64
hash-list = "h=" hash-name *(":" hash-name)
hash-name = value
   ;; Hash Function Textual Name, from
   ;; http://www.iana.org/assignments/hash-
   function-text-names
iteration-count = "i=" 1*DIGIT

client-first-message =
   [authzid ",",] username ",," hash-list ",," nonce
server-first-message =
   nonce ",," hash-list ",," salt ",," iteration-count
client-final-message-without-proof =
   nonce ",," channel-binding
client-final-message =
   client-final-message-without-proof ",," proof
server-final-message =
   verifier

7. Security Considerations

If the authentication exchange is performed without a strong security layer, then a passive eavesdropper can gain sufficient information to mount an offline dictionary or brute-force attack which can be used to recover the user’s password. The amount of time necessary for this attack depends on the cryptographic hash function selected, the strength of the password and the iteration count.
supplied by the server. An external security layer with strong encryption will prevent this attack.

If the external security layer used to protect the SCRAM exchange uses an anonymous key exchange, then the SCRAM channel binding mechanism can be used to detect a man-in-the-middle attack on the security layer and cause the authentication to fail as a result. However, the man-in-the-middle attacker will have gained sufficient information to mount an offline dictionary or brute-force attack. For this reason, SCRAM includes the ability to increase the iteration count over time.

If the authentication information is stolen from the authentication database, then an offline dictionary or brute-force attack can be used to recover the user’s password. The use of salt mitigates this attack somewhat by requiring a separate attack on each password. Authentication mechanisms which protect against this attack are available (e.g., the EKE class of mechanisms), but the patent situation is presently unclear.

If an attacker obtains the authentication information from the authentication repository and either eavesdrops on one authentication exchange or impersonates a server, the attacker gains the ability to impersonate that user to all servers providing SCRAM access using the same password and salt. For this reason, it is important to use randomly-generated salt values.

If the server detects (from the value of the client-specified "h" attribute) that both endpoints support a stronger hash function that the one the client actually chooses to use, then it SHOULD treat this as a downgrade attack and reject the authentication attempt.

8. IANA considerations

(Hash function names registry, SASL mechanism registration.)

9. Acknowledgements

The authors would like to thank Alexey Melnikov and Dave Cridland for their contributions to this document.
10. Normative References


[RFC3174] Eastlake, Jones, "US Secure Hash Algorithm 1 (SHA1)", RFC 3174, Motorola, September 2001


11. Informative References


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Appendix A: Other Authentication Mechanisms

The DIGEST-MD5 mechanism has proved to be too complex to implement and test, and thus has poor interoperability. The security layer is often not implemented, and almost never used; everyone uses TLS instead.

The PLAIN SASL mechanism allows a malicious server or eavesdropper to impersonate the authenticating user to any other server for which the user has the same password. It also sends the password in the clear over the network, unless TLS is used. Server authentication is not supported.

(To be completed.)
Appendix B: Design Motivations

(To be written.)

Appendix C: SCRAM Examples

(To be written.)

Appendix D: SCRAM Interoperability Testing

(To be written.)

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Open Issues

- The appendices need to be written.

- Should the server send a base64-encoded ServerSignature for the value of the "v" attribute, or should it compute a ServerProof the way the client computes a ClientProof?

- What about this LDAP attribute to store authentication information?

- It is entirely unclear to me how best to handle channel bindings. Should the channel binding data be sent directly at all?

- It’s not clear from the document that the hash function to use for a particular authentication exchange is selected by the client before the exchange begins.

- Should the title include the acronym SASL to help the greppers?

Changes since -04

- Update Base64 and Security Glossary references.

- Add Formal Syntax section.

- Don’t bother with "v=".

- Make MD5 mandatory to implement. Suggest i=128.

Changes since -03

- Seven years have passed, in which it became clear that DIGEST-MD5 suffered from unacceptably bad interoperability, so SCRAM-MD5 is now back from the dead.

- Be hash agnostic, so MD5 can be replaced more easily.

- General simplification.