Agents

A - Alice
M - Webauthn authenticator (passkey manager)
B - Browser with SubtleCrypto API and libsodium library
S - Quick Crypt server
R - https://www.random.org/cgi-bin/randbyte?nbytes=48
D - Insecure persistent storage system

Browser and Libsodium Functions

E_a - Symmetric cipher using AEAD algorithm a. One of:
1. AES-256 in Galois/Counter mode from SubtleCrypto
2. XChaCha20 with Poly1305 MAC from libsodium
3. AEGIS 256 from libsodium

D_H - HKDF key derivation using SHA-512 from SubtleCrypto
D_P - PBKDF2 key derivation using SHA-512 from SubtleCrypto
H - BLAKE2b MAC generator from libsodium
V - BLAKE2b MAC validator from libsodium
G - Cryptographic pseudorandom generator from SubtleCrypto

Cipher Variables

N - Block number
m - Clear text message
m_0 - Clear text block 0
m_N - Clear text block N
p - Password text
h - Password hint text
u_c - 256 bit user credential
a - Symmetric AEAD cipher and mode: [1, 2, 3]
i - PBKDF2 iteration count, minimum 400,000
k_M - 256 bit message cipher key
k_H - 256 bit hint cipher key
k_S - 256 bit MAC key
kp - Key purpose text
r - 384 bits of either true or pseudo random data
l - n_{IV} bit length: [96, 192, 256]
n_{IV} - True or pseudo random initialization vector
n_S - 128 bit true or pseudo random salt
lp - Loop count (0-15)
le - Loop end (0-15)
ad - Additional data
v - Cipher data version
h_E - Encrypted hint
h_El - Encrypted hint length
m_E - Encrypted message
t - 256 bit MAC tag
pl - Payload length
cd_0 - Cipher data block 0
cd_N - Cipher data block N
cd - Cipher data
b - Valid or invalid MAC tag
err - Error message

Message Encryption by A

$A \overset{\text{webauthn}}{\leftrightarrow} B, M \overset{\text{webauthn}}{\leftrightarrow} S$
$B \leftarrow S : u_c$
$A \rightarrow B : m, i, a, le$
$lp = 0$
$LOOP : B$ compute
    $A \rightarrow B : p, h$
    $v = 4$
    $r = G(384) \vee B \overset{\text{https}}{\leftarrow} R : r$
    $n_S = r[0 : 128)$
    $n_{IV} = r[128 : 128 + l)$
    $k_M = D_P(p \parallel u_c, n_S, i)$
    $k_S = D_H(u_c, n_S, kp_S =$ "cipherdata signing key")
    $cd = cd_0 \parallel cd_N \parallel ...$
    $m = cd$
    $lp = lp + 1$
    goto LOOP if lp $< le$
$A \leftarrow B : cd$

Block 0 Encryption by B

$k_H = D_H(u_c, n_S, kp_H =$ "hint encryption key")
$h_E = E_a(h, n_{IV}, k_H)$
$h_E l = len(h_E)$
$ad = a \parallel n_{IV} \parallel n_S \parallel i \parallel le \parallel lp \parallel h_E l \parallel h_E$
$m_E = E_a(m_0, n_{IV}, ad, k_M)$
$pl = len(ad \parallel m_E)$
$t = H(v, pl, ad, m_E, k_S)$
$cd_0 = t \parallel v \parallel pl \parallel ad \parallel m_E$

Block N Encryption by B

$r = G(384) \vee B \overset{\text{https}}{\leftarrow} R : r$
$n_{IV} = r[0 : l)$
$ad = a \parallel n_{IV}$
$m_E = E_a(m_N, n_{IV}, ad, k_M)$
$pl = len(ad \parallel m_E)$
$t = H(v, pl, ad, m_E, k_S)$
$cd_N = t \parallel v \parallel pl \parallel ad \parallel m_E$

Message Storage by A

$A \rightarrow D : cd$

Message Decryption by A

$A \leftarrow D : cd$
$A \overset{\text{webauthn}}{\leftrightarrow} B, M \overset{\text{webauthn}}{\leftrightarrow} S$
$B \leftarrow S : u_c$
$A \rightarrow B : cd$
$lp = 0$
$LOOP : B$ compute
    $t, v, pl, ad, m_E = cd_0$
    $a, n_{IV}, n_S, i, le, lp, h_E l, h_E = ad$
    $k_S = D_H(u_c, n_S, kp_S =$ "cipherdata signing key")
    $b = V(v, pl, ad, m_E, k_S, t)$
    if $!b$:
        $A \leftarrow B : Err$
    $k_H = D_H(u_c, n_S, kp_H =$ "hint encryption key")
    $h = E_a^{-1}(h_E, n_{IV}, k_H)$
    $B \rightarrow A : h$
    $B \leftarrow A : p$
    $k_M = D_P(p \parallel u_c, n_S, i)$
    $m = m_0 \parallel m_N \parallel ...$
    $cd = m$
    $lp = lp + 1$
    goto LOOP if lp $< le$
$A \leftarrow B : m$

Block 0 Decryption by B

$m_o = E_a^{-1}(m_E, n_{IV}, ad, k_M)$

Block N Decryption by B

$t, v, pl, ad, m_E = cd_N$
$a, n_{IV} = ad$
$b = V(v, pl, ad, m_E, k_S, t)$
if $!b$:
    $A \leftarrow B : Err$
$m_N = E_a^{-1}(m_E, n_{IV}, ad, k_M)$

Webauthn Variables

u_n - A's chosen user name
u_i - 128 bit user id guaranteed to be unique
u_c - 256 bit user credential
o - Quick Crypt origin "https://quickcrypt.org"
ch - 256 bit challenge value
ro - Registration options, including o, ch, u_i
rr - Registration response, including signed ch
ao - Authentication options, including o, ch
ar - Authentication response, including signed ch
cw - Alice's webauthn authenticator credentials

Registration by A

$A \rightarrow B : u_n$
$B \rightarrow S : u_n, o$
S create and store :
    $u_i = G(128)$
    $u_c = G(256)$
    $ch = G(256)$
$B \leftarrow S : ro$
$B \rightarrow M : ro$
$A \rightarrow M : cw$
M create and store passkey, sign ch
$B \leftarrow M : rr$
$B \rightarrow S : rr, u_i, ch$
S verify signature, store rr, remove ch
$B \leftarrow S : u_i, u_n, u_c$
$A \leftarrow B : u_i, u_c$

Authentication by A

$B \rightarrow S : o[, u_i]$
S create and store :
    $ch = G(256)$
$B \leftarrow S : ao$
$B \rightarrow M : ao$
$A \rightarrow M : cw$
M sign ch
$B \leftarrow M : ar$
$B \rightarrow S : ar, ch$
S verify signature, remove ch
$B \leftarrow S : u_i, u_n, u_c$

Recovery from Lost Passkey by A

$A \rightarrow B : u_i, u_c$
$B \rightarrow S : u_i, u_c, o$
S delete existing rr, create and store :
    $ch = G(256)$
$B \leftarrow S : ro$
$B \rightarrow M : ro$
$A \rightarrow M : cw$
M create and store passkey, sign ch
$B \leftarrow M : rr$
$B \rightarrow S : rr, u_i, ch$
S verify signature, store rr, remove ch
$B \leftarrow S : u_i, u_n, u_c$